Integrating Environmental Sustainability Issues in STEM Problem-Solving Activities: Promoting Knowledge and Awareness in Gifted Science Students in Thailand

A Thesis Submitted for the Degree of Doctor of Philosophy

by

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Table of Contents

List of Figures

List of Tables

Acronyms

ESD	Education for Sustainable Development
EHoM	Engineering Habits of Mind
EDP	Engineering Design Process
IPST	The Institute for the Promotion of Teaching Science and Technology (Thailand)
MOE	Ministry of Education
NGSS	Next Generation Science Standards
OBEC	Office of Basic Education Commission
OEC	Office of The Education Council
OECD	Organisation for Economic Co-operation and Development
PSS	Problem-Solving Skills
SD	Sustainable Development
SDGs	Sustainable Development Goals
SEP	Sufficiency Economy Philosophy
SMTD	Science, Mathematics Talented Development
STEM	Science, Technology, Engineering and Mathematics
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCED	World Commission on Environment and Development
YES!	Young Engineers For Sustainability programme

Abstract

Education for Sustainable Development (ESD) is crucial for enhancing knowledge and skills and fostering responsibility. In Thailand, where an official ESD curriculum is absent, the Sufficient Economy Philosophy (SEP) serves a similar purpose. This study addresses the gap in research by exploring the integration of ESD in primary school STEM education, focusing on the pedagogical potential of STEM activities. The 'Young Engineers for Sustainability' (YES!) intervention is designed to incorporate environmental sustainability, SDGs, STEM problem-solving, collaboration, and gifted development for gifted science students. The study, utilising a bricolage approach, encompass numerous qualitative methods, such as open-ended questionnaires, engineers' logbook, interviews, observation and reflective diary, reveals that STEM problem-solving activities effectively promote students' SD knowledge, competencies, and engagement in sustainable practices. The YES! programme implemented in eight gifted classroom in Thailand, empowers primary students from grade 4 - 6 to reflect on environmental issues, collaborate with peers, and develop problem-solving skills, contributing to their autonomy and awareness of sustainable development. The final findings highlight the positive impact of STEM interventions in fostering sustainable development knowledge and competencies among primary school students and collaborative skills. This underscores the potential of innovative approaches, like Yes! Programme, to bridge the gap in ESD integration in STEM education, offering valuable insights for future educational initiatives.

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Declaration

I hereby affirm that the research presented in this thesis, unless explicitly stated otherwise within the text, represents the original work of the author. This thesis has not been previously submitted to any other academic institution for the purpose of obtaining a degree and does not incorporate any material that has been previously submitted for such a purpose. It has successfully undergone a plagiarism check conducted through the use of 'Turnitin by the University Library.'

Tawinan Saengkhattiya

CHAPTER ONE: INTRODUCTION

This research focuses on undertaking an Education for Sustainable Development (ESD) in STEM education to equip gifted science students with sustainable principles and the essential skills to practise in the twenty-first century. Specifically, it investigates how environmental issue-based STEM (science, technology, engineering, and mathematics) problem-solving activities can teach young, gifted science learners' knowledge and awareness for sustainable development (SD) while enhancing their problem-solving skills and collaboration. The study considers the educational context in Thailand, where ESD was initially implemented as a whole-school approach in 2006 (Nuamcharoen and Dhirathiti, 2018). In 2007, Thailand adopted a concept called Sufficiency Economy Philosophy (SEP), which is a proper way to promote sustainable development within the country's educational system (Didham and Ofei-Manu, 2012; Mongsawad, 2010; TICA, 2021).

The SEP has become part of the national curriculum since 2008, and many schools implement SEP-based education programmes and activities (Dharmapiya and Saratun, 2016; Ministry of Foreign Affairs, 2021; Tungkasamit *et al*., 2014). While some published studies have focused on the integration of SEP at the secondary level (Pagsangkanae and Yuenyong, 2019), there has been a limited attempt to integrate SEP into STEM education, particularly in primary science.

ESD is an important model that supports the attainment of universally espoused sustainable development through quality education and implementation of the sustainable development goals (SDGs) (UNESCO, 2017). While multiple countries approved ESD in educational policies, teacher training, and curricula, the emphasis often addresses particular issues, such as climate change, poverty, and quality of life, and does not include learning content, teaching approaches, and expected learning outcomes (UNESCO, 2020).

In the UNESCO framework for achieving ESD by 2030, corporate ESD at the country level was urged to ensure cohesive action by incorporating ESD initiatives into existing national frameworks pertaining to the Sustainable Development Goals (SDGs), education, or other pertinent frameworks for the year 2030 to facilitate the alignment of efforts and promote a unified approach towards SD objectives (UNESCO, 2020). Effective ways to deliver ESD include a whole school approach and cross-curriculum learning. This research aims to integrate ESD by focusing on environmental sustainability issues, STEM education, and gifted education in Thailand. The goal is to promote SD in the science classroom, which ensures interdisciplinary practice and raises awareness among Thai students at a younger level.

However, before delving into the study in the later section of this thesis, I describe the rationale behind my decision to pursue this path, which aims to clarify my stance on educational research, my worldview, and my methodology for acquiring knowledge throughout my academic career. This chapter aims to provide a concise overview of key elements pertaining to the study at hand. These elements include an introduction to the concept of sustainable development (SD) and its interconnectedness with environmental sustainability issues, an elucidation of gifted science students, and an exploration of the role of STEM problem-solving in the context of ESD. The following chapter serves as a foundation for enhancing comprehension of the research design and methodology, which are elaborated on in subsequent sections. In conclusion, this chapter concludes by presenting the research concepts, research query, and objectives, as well as emphasising the significance of the research.

1.1 Personal Motivation for Research

I grew up in Chiang Rai, 860 km away from Bangkok, the capital of Thailand. In my childhood, the northernmost part of the country was surrounded by forests and golden rice fields, making me feel connected to nature. I wish I could still live there with my family forever.

I remember playing with my cousin and neighbours near my grandmother's house at Donton Hill, a small town in rural Chiang Rai, during my childhood. My grandmother had gardens of longan fruit and fields of sticky rice, which I considered as my natural playgrounds. Climbing trees, rushing down the slope from the top of the hill, and passing through the rice fields past her home to reach the farthest edge were my daily pastimes at her house. Sometimes, we would leap into the adjoining gully for a swim.

When I was little, my grandmother cooked meals with ingredients we rarely bought, as we harvested our own rice and vegetables. We also had free-range chickens. Special dinners included algae from the gully, along with freshwater crabs and fish. Our garden produces bananas, guavas, coconuts, mangoes, lychees, and marian plums; the fresh fruits vary daily. I enjoyed playing outside, especially when it was not too hot. During the rainy seasons, although we could not play outside due to lightning, I adored the rain. Winter was the most memorable season since the sky was clear and the sun was bright. Wearing a knitted jacket and sitting outside to soak up the warmth was always a joy. The evenings were special, as we would gather around a campfire, chatting and sharing moments with family.

Time passes, and memories become memories. Summers are excessively hot; therefore, people avoid going out during the midday heat. Each year, we have become increasingly aware of water-related issues; heavy rains create floods during the monsoon season, while scarce rainfall in summers results in drought. Winters are too cold, and people suffer as they have no proper shelter and warm clothing. Additionally, bushfires are an occasional yet troubling issue. When I was 20, I moved to Chiang Mai for my studies, and I experienced poor weather condition as the clear sky turned grey from smoke and haze. Thai scholars revealed that contributing factors were bushfire and agricultural waste burning (Pongpiachan, 2016, Pongpiachan *et al.*, 2017), possibly caused by human activities. Years later, Chaing Mai and Chiang Rai had constant air pollution, especially from January to March. Seven years later, I relocated to Bangkok for my career, only to find the air thick with PM2.5 particles. Recently, Thailand experienced the COVID-19 pandemic and air pollution at the same time, forcing Thais to wear masks for protection against both COVID-19 and PM2.5. In 2023, although COVID-19 is not considered a threat anymore, the issue of PM2.5 pollution continues to persist.

In Thailand, the excessive use of chemicals in agricultural sector has led to an increase in pollution within rice fields, making natural food less healthy. Hazardous compounds in field crabs and fish cause severe diseases since they enter our food chain and ultimately our bodies. For example, freshwater crab paste, known as 'Nam pu' in northern Thai cuisine, contains pesticides (Laohaudomchok *et al*., 2021), which put locals at risk when eating traditional food. Since the locals' lives are at risk, this raises a critical question: Is that the quality of life we expected?

The pressing environmental issues we face often lead us to wonder about solutions and responsibility. Is it solely the government's duty, or does it also fall upon the individuals who directly contribute to these problems, like those starting bushfires, using cars excessively, or relying heavily on plastic? At what point do we, as ordinary citizens, become part of the solution? Reflecting on this, I realised that our behaviour could have environmental consequences. My family and I initiated small but meaningful changes, starting with the dust issue in the winter. We stopped burning garbage, which once contributed to smoke pollution. Instead, we buried it and turned it into tree fertiliser at home. We started using our own bags for grocery shopping and reduced the number of single-use plastic as much as we could. These steps, though seemingly small, are our contributions towards a larger change for environmental sustainability.

Beginning with ourselves can actually help. However, support from businesses and the government can encourage people to change their habits. The country's policy and private sector cooperation have changed the community's lifestyle, including the use of plastic bags. As I travelled the world and studied in Sweden and the UK, I saw a variety of eco-friendly practices, particularly in the reduction of plastic bags and waste management. Sweden is aiming for zero waste with its meticulously managed recycling system. Shoppers use no-bags and recycle soda bottles in grocery machines to comply with government policy. The bottles and cans are returned using the barcode, and people receive their deposit money back. People in the UK are encouraged to use their own bags when shopping, or retailers charge 30 pence for a single-use plastic bag. In recent years, plastic straws and cutlery have been replaced with paper and wooden materials, respectively.

Thailand's government proposed a plastic ban campaign in early 2019 and announced it in 2020. The 'Every Day Say No to Plastic Bags' campaign followed a joint agreement between the Thai government and the Thai Retailers Association (Bangkok Post, 2019). Public sectors, such as department stores and convenience stores, have joined this movement by refusing the use of plastic bags. While we can reduce plastic consumption, the nation still confronts other environmental challenges. What can motivate Thais to modify their habits and be concerned about the environment? Education matters for building a sustainable, environmentally conscious society. I strongly believe that education can equip people with the knowledge, skills, and attitude to actively address personal, community, and global environmental issues.

The following section presents the research's context, starting with environmental sustainability issues. Understanding the importance of environmental sustainability can be challenging without first-hand experience. However, given the uncertainties about our planet's future, environmental sustainability for future generations is best achieved through raising awareness and having responsible action (European Commission *et al.*, 2021). This research focuses on environmental sustainability issues to enhance students' awareness of sustainability as well as promote students Problem-solving skills and collaboration.

1.2 Environmental Sustainability Issues and Sustainable Development (SD)

> *Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future*. (World Commission on Environment and Development, 1987, P.39)

This quote is the universally agreed definition, so called ‘Brundtland definition’ to define ‘sustainable development’ (Waas *et al.*, 2011). The global attempts are currently focused on reaching that state, and ‘sustainable development’ (SD) is commonly discussed in global discourse, research, policy, and practices around the world. Significantly, the current global agenda has been pushed forward to include all countries that agreed in 2015 to achieve this aim by 2030, according to the latest global framework for sustainable development, the United Nations' 17 Sustainable Development Goals (SDGs) (United Nations, 2015). These goals illustrate all aspects of SD, one of which relates to climate change and environmental sustainability issues such as water shortages and natural disasters.

In 2020, the United Nations launched the film ‘Nation United: Urgent Solutions for Urgent Times,’ calling on individuals and communities worldwide to tackle world issues, including climate change (United Nations, 2020). This global initiative highlights the significance of collective action from all sectors of society to reduce environmental impact and foster a sustainable future. Everyone has a significant role to play in this effort and can contribute to a sustainable society by engaging in environmentally conscious practices and spreading awareness about the urgent need for environmental preservation.

At the UN Climate Action Summit in New York on September 23, 2019, 16-year-old Swedish climate activist Greta Thunberg said, “*You say you 'hear' us and that you understand the urgency. But no matter how sad and angry I am, I don't want to believe that. Because if you fully understood the situation and still kept on failing to act, then you would be evil. And I refuse to believe that* ” (United Nations, 2019a, 42:34), highlighting the urgency. This speech illustrates the young generation's voice on climate change. It has ignited global climate change discourse and inspired individuals of all ages to be environmentally mindful worldwide (Mortelliti, 2021). Young climate change strikers left school and toured the streets to demonstrate the urgent need for reform before climate change worsens (Alter *et al.*, 2019). Students' empowerment and active engagement in this movement demonstrate their knowledge and awareness of environmental sustainability and the impacts of climate change. This movement express their active involvement in society to advocate for and take action on this global issue.

Climate change is an example of an anthropogenic environmental issue. Due to its numerous consequential effects, it has remained a significant concern (NASA, 2019). Rising global temperatures, extreme weather, and ecosystem changes directly and indirectly affect individuals. Globally, all effects are adverse, floods, droughts, and heatwaves worsen as the global mean temperature rises, and the specific impacts of these temperature changes vary by region, leading to uncertainty about their precise effects in different areas (Arnell *et al*., 2019). Consequently, environmental sustainability is threatened by numerous environmental issues, including global warming, urban air pollution, water shortages, environmental disturbance, and biodiversity (Steg and Vlek, 2009).

> *The natural environment is deteriorating at an alarming rate: sea levels are rising; ocean acidification is accelerating; the last four years have been the warmest on record; one million plant and animal species are at risk of extinction, and land degradation continues unchecked.* (United Nations Secretary, General António Guterres, 2019 in United Nations, 2019b, P.2)

The Earth's average surface temperature has risen significantly due to the increase in gas emissions into the atmosphere. This warming trend extends to our oceans, which absorb a substantial amount of this heat and become warmer. Scientists have observed that the melting of polar ice is a direct consequence of this warming. They predict that the loss of ice mass will significantly contribute to future sea level rise (Hansen *et al.,* 2016). The effects are critical, including melting ice shelves, Earth's energy imbalance and ocean temperature rising, ocean stratification, ice sheet mass decreasing, and ocean-contact ice sheets breaking rapidly (Hansen *et al.,* 2016). With the loss of ice and the imbalance in evaporation, the sea level rises and becomes more concerned with not only environmental perspectives but also social and economic ones. The sea level is rising at about 3.1 millimetres each year and is expected to rise and reach 0.5 metres in 2050 (Nerem *et al.,* 2018). Due to increasing sea levels, 800 million coastal residents could be compelled to relocate (World Economic Forum, 2019).

In addition to climate change, air pollution that contains hazardous pollutants poses a substantial threat to the economy, public health, materials, and the environment (Schwela, 2010). The effects of air pollution underscore the necessity of maintaining clean air quality, particularly in countries like China, India, and Thailand that have experienced severe levels of air pollution (Kim Oanh *et al*., 2006). One hazardous pollutant is 2.5-micrometre particles, called PM2.5 (Schwela, 2010), frequently generated by human activities such as industrial emissions and vehicle exhaust (Department for Environment, Food, and Rural Affairs, 2020). It poses substantial health risks when inhaled due to its toxicity (Brooker *et al*., 2007). Consequently, it may affect the respiratory and cardiovascular systems, leading to diseases, especially in young infants (Franklin *et al*., 2007; Wei *et al*., 2019). Schwela (2010) also highlights the impacts of air pollutions, specifically SO_3 and NO_3, on plant growth and agricultural production.

Moreover, water sustainability is a key focus of SDG 6: Clean water and sanitation (United Nations, 2015). This goal addresses critical issues related to water, encompassing both natural disasters like floods and droughts and essential aspects of human living, such as consumption, sanitation, water distribution, and equitable availability of water sources (UNESCO, 2019a; UN Water, 2021). Pollutants that pollute water sources, such as ponds, lakes, and rivers, also contribute to water sustainability. Plastics, chemical wastes, farm wastes, and fertilisers are the predominant pollutants produced by households and industries (Schwarzenbach *et al*., 2010).

Environmental sustainability issues are often the impacts of human activities such as overconsumption of natural resources and rapid urbanisation. Scholars agree that climate change and environmental degradation correlate with human activities (Cook *et al*., 2016; Shine *et al*., 1999). The use of natural resources for economic growth, combined with the challenges posed by overpopulation, overconsumption, and urbanisation, leads to significant environmental degradation (Harte, 2007; Ripple *et al*., 2020). Without caution, the growing economy and society pose a significant threat to our planet. While stopping economic growth is impossible, changing human behaviour can avert resource depletion and environmental damage. Environmental sustainability aims to enhance human well-being by safeguarding natural resources for human needs and ensuring that the capacity to absorb human waste does not surpass its limits, therefore preventing harm to humans (Goodland, 1995). Thus, we have a responsibility to prioritise the preservation of the environment and ensure its sustainability.

According to Brundtland's definition of SD, ensuring equity between present and future generations is the ethical concept embodied in this definition, and the needs of those generations are a good environment, a peaceful society, and a healthy economy (Diesendorf, 2000). Diesendorf (2000) made a clear statement that sustainability and sustainable futures are seen as the ultimate goals of the SD process. Wals (2015) indicated that sustainability consists of three parts that are arranged in a hierarchy and interact with each other:

- The biological, geological, and climatological substrates and their planetary boundaries.
- The social relationships between humans, but also between humans and the non- or more-than-human world, including the natural substrates.
- the human-made structures, belief systems, institutions, and instruments—economic, cultural, political, and other that shape these relationships and are shaped by them.

To accomplish sustainability by achieving SD, an individual needs to think, make decisions, and act responsibly to trigger the change. To foster a sustainable community, those fragments of SD can be reached, and scholars agree that education can help achieve SD (Didham and Ofei-Manu, 2012; Wals, 2015). Additionally, SDGs can also be achieved through education (Asia Society/OECD, 2018). Education provides learners with the agency and sense of purpose they need, as well as the skills to influence their own lives and contribute to the lives of others (OECD, 2018b), enhancing collective empowerment for social transformation (Diesendorf, 2000). ESD is not only focusing on the country's economic and social growth but also prioritising the environmental impact, ensuring that the natural resources are not overused, overconsumed, or destroyed by the present generation; therefore, it is promising to meet the needs of future generations (UNESCO, 2017).

Sustainability education is currently referred to as 'Education for Sustainable Development' (ESD) or 'Education for Sustainability' (EfS). UNESCO (2014) defines these terms as the teaching and learning of SD, which include several issues (UNESCO, 2017). It is essential to learn about SD to ensure a sustainable future in formal and informal educational contexts (UNESCO, 2017). In 2015, the United Nations established the 17 Sustainable Development Goals (SDGs), covering all sustainability issues to be considered in ESD (United Nations, 2015). According to the 2020 roadmap for ESD 2030 (UNESCO, 2020), it sets a strategic approach to encourage global transformation by 2030, aligned with the SDGs. This roadmap identifies five key priority action areas essential for the successful implementation of ESD; policy, learning environment, support for educators, youth, and the community (UNESCO, 2020). These priority action areas are essential to ensuring that the objectives of the SDGs are met through education.

Vare and Scott (2007) explained that ESD involves two interrelated approaches: 1) learning for SD, which promotes knowledge and skills and encourages changes in our habits; and 2) learning as SD, by learning to critically assess expert viewpoints and SD ideas and studying sustainable life's contradictions. It is essential to equip students with the knowledge and tools to actively contribute to sustainable practices, which enhances their ability to confront and make informed decisions in a complex and uncertain future. This approach is key in establishing and promoting students' competencies for SD, ensuring they are prepared to effectively address and navigate these critical issues (Leicht *et al*., 2018; Redman and Wiek, 2021; Wals, 2015; Wiek *et al*., 2011).

Clearly, knowledge, skills, values, and attitudes are promoted to equip students to become citizens who are genuinely concerned about SD, guiding them towards becoming sustainable citizens. Wals and Lenglet (2016) described ‘sustainability citizens’ as those who can challenge unsustainability, participate in new and more sustainable systems and practices, and become resilient to change as individuals or communities. Learning for SD can boost self-efficacy in both decision-making and action since it empowers learners to realise their potential to effect change.

Furthermore, in 2018, the OECD incorporated an assessment of students' global competencies through the PISA programme (Asia Society/OECD, 2018; OECD, 2018b). Among the four dimensions used to evaluate students, two key aspects are students’ understanding of both local and global issues and taking action for sustainability (OECD, 2018b). Those issues covered environmental risks, poverty, economic interdependence, immigration inequality, environmental risks, conflicts, and cultural and image differences regarding sustainability, which need to be tackled for sustainable development. Also, competence includes the abilities, capabilities, and behaviours that lead to long-term development and peaceful cooperation (Asia Society/OECD, 2018). Thus, developing competence is essential for achieving SD. The European Commission *et al.* (2021) emphasise the importance of preparing students from an early age with competencies that enable them to be both concerned about and capable of thinking critically about SD. This approach is supported by the studies of Samuelsson (2011) and Siraj-Blatchford *et al.* (2010), who highlight the significance of such competencies in fostering sustainable thinking among students.

In Thailand, the significance of sustainable development (SD) is well-recognised and has been increasingly promoted within the education system. The Thai Ministry of Education announced the second decade of educational reform (2000–2019), which focuses on developing the quality of Thai citizens and teachers, improving school quality, and learning resources across formal, non-formal, and informal education systems. It also supports the development of lifelong learning. An emphasis on administrative management is noted, particularly in terms of power distribution and stakeholder participation (Chiwpreecha and Prateepchotporn, 2020).

Although there is no official ESD curriculum, ESD is integrated into the Thai educational plan under the unique terminology of 'Sufficient Economy Philosophy' (SEP), which represents the Thai pathway for achieving SD (Didham and Ofei-Manu, 2012; Chiwpreecha and Prateepchotporn, 2020; Ministry of Foreign Affairs, 2021). The Ministry of Education has adopted the King's philosophy of sufficient economy (Piboolsravut, 2004) as its policy, promoting it across all Thai institutions, and embedding it into the national curriculum for the benefit of the Thai community (Didham and Ofei-Manu, 2012; Dharmapiya and Saratun, 2016; Chiwpreecha and Prateepchotporn, 2020). SEP is integrated in schools, and studies report the successful implementation of the SEP (Chiewpreecha and Prateepchotporn, 2020; Dharmapiya and Saratun, 2016; UNESCO, 2013), and ESD is embedded as a whole school approach (Nuamcharoen and Dhirathiti, 2018). Similar, the ESD school is adopted for the whole school under the Asia/Pacific Cultural Centre for UNESCO, in collaboration with the Office of Basic Education Commissions (OBEC), in which a broad ESD concept is embedded in schools (Nuamcharoen and Dhirathiti, 2018). This strategy required the cooperation of school stakeholders and their vision, and it has been reported that a number of ESD-integrated schools have discontinued it (Nuamcharoen and Dhirathiti, 2018).

Thai scholars support the need for ESD in primary education and engaging environmental education to address SD (Laiphrakpam *et al.*, 2019; Nuamcharoen and Dhirathiti, 2018). A central concern of this thesis is the design of an educational setting that not only engages primary students in learning but also enables them to acquire knowledge and awareness of SD and apply these concepts within the classrooms. Primary school children not only have the right to learn about sustainability but are also fully competent to learn about it (Siraj-Blatchford *et al*., 2010; Somerville and Williams, 2015). Thus, I decided to explore the primary level because, as agreed by many scholars, prior knowledge is taught, forming a basis for integration with ESD, especially in science education (European Commission *et al*., 2021; Summers and Kruger, 2003; Strachan, 2022; Trott and Weinberg, 2020). The Thai science standard at this level imparts knowledge regarding environmental facts and issues (IPST, 2017). Based on that, students benefit when they apply their classroom knowledge to solve practical tasks related to environmental sustainability issues.

1.3 STEM Problem-Solving Activities For Learning Sustainable Development

According to the PISA tests in 2008, 2012, 2015, 2018, and 2022, Thailand's student scores in science and mathematics are below the average of other OECD member countries' scores (IPST, 2021; IPST, 2023). Based on the OECD 2023 fact sheet report and PISA scores (OECD, 2023), the data suggests that Thai students' learning ability in science and mathematics needs improvement and STEM knowledge and life skills are considerably important. It is imperative for the government to foster the development of human resources in STEM disciplines at all levels of proficiency and across the entirety of society (Promboon *et al*., 2018). Similarly, other countries like the Unted State faces a similar issue with their students' Pisa scores and related tests (Bybee, 2013). According to Tytler (2020), STEM education is centralised in schools today to enhance students' outcomes, and is an essential tool in developing nations' economic competitiveness for future growth

Considering the need for a STEM competent workforce, transition to an innovative society, and the realisation of sustainable development agendas (Guzey *et al*., 2016; Morgan and Kirby, 2016; NRC, 2013; Ritz and Fan, 2015; Suriyabutr and Williams, 2021), it is clear that education reform is necessary. Education for the future must prepare students and teachers with essential skills for the 21st century, which are curiosity, creativity, problem-solving, and strategic learning skills (Häkkinen *et al*., 2017; OECD, 2018a). STEM is being used to increase academic learning ability, generate skilled human resources and enhance STEM literacy (Bybee, 2010; Kelley and Knowles, 2016) and to the extent in the scientific and engineering specialities. Sanders (2009) asserts that STEM education primarily involves increasing the number of students majoring in STEM disciplines. Thereby, the implementation of STEM and the research regarding STEM are becoming popular (Wendell and Rogers, 2013; Li *et al*., 2020), which are becoming increasingly acknowledged as essential catalysts for national progress, economic efficiency, and community (Guzey *et al*., 2017; Tytler, 2020).

STEM is commonly known in the education system worldwide as it combines multidisciplinary courses including science, mathematics, engineering and technology, and allows students to apply their knowledge of STEM disciplines to solve problems with principles, engineering plans, and technological developments. However, as Bybee (2010) points out, there is still less emphasis on engineering. In addition, students' engagement and teachers' inadequacy of knowledge and skills for teaching STEM education are highlighted as issues (Suriyabutr and Williams, 2021). To promote STEM education, different definitions and various frameworks have been identified (see Chapter 2). Nevertheless, the concept of STEM education lacks a precise and universally agreed-upon definition (Sanders, 2009; Bybee, 2010; Li *et al.,* 2020). Similar to Thailand, a unified definition or understanding of STEM education in Thailand is deficient (Promboon *et al*., 2018). Such a debate shows that more pertinent direction and sound practises need to be provided to fully realise its capacity to meet present and future global concerns, such as sustainable development.

Global initiatives for STEM education have led to educational reforms guided by principles set by governments, institutions, and businesses. Evidence of adopting STEM in educational policy in various countries and territories, such as the United States, United Kingdom, Canada, Australia, and New Zealand, as well as certain European and Asian countries, has included STEM in their national policies to address the shortage of STEM workers required to run a competitive economy (NRC, 2013; Kennedy and Odel, 2014; Freeman *et al*., 2019; Cheng and

Yeh, 2022). In the United States, The Next Generation Science Standards (NGSS) were implemented in K-12 education to improve science and mathematics performance in US schools fostering globally competitive STEM education (NRC, 2013; Hoeg and Bencze, 2017), leading to research and practice across the country.

Similarly, in Hong Kong, transitioned STEM extracurricular activities into the formal curriculum are found with the guidelines for integration (Cheng and Yeh, 2022). In the UK, a National Curriculum review in design and technology is ongoing, while the development of the computer curriculum involves collaboration between the Department of Education and Engineering organisations (Morgan and Kirby, 2016). According to the report, some organisations are seeking to influence government policy to enhance STEM participation and achievement, while others are improving STEM education (Royal Academy of Engineering, 2016). Organisations including the Royal Academy, Engineering UK, Institute of Mechanical Engineering, and the Institute for Engineering and Technology aid programmes tailored to young individuals who demonstrate a keen interest in and enthusiasm for the fields of STEM (Bianchi and Chippindall, 2016)

Thailand has also recognised the importance of STEM education and incorporated it into its educational reform. In 2012, Thailand started to adopt STEM education as a country policy, as it could be a strategy and innovation to drive Thai education (Promboon *et al.,* 2018). This movement strives to transform science and mathematics teaching in the country. In 2013, STEM education was implemented and taught in Thai schools (Srikoom *et al.,* 2017). To enhance the knowledge-based economy and facilitate Thailand's transition out of the ‘middle income trap’, educating students in the STEM professions is a highly effective means of fulfilling these requirements (Promboon *et al*., 2018). In 2016, IPST Thailand and its partners provided STEM activities connected to several subjects, such as chemistry, physics, and technology, for teaching at the primary to secondary level and activity books and manuals for students and teachers. It was published in 2014 under a project to drive STEM education in the school (STEMedthailand.org, n.d.), STEM subjects teaching and learning are implemented and promoted, increase innovation study in schools, increase innovative product invention at the university level, and enhance students’ 21st-century skills (IPST, 2017). Educators are also encouraged to cultivate teaching practices to serve this movement (Srikoom *et al*., 2017). Significantly, STEM is embedded in the basic curriculum as science and technology emerge (IPST, 2017; Sutaphan and Yuenyong, 2019).

Thai scholars view the role of STEM as essential for educational reform, facilitating the integrated and innovative teaching and learning strategies (Promboon *et al*., 2018; Suriyabutr and Williams, 2021). In terms of quality education, STEM plays essential roles in reshaping science and mathematics education and is integrated for providing a better education to new generations by address the complex and changing problems of the twenty-first century (Promboon *et al*., 2018). Sritrakul (2018) argues that both quantity and quality of previous Thailand education have failed to fulfil the demands of the global labour market, according to the drop in the IMD world ranking and the below-average OECD's PISA score (Sritrakul, 2018). STEM is seen as a means to enhance high-level abilities in science and mathematics, address the issue of low PISA scores, and foster competitive abilities in Thai students.

As STEM encompasses four disciplines, many scholars have recommended integrated STEM, as its benefits in promoting knowledge and skills are the focus, especially incorporating problem-based and engineering design (Bryan *et al*., 2016; Kelley and Knowles, 2016; Nadelson and Seifert, 2017; Tytler, 2020). This study aims to extend the STEM learning environment beyond learning science knowledge linked to the environmental sustainability issue. The emphasis on knowledge and practice in finding solutions to problems aligns with engineering (UNESCO, 2021a). The National Academies of Sciences, Engineering, and Medicine (NASEM) asserts that science and engineering learning extends beyond acquiring knowledge and skills by facilitating a constructive process of developing a positive sense of identity and encouraging students to see themselves as capable contributors to these professions and society, which could be beneficial for learning sustainability (NASEM, 2022).

Furthermore, to address challenges regarding the lack of engineering and technology in STEM learning, the research emphasised this issue, as Bybee (2010) recommended expanding technology and engineering courses and effectively integrating them into science and mathematics education. This research enhance students with engineer skills in practice following Engineering Habits of Minds (EHoM) framework and learn how engineers find the solutions (Lucas *et al.*, 2014) toward real world issue, especially finding sustainable solutions and how these practices support the achievement of the Sustainable Development Goals (SDGs) (UNESCO, 2021a). This process, technology is involved in creating and using tools, equipment, and procedures to apply scientific and mathematical knowledge in order to solve the environmental sustainability issue as a product of the engineering design process and context that involved engineer careers.

For fostering gifted students, STEM education is an effective strategy, as proven by numerous studies (Robinson *et al*., 2014; Ülger and Çepni, 2020; Ozkan and Kettler, 2022). Gifted students need more than academic knowledge to lead in the 21st century, where innovation, creativity, and sustainability drive economic competitiveness and development.

Students must acquire the values, attitudes, and skills necessary to overcome future obstacles (OECD, 2018b). Yang *et al.* (2023) content that STEM education can be implemented with young gifted students as they can acquire advanced STEM skills at developmentally appropriate level. This study identifies it as a method of instruction that promotes essential skills and enhances primary school gifted students' understanding of SD (See chapter 2). Following ESD's concept, students need to justify their thinking and behave responsibly. According to Jickling (1994), students must be aware of the sustainability arguments, try to clarify them, and be aware that SD is being called into question. Students should be encouraged to engage in debates and determine the strengths and weaknesses of opposing viewpoints (Jickling, 1994). Chapter 2 presents various ESD practices and teaching and learning strategies.

1.4 Gifted Science Students in Thailand

> *Education shall be based on the principle that all learners are capable of learning and self-development, and are regarded as being most important. The teaching and learning process shall aim at enabling the learners to develop themselves at their own pace and to the best of their potentiality. (Thailand National Education Act of 1999, amended (No. 2) in 2005, (No. 3) in 2010 and (No. 4) in 2019, Section 22.)*

The aforementioned quote from the Thailand National Education Act emphasises the necessity of educational development tailored to individual students. Therefore, the Thai educational system includes gifted students who exhibit exceptional ability, along with students with special needs (see definition of giftedness in Chapter 2). The 20-year Thailand National Strategic Plan (2017-2037) addresses the policy with recognition of multiple intelligence, involving supporting people with special talents as human resources development for developing the country to have security, prosperity, and sustainability (Office of the National Economic and Social development, 2018). Additionally, the Thailand Educational Scheme (2017–2036) addresses the role of different educational settings, from central organisations to local educational institutes, to incorporate giftedness into their policies and practices and continuously promote and support the development of talented people at all levels, aligning with the country's development direction (National Strategy Secretariat Office, 2018; ONEC, 2017; OEC, 2021)

Therefore, giftedness in science is a noteworthy focus in Thailand's education policy. According to the Office of Educational Council (OEC), various programmes have been established to support giftedness in science (OEC, 2021). One example is the Enrichment Programme of Science, Mathematics, Technology, and Environment (SMTE), which was implemented in schools and organised under the collaboration of many organisations, such as the Office of the Basic Education Commission, the Institute for the Promotion of Teaching Science and Technology (IPST), the Ministry of Higher Education, Science, Research, and Innovation, and the National Science and Technology Development Agency (NSTDA) (OEC, 2021). A school programme called 'special classroom', which is defined by the school gifted programme, is established following the regulations of the Office of Basic Education at the primary and secondary levels (OBEC, 2022). Currently, there are 220 classrooms established at the secondary level, which received support from IPST Thailand for the STEM disciplines including biology, chemistry, physics, and technology (ONEC, 2018).

Moreover, IPST, a Thai government agency under the Ministry of Education, is dedicated to implementing gifted support policies and practices focusing on science, mathematics, and technology. IPST promotes gifted science students with the Development and Promotion of Science and Technology Talents Project (DPST). The DPST programme provides sponsorship for talented students from the secondary to the doctoral level, training, extracurricular activities, and research support for students to become Thailand's leaders in their scientific field, collaborating with DPST centre universities across Thailand (DPST, 2017).

The Science and Mathematics Olympiad is another example of a gifted support initiative. The IPST International Mathematics and Science Olympiad (IMSO), which was established in 1989, has the purpose of recognising and helping academically talented students in the fields of science and mathematics in Thailand. The programme, which is administered by IPST and the Promotion of Academic Olympiads and Development of Science Education Foundation (POSN), employs a state-wide selection process, attracting an annual engagement of almost 75,000 students. These students not only serve as representatives of Thailand in international competitions but also make substantial contributions to society. A significant number of individuals pursue careers as researchers, professors, and physicians, thereby contributing to the advancement of innovation and scientific knowledge in several fields. Specifically, out of 526 Thai representatives, a notable proportion of 102 individuals currently hold positions as university lecturers and researchers (Olympic IPST, 2016).

For the primary school level, IPST established the Science and Mathematics Talend Development Programme (SMTD), publicly called IPST Genius, in 2001 (Genius IPST, 2016).

This programme identifies and advances pupils who demonstrate exceptional aptitude in mathematics and the sciences. This initiative facilitated a range of students' development interventions, comprising a one-day STEM camp, a summer camp, an online camp, and professional development programmes for schoolteachers (Genius IPST, 2016).

In addition to nationwide programmes, the Ministry of Education also promotes giftedness in STEM through special science, mathematics, and technology schools. Mahidol Wittayanusorn School and twelve locations of Princess Chulabhorn Science High School are located in different cities around Thailand, and the Thai government plans for the expansion within 2026 (ONEC, 2018; MOE360, 2021). Kamnoetvidya Science Academy is the latest science school, also established in 2013 (Anuruthwong, 2017), to serve academically gifted students at the high school level.

Evidently, gifted education is part of the area considered by the Thai government, and it invested significant funding in those special schools and national programmes to nurture gifted science students in practice. However, the Keenan Foundation stated that Thailand still lacks the talents to solve the problem in science. Highly-abled learners in this subject are only 2% in Thailand, which is significantly lower than in China, Singapore, and South Korea, with several high-ability learners in science at approximately 44%, 37%, and 20%, respectively (Keenan Foundation Asia, 2023). This number suggests the need for the country to consider national educational policy and management to increase the number of students who have higher performance in this subject.

Considering the above, gifted science students constitute the primary focus of this study. In this context, 'gifted in science' refers to individuals who are considered 'talented' or 'gifted' and exhibit exceptionally outstanding capabilities in the field of science, encompassing not only scientific performance but also cognitive aptitude (for a definition of giftedness in science, please refer to Chapter 2). This definition is derived from the IPST-established identification procedure. Moreover, these terms comprise gifted students who are enrolled in gifted school programmes or participate in specialised classrooms.

Gifted science students have the potential to learn science. Gifted learners in learning science achieve high levels in school practical work and can commit to some science-related tasks as well as demonstrate the ability to use sophisticated models, which is not expected at an average level (Taber, 2007a). This achievement demonstrates that STEM education, particularly in science, presents an opportunity to enhance the knowledge of gifted students. Research by Robinson *et al.* (2014b), Mann and Mann (2016), Ülger and Çepni (2020), and

Ozkan and Kettler (2022) confirms the advantages of STEM education for nurturing gifted science students with knowledge and skills as well as social emotional development.

Terry *et al*. (2008) argue that STEM integration promotes problem-solving skills and fosters essential talents like collaboration, vital for the 21st century. It also fosters environmental awareness and sustainable development (SD), offering holistic knowledge in social, economic, and environmental aspects. To prepare future leaders, equipping students with creative thinking, problem-solving abilities, and social awareness is crucial (Terry *et al*., 2008). As Anuruthwong (2017) suggests that future research on gifted education in Thailand should focus on the supportive system, identification, gifted provision, and teaching strategies. Gifted students need access to resources, opportunities, and assistance to engage in investigative, creative, or hands-on endeavours. Therefore, this research focuses on integrating STEM education to nurture gifted students in Thailand with SD knowledge and skills.

1.5 Significance of the Study

Engaging young gifted science students in the development of SD knowledge, problem-solving skills, and collaborative skills is the objective of this research. Previous studies have indicated that cognitive and behavioural development in students is positively impacted by their early exposure to environmental and sustainable concerns (Siraj-Blatchford *et al.,* 2010; Green and Somerville, 2014; Somerville and Williams, 2015). Priority is given to science education at this level, as it establishes the groundwork for ESD (Summers and Kruger, 2003; Strachan, 2022) via a STEM-based learning approach and scientific enquiry. The research examines the viewpoints of Thai students and teachers regarding STEM problem-solving activities as an approach to attaining essential skills, SD understanding, and awareness.

SEP influences the implementation of ESD in Thailand (Didham and Ofei-Manu, 2012). However, despite the current incorporation of SEP into compulsory education (Dharmapiya and Saratun, 2016), there is a greater need for the integration of ESD at the primary level (Nuamcharoen and Dhirathiti, 2018) and for more engaging environmental education (Laiphrakpam *et al*., 2019). This research addresses these gaps by providing meaningful and engaging STEM learning opportunities that promote SD-specific knowledge, attitude, and skills in the science classroom. Additionally, it integrates STEM education as a learning context, which directly benefits gifted students through the application of STEM knowledge and skills, and ESD principles and practices. This research employs holistic approaches to foster competencies for sustainability, as research regarding pedagogical approach linkage with the competencies is still scarce (Lozano *et al*., 2017), which are predominantly found in higher education (Albareda-Tiana *et al*., 2018).

Despite the government's prioritisation of gifted education, research and provisional programmes are needed to support Thai gifted students (Anuruthwong, 2017). Taber (2007a) suggests that gifted students are similar to all learners who need a curriculum that fulfils their requirements and challenges them. Furthermore, according to Lucas and Hanson (2021), further qualitative research is needed to gain a deeper understanding of engaging engineering and to evaluate techniques that could increase engineering's visibility for young students. There are room for more research that investigate EHoM especially related to curriculum unit and analysis (Guzey *et al*., 2016; Karatas-Aydin and Işıksal-Bostan, 2023; Wheeler *et al*., 2019). According to the benefits of STEM education with problem-based learning, this enables gifted students to solve a problem while also facing a challenge. The study underscores the importance of implementing an outreach initiative, with a particular focus on extracurricular programmes, in order to support gifted, STEM, and ESD practises for teachers.

1.6 Research Questions

The research questions of this study are:

1. How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?
2. How does the implementation of integrated STEM-based activities enhance awareness of sustainable development and improve problem-solving and collaborative skills among gifted students in science?

1.7 Research Objectives

Research Objectives of this study are:

1. To explore the understanding and awareness of sustainable development while also assessing problem-solving and collaborative skills through engagement in a STEM-based programme among primary gifted students in science.
2. To explore the perceptions of primary teachers regarding integrated STEM based activities' effectiveness in fostering students' understanding, awareness, problem-solving skills, and collaborative skills pertaining to sustainable development.

1.8 Thesis Outline

This thesis includes seven chapters covering various research phases. It begins by justifying the research and providing background information. The study encompasses a literature review, method selection, data collection, analysis, and a discussion of findings. At the conclusion, a summary of the findings, contributions of the research, limitations, and suggestions for further research are discussed. Each chapter is elaborately discussed below. Chapter 1 of this thesis summarises the study's background and elucidates the topic, research questions, aims, and objectives. It underscores the research's contributions to STEM education, ESD, and gifted education. The literature review in Chapter 2 aims to provide the theoretical foundation underpinning the thesis. It delves into key concepts such as SD, ESD, STEM education, and collaboration, while Chapter 3 focuses on gifted education, the strategy to promote SD with STEM education, and the conceptual framework. These concepts inform the design of instructional activities, aligning with the conceptual framework to engage gifted science students in learning SD knowledge, awareness, and skills.

The research methodology, comprising philosophical perspectives, epistemology, theoretical frameworks, learning theories, and research design, is elaborated upon in Chapter 4. It investigates the data collection procedure during Phases 1 and 2 and provides a comprehensive account of the evolution of pedagogical activities. A discussion of the 'Young Engineers for Sustainability' (YES!) programme, which encompasses eight classrooms across seven Thai institutions, is accompanied by examining the ethical implications involved. Chapter 5 provides an in-depth examination of data analysis, illuminating the sequential procedures by the chosen research techniques. Then, in Chapter 6, the findings obtained from each data collection method are discussed, as it provide perspectives from both teachers and students, integrated from multiple data sources. The concluding chapter emphasises the importance of the intervention in the context of gifted education and ESD in Thailand. The document delineates strategies for developing an enrichment programme tailored to gifted science students and proposes measures to broaden its reach and impact, advancing STEM education that embed sustainable development.

CHAPTER TWO: LITERATURE REVIEW (1)

The purpose of this literature review is to establish a solid theoretical foundation to substantiate the present argument. A literature review framework serves as the initial stage, presenting fundamental ideas obtained through an examination of interdisciplinary literature. These ideas include learning theories, Education for Sustainable Development (ESD), STEM education, collaboration, gifted development, and research methodology. Diverse perspectives are taken on the investigation of ESD and effective strategies, with particular emphasis on the promotion of SD learning among young students. Additionally, the evaluation of STEM education provides valuable perspectives on approaches that foster student learning and skills, clarifying the manner in which STEM education can be an effective learning strategy to promote SD learning and skills. Moreover, collaboration is recognised as an essential skill for fostering continuous learning, advancement of skills, and problem-solving, and it contributes substantially to the accomplishment of SD. Therefore, this chapter presents empirical evidence for examining the connections between ESD and STEM education that lead to the enhancement of SD learning and skill development.

2.1 Framework for Literature Study

The literature study in this research aims to explore the initial information to create a framework from the existing knowledge, research, and practice related to the research topics (Arksey and O'Malley, 2005; Pham *et al*., 2014; Paré *et al*., 2015). In what follows, an in-depth explanation is conducted by searching for different sources, including journals, reports, books, and websites. The document sources for this research were primarily gathered from Google Scholar and various journals focusing on sustainability, STEM education, educational psychology, and environmental education. The objective was to define key concepts, explore existing frameworks, and review practices using significant keywords such as 'STEM education', 'Gifted education', 'ESD', and 'STEM' which are the core topics related to research questions. The topics and subtopics serving as criteria for framing the literature review are detailed in Table 1 below.

Disciplines	Area of study	Aspects
Learning theory	• Different theories to be adopted in this research	• Social construction learning • Experiential learning
STEM problem solving approach	• Practical intervention or approaches	• Benefits of STEM education • Framework for STEM education
	• Intervention in school	• STEM intervention in school (Primary and secondary level)
	• Policy and practices in Thailand	• STEM in Thailand context
Education for Sustainable Development (ESD)	• World movement and history	• Background of ESD and country implementation
	• Definition and public understanding • Policy and Practices in the world and Thailand	• Frameworks for shaping ESD practice • Curricula or intervention • ESD with gifted education
Gifted education	• Definition of giftedness • Characteristic of science gifted student	• Conceptualisation of giftedness • Characteristics of gifted • Gifted in this research context
	• Gifted development	• Gifted and Talend development model • Gifted enrichment programme • ESD related topics in gifted development • Gifted in Thailand
Environmental sustainability issues	• Current environmental issues in the world and Thailand • Scientific knowledge behind the issues	• Global issues and local issues • Fact of environmental issue • Science knowledge related to issues
Collaborations	• Definitions • Research and practice	• Collaboration and its important • Approach for enhance collaborative skill • Research about collaboration
Research methods in Education	• Philosophical aspects • Approach • Methods • Data analysis	• Epistemology • Interpretivism • Mixed or Multimethod, Case study research • Research methods (i.e., Thematic analysis)

Table 1 Summary of Criteria for the Literature Study.

Table 1 outlines the scope of the literature review in this research, which comprises learning theory, ESD, STEM education, and collaborative skills. The following sections thoroughly discuss the details of each topic. The conceptualisation and development of gifted students, along with conceptual frameworks for creating STEM activities for learning SD and skills, are discussed later in Chapter 3 (literature review (2)).

2.2 Learning Theory Around the Research Topic

Understanding the learning process is crucial to enhancing student learning and forms the foundation of educational research on teaching and learning. Thus, learning theories produced over time by scientists in both the educational and psychological areas are key factors that might influence the learning and teaching practices of teachers to create effective practice (Artino and Konopasky, 2018). Following the research objectives, the learning theories must be examined. To develop the teaching and learning intervention employing the STEM problem-solving approach and the integration of ESD based on STEM education, numerous learning theories can be determine the appropriate practice for this study. These theories inform the development of the conceptual framework and instructional approach, which subsequently shape the educational intervention aimed at enhancing gifted science students' learning. As noted, the intervention must equip gifted science students with knowledge regarding SD, STEM skills, and collaborative skills. The phrases 'pedagogy' and 'curriculum' are associated with this research, focusing on instructing and fostering student learning.

Several researchers define pedagogy as the study of how teachers instruct. In his work, Tinning (2009) described pedagogy as a science of teaching, the collaboration of a teacher and a student, and the processes of knowledge generation and reproduction of subjectivities, identities, and values. Pedagogy can be defined as a practice that can encompass art, science, and craft. It includes the provision of some aspects of the learning environment (such as play and exploration) in the early years of schooling (Siraj-Blatchford *et al*., 2002). Another scholar noted that pedagogy is concerned with the connection between the teacher and students. In terms of pedagogy in teacher education, Loughran (2008) states that teachers design pedagogic episodes to provide students with teaching experiences that can shape students' evolving views. This approach is about understanding teaching and learning processes and inspiring and motivating students. It's about the interaction between teachers and students, not just in the classroom, but in shaping their future. It's about more than just knowledge transfer; it's about instilling a love for learning and a desire to understand the world around them.

Given the multidisciplinary nature of this study, which combines knowledge of SD, problem-solving skills, and collaborative skills, It is crucial to investigate effective instructional methods for young, gifted science students. This study is vital to ensuring these students are equipped with the diverse skills set required for future challenges. It is essential to present some learning theories, such as theories of learning motivation, experiential theory, and social learning theory, at the outset to influence the planning and instruction strategies for young learners. In addition, they reflect the views of instructors and influence the teaching and learning approach. As Yeomans and Arnolds (2006) indicate, teacher expectations affect student performance. Therefore, this study employs theories regarding motivation, experiential theory and social learning theory to enhance students' motivation in SD learning, but also to empower them with problem-solving abilities and collaborative skills.

2.2.1 Motivation for SD Learning

In Chapter 1, SD is defined as the aim that all countries must achieve in order to ensure that, while developing, human life is protected, and natural resources are preserved for future generations. When discussing learning for SD, the definition of ESD is described as teaching and learning to create a sustainable future. Thus, transforming people's thinking and behaviours is the expected outcome of the discipline, from focusing on learning knowledge and skills by shaping students' thinking, informing decision-making, and considering behaviour. Evidently, human behaviour is one of the main sources of environmental sustainability issues. Action, target, context, and time are the four components that Fishbein and Ajzen (2009) define as behaviours. While action is a component of behaviours, a category of behaviour may include at least one type of action that has been performed (Fishbein and Ajzen, 2009). To achieve SD, behavioural change and sustainability action are required, as many SD issues, such as ongoing degradation, are linked to human, including the actions and behaviours of individuals and societies (Fischer *et al.,* 2012). Consequently, the first learning theory to be considered revolves around behaviourism.

As commonly understood, SD is concerned with social and economic fairness and the preservation of ecological stability for future generations. Many sustainability issues are social, environmental, and economic quandaries that must be resolved. Equity and justice, as well as value and belief systems, are part of the approach to focusing on behaviour and sustainability aside from reforming formal institutions, engaging citizens, strengthening civil society institutions, curbing consumption, and limiting population growth (Fischer *et al*., 2012). Students are future adults who are undeniably affected by the sustainability issue. It is unfair for them to face the outcome of the past and present generations. Some of them may have had experiences with this issue before, especially students in Thailand, a developing country that confronts different kinds of sustainability issues. Such motivation can draw from experiences to fuel the desire to be part of the change, solve problems, and acquire knowledge.

The reality of the situation must be taught, including why it occurs, how it occurs, and the impact stemming from it. By not focusing on creating fear, educational approaches should focus on raising awareness, promoting critical thinking and providing opportunities to act (Wals, 2020). In this study, the positive aspects are the space for practice problem-solving, the discussion on behavioural aspects and the value of STEM skills that can help mitigate more complex problems in the future. On one hand, fairness taps into people's sense of justice and encouraging them to act. Kopnina and Cherniak (2016) described that fairness is frequently articulated in economic terms, implying a fair allocation of natural resources, and depends on the functioning of a neoliberal market economy in reality. Determining fairness may lead to motivation for student learning. Thus, how a person thinks about what is fair and what is unfair can impact their motivation, attitudes, actions and behaviours.

This perspective suggests that motivation stemming from a sense of unfairness may be integrated with the learning process for change. As a result, when students develop a sense of justice and recognise unfairness, it may fuel their desire to enact change and create fairness in the future. Knowledge about critical issues facing humanity must be provided in learning to foster a sense of justice and create motivation to determine behavioural change regarding sustainability. For example, some unfair issues in ESD identified by Glavič (2020) include the climate crisis, where a scarcity of resources is hindering progress, social inequalities and disparities in development stages causing stress in societies, and the challenges posed by the neoliberal economy in various countries worldwide. These issues highlight the unfair aspects of sustainability that need to be addressed in educational contexts. As a result, this theory emphasises the significance of incorporating real-world sustainability issues into teaching and learning.

It focuses on engaging students with scenarios that reflect actual injustices in the world, thereby raising their awareness of these issues. This approach aims to raise students' awareness of unfairness in the real world, and inspire motivation to solve these problems and strive to create fairness in their world. As this research focuses on classroom practice, students' motivation to learn is critically important for teaching and learning (Schunk *et al*., 2013). Martin (2004) defines motivation to learn as a student's level of enthusiasm and determination to acquire knowledge, perform tasks efficiently, and reach their full potential. However, Bojović and Antonijević (2017) argue that realistic limitations regarding student motivation must be accepted, such as the choice of students as assigned by the programme, teachers who cannot manage learning for the large group of students, and failures that students create that cause negative attitudes. However, students' motivation can be enhanced, and three components are crucial to meeting their needs which are competence, autonomy, and relatedness (Deci and Ryan, 2002).

Deci and Ryan (2002) indicate in their theory of self-determination theory (SDT) that motivation can occur in both intrinsic and extrinsic forms. The study of Deci and Ryan (2008) which differentiates types of motivation and autonomous motivation is of research interest as it involves intrinsic motivation and extrinsic motivation and shows that individuals have recognised the value of an activity and have successfully incorporated it into their self-concept. One aspect of SDT is related to the awareness of an individual, which is one motivation for learning involving self-reflection regarding what one is interested in or aware of. This motivation is related to Bandura's (1997) self-efficacy theory, suggesting that reinforcing what students learn can further motivate them. Bandura (1997) provides social persuasion as one of the strategies for boosting self-efficacy, which may contribute to engaging students in creating change for our future.

Bandura (1997) claimed that in social persuasion, individuals who are verbally convinced that they possess the talents to master specific activities are more likely to mobilise and sustain effort than those who hold self-doubts and fixate on personal flaws when difficulties arise

(Bandura, 1994). The stronger a person's belief in their capability, the more likely they are to feel skilled and competent, which in turn enhances their sense of personal efficacy (Bandura, 1994). Thus, the belief that students could participate in the problem-solving process and even solve environmental sustainability issues can motivate students to engage in the intervention of this research. Furthermore, those who are successful in problem-solving activities may change their minds and gain confidence in dealing with more complex problems in the future, especially SD issues. This is an important point to consider when engaging students in interventions that aim to increase their confidence in solving SD issues.

Additionally, motivation plays a crucial role in engaging gifted students, who are the focus of this research. Gifted students are defined as those with high abilities (Renzulli, 2005), and innate talents (Gagné, 1985). However, there is no definite definition of gifted students (Taber, 2015). Further discussion on gifted students is highlighted in the upcoming section. However, as this research targets gifted science students, the challenge lies in effectively engaging gifted science students in the learning process. Many studies defined them as being enthusiastic about problem-solving and easily bored with what they already knew (Silverman, 2003; Taber, 2007a). Thus, the educational context must be designed to expand beyond the initial knowledge-base of gifted students. Little (2012) contends that the curriculum is a motivating factor for gifted students and it must be goal-oriented, meet their interest, be relevance, and be meaningful.

Motivating these students by providing a learning environment that enhances their existing abilities and offers value and relevance to their experiences is essential. The knowledge imparted must be engaging and closely related to real-life scenarios. It should be integrated with scientific learning and present challenges that stimulate the intellectual curiosity of these students (Taber, 2015). Following this approach, integrating engaging STEM content related to real-world scenarios can pique students' interest. Moreover, creating challenges for engaging gifted students is essential to learning for sustainability, especially for skill development such as problem-solving and collaboration.

According to Clinkenbeard (2012), a high achiever can complete any task, whereas a less compliant gifted student and an underachiever may not be interested in or work on tasks that are too easy to complete. Simple problems might not encourage their learning and may trigger a negative outcome, as they can be disengaged and unable to comprehend and learn new things (Taber, 2015). Therefore, challenging tasks can motivate them to learn and serve as a reward for their accomplishment. The emphasis on SD issues also makes students aware that learning is relevant and meaningful.

2.2.2 Learning by Doing

In addition to the motivation that drives the student to learn, learning theories also emphasise the learning environment which is crucial for determining how to equip students with knowledge and skills in educational settings. One learning theory that focuses on providing an environment for students to experience knowledge is the experiential learning theory. Experiential learning through hands-on problem-solving activities enables students to actively engage in real-world scenarios, enhancing their problem-solving skills and fostering deeper knowledge retention. Kolb (1984) defines learning in his experiential learning theory as the process by which knowledge is generated through experience. Thus, experiential learning theory focuses on the concept of learning through experience or 'learning by doing' (Kolb and Kolb, 2013).

Following experiential learning, critical thinking skills and problem-solving skills can be acquired and improved (Sangwan and Singh, 2022). Students can follow the four steps of the experiential learning cycle: concrete experience (Do), reflective observation (Reflect), abstract conceptualisation (Think), and active experimentation (Apply) (Kolb, 1984; Kong, 2022). Students will see progress in learning when they complete all of those steps, from experiencing it to applying the knowledge to new contexts (McLeod, 2017).

Learning STEM from experience is crucial. Through the process of problem-solving, students can learn and practise problem-solving skills (So *et al*., 2017). It is supported by Dewey (1938), who believed that schools and classrooms should reflect real-life situations and enable children to engage in learning activities interchangeably and flexibly in a range of social settings, as he had envisioned (Dewey, 1938; Gutek, 2014, cited in Williams, 2017). Dewey's (1938) approach describes the learning environment as one where experiencing and solving problems constitute the core of the learning process. Accordingly, Glancy and Moore (2013) support Vygotsky's idea that learning from experiences fosters student learning as it grounds students' understanding of concepts. This method aligns with problem-based learning in the classroom, which is described further in the STEM approach (see Section 2.4). Similarly, Schiro (2013) supports the idea that hands-on problem-solving methods will be the norm in student-centred classrooms, where students 'learn by doing'. When teachers plan for instruction, they will take student interests into account and integrate curricular disciplines with an emphasis on project learning. Instead of focusing solely on academic improvement, the educational experience should include the intellectual, social, emotional, physical, and spiritual growth of all students (Schiro, 2013).

In this research, students' hands-on problem-solving experiences are provided as the main process for learning. Integrated experiential learning following Kolb's cycle allows students to do multiple tasks that promote problem-solving skills (Long *et al*., 2020), specifically the incorporation of a reflection process that involves reflection, evaluation, assessment, and retrospection (Sangwan and Singh, 2022).

2.2.3 Learning by Working in Teams

An additional theory identified in the literature review, and a key objective of this research, is to foster collaboration skills suitable for the twenty-first century. Social constructivism, a learning theory related to learning environments, focuses on the role of peers in influencing individual learning. Vygotsky's theory of children's development, emphasises the sociocultural context in which students learn through discussion. Vygotsky posited that the cognitive development of children is influenced by their environment. Scholars affirm that this hypothesis promotes collaborative learning among students (Le *et al.,* 2018). Sociocultural concepts are utilised when students acquire knowledge of a subject via collaborative practice such as conversation. Drawing from Vygotsky's theory, activity theory is integrated into practice in the STEM problem-solving intervention (Hite and Thompson, 2019; Gyasi *et al.,* 2021). This theory frames students' social experiences as enhancing interpersonal skills by analysing student interaction (Hite and Thompson, 2019).

Furthermore, according to Vygotskian theory regarding the zone of proximal development, collaborative activities help children learn by fostering social connections (Vygotsky, 1978). This thesis focuses on building spaces for students to study, share ideas, and promote their knowledge. Group talk, teamwork, or any instructional interaction in an educational or training institution can develop knowledge through social construction (Akpan *et al*., 2020). Demssie *et al*. (2022) define social constructivism as the integration of multiple learning approaches and environment that allow learners to actively engage in collaboration in real-world context. Students are encourage to exchange idea and foster system thinking competence in their study. In an experiential learning environment where problem solving is focused, Sangwan and Singh (2022) assert that collaboration is a more effective approach for cultivating problem solving than individual problem solving, as it promotes teamwork. Therefore, the focus on peer learning highlights the significance of teamwork, the acquisition of knowledge, and collaboration, which not only fosters learning but also facilitates skill development.

In addition to this, understanding the theories behind learning motivation, self-determination, experiential learning, and collaborative learning helps make an intervention that combines teaching students SD with problem-solving and collaborative skills. When designing STEM activities for collaborative learning on environmental sustainability issues, incorporating these theoretical frameworks will guide this thesis in developing pedagogical approaches that promote SD learning and foster skills in gifted science students. Motivation is a critical factor in maintaining engagement in the programme. The theory of self-determination emphasises the importance of intrinsic motivation and autonomy. Kolb and Dewey's theory emphasises experiential learning and practical, hands-on experiences. Based on Vygotsky's sociocultural perspective (Vygotsky, 1978), collaborative learning emphasises the significance of shared knowledge construction.

2.3 Education for Sustainable Development (ESD)

According to common definition of Sustainable Development (SD), SD involves balancing economic growth, environmental conservation, and social well-being while addressing present requirements without affecting future generation needs. Teaching and learning for SD is important as it engages key stakeholders in the process of change, with youths being one of the most important groups. As future generations, youths play a vital role in shaping and implementing sustainable practices. Their involvement is essential for the long-term success and impact of sustainability initiatives as they have capacity to envision and provide creative solutions toward sustainability issue (UNESCO, 2020). Education for Sustainable Development (ESD), Sustainability Education, or Education for Sustainability (EfS) means implementing SD content into teaching and learning. Motivating and empowering students through various teaching and learning methods is key to fostering behavioural change, decision-making, and action towards SD. This involves incorporating SD-related issues into educational activities, thereby enhancing their understanding and commitment to sustainability (UNESCO, 2018; UNESCO, 2020). Individuals must confront uncertainty, make difficult choices, face risks, and adapt to the fast rate of global change while also developing an understanding of their complex reality (Rieckman, 2018). The global movement of ESD, how ESD can be integrated in primary education, and how ESD is implemented in Thailand are discussed in the following sections.

2.3.1 Global Movement For ESD

Implementing initiatives associated with the ESD movement on a global scale has required a significant amount of time and effort. In 1987, the report ‘Our Common Future’ by the World Commission on Environment and Development, was published (Brundtland, 1987). It introduced the concept of SD, emphasising the importance of balancing economic development with the preservation of resources for future generations. Later in 1992, Agenda 21 was released as the action guideline for member countries to achieve SD by providing current and future generations with sufficient resources for a good quality of life (UNCED, 1992). Promoting youth involvement in environmental protection, economic promotion, and social development through various types of education is emphasised.

After that, the United Nations announced the ESD (DESD) decade from 2005 to 2014 at the World Summit on Sustainable Development in Johannesburg. (DESD, 2005). This programme encouraged educators to integrate SD components, including economic, social, and environmental, into education. (DESD, 2005). It emphasised the role of education in advancing SD. During ESD, the Bonn Declaration was launched in 2009, advocating for education reform to include SD and promoting action with guidelines, including the integrating approach for the 21st century. (UNESCO, 2009)Implementing ESD also stresses social and environmental issues, such as water, energy, climate change, disaster and risk reduction, loss of biodiversity, food crises, health risks, social vulnerability, and insecurity. (UNESCO, 2009). ESD has prioritised the enhancement of skills development and the examination of issues within the SD framework. Academics supported the integration of ESD into all educational levels, processes, and disciplines to ensure that everyone could learn and advocate for SD. In 2015, at the United Nations Assembly, Sustainable Development Goals (SDGs) were introduced as a guideline to reach SD by 2030, encouraging local and global implementation. One hundred ninety-three countries agreed to comply with 17 goals (United Nations, 2015). The SDGs are illustrated in Figure 1.

Figure 1 UN Sustainable Development Goals (United Nations, 2015)

UNESCO encourages countries to engage with the SDG Education 2030 Agenda to ensure that educational policies prioritise social justice and equality for humanity (Vaccari and Gardinier, 2019). To reach a successful implementation of ESD, SDGs are implemented to strengthen ESD initiatives targeted at achieving the 17 SDGs, such as incorporating ESD and SDG information into learning at all levels of education (UNESCO, 2019). By focusing on youth, ESD contributes to SDG 4 Target 4.7, providing all students with essential skills and knowledge to enhance SD and encouraging them to prioritise SD issues (UNESCO, 2020).

Evidently, ESD integration and initiatives have been found in many countries since DESD. In the Nordic region, the Swedish government has integrated ESD into the curriculum from compulsory schooling to the upper secondary level (post-16 education), where teaching and learning of environmental issues are promoted with the SD concept (Fredricks and Eccles, 2008; Svalfors, 2017; Skolverket, 2018; Frederiksson *et al*., 2020). Schools should impart students with the knowledge necessary for creating a positive environment, as well as their interest in and decision for SD (Skolverket, 2018), to cultivate reflective and action-oriented citizens (Frederiksson *et al*., 2020). In Norway, basic education issues for developing future competence were considered, while SD themes were incorporated in Norwegian curriculum and 'Sustainable backpack programme' was established by the Norwegian government (Munkebye *et al.*, 2020). Schools receive support for implementing this programme.

Rolls *et al.* (2015) reported that practitioners and researchers implement ESD within formal and informal education in Denmark. However, the integration of ESD is still considered scarce, indicating room for further development and implementation in educational practices (Rolls *et al*., 2015), and no overarching national policy and action plan were established except for the educational general guidelines (European Commission *et al*., 2021). Furthermore, initiatives created a shift from knowledge to behavioural transformation, such as a whole-school approach in some primary and secondary schools (McKeown and Hopkins, 2007; Breiting and Schnack, 2009, cited in Rolls *et al.,* 2015).

According to the European Commission *et al.* (2021), almost all EU countries' policymakers prioritised ESD as their national strategies, policies, and action plans for education for environmental sustainability, however, they are solely focusing on mainstreaming education for SD. The whole school approach includes the implementation of ESD-related school curriculum, aiming to shift institutional environmental sustainability adoption and integrate SD into all aspects of school life and culture (European Commission *et al.,* 2021). The eco-school programme is promoted across different regions in Europe, such as Slovenia, the United Kingdom, and Sweden, in which environmental sustainability addresses issues related to energy, water, and biodiversity (Chatzifotiou and Tait, 2017; Boeve-de Pauw and Van Petegem, 2018; European Commission *et al.,* 2021). ESD is a national priority in Germany and has been incorporated into school curricula (Müller *et al.*, 2021).

In the United Kingdom, the direction of ESD in the UK tends toward citizenship education (McKeown and Hopkins, 2007). It had been reported that ESD was less emphasised in educational policy (UK National Commission for UNESCO, 2013; Martin *et al*., 2015). However, Bamber *et al.* (2016) state that the education policy is currently decentralised both administratively and territorially, and the central government continues to support the ESD and Global Citizenship (GC) initiatives. However, as Martin *et al*. (2015) noted, the local government and NGOs were in charge of the ESD initiatives. In 2022, the UK government published 'Sustainability and Climate change: A Strategy for the Education and Children's Services Systems' outlining strategic action areas for education and the children's service system, specifically targeting sustainability and climate change. Therefore, the UK committed to embedding climate change education starting from the early years foundation stage framework that develops children's understanding of the world and natural environment (Department for Education, 2022).

Under the influence of government change in England, sustainability and global citizenship have disappeared from curriculum (Bourn *et al.*, 2016). Even though many institutions have actively promote ESD, ESD is found in subjects likes geography and science, where teacher education depends on individual, network and organisation (Bourn and Soysal, 2021). In Scotland, which is striving to promote responsible citizens, sustainability is integrated as a key component of the curriculum for excellence (Education Scotland, n.d.; UK National Commission for UNESCO, 2013; Bamber *et al*., 2016). Students are encouraged to be ethical, being able to evaluate issues revolved around environmental, scientific, and technological issues, as well as understand culture and diversity. Similarly, the Welsh national curriculum explicitly incorporates ESDGC and advocates for it via personal social education, which stems from its emphasis on sustainability (Estyn, 2013, cited in Bamber *et al.* 2017). The Eco-School Programme is reported to cover 90% of schools in Wales (UK National Commission for UNESCO, 2013). In Northern Ireland, ESD has been an officially mandated subject of the school curriculum since 2007, administered by the Department of Education, and the whole school approach is embedded in schools across Northern Ireland (UK National Commission for UNESCO, 2013).

In the United States, SD is integrated into the national standard, specifically outlined in the Sustainable Standard (Nation Education for Sustainability K–12 Student Standards) and the Common Core State Standard (CCSS). These provide guidelines for the implementation of ESD in schools, offering instruction guidelines and teaching and learning methods to engage students in sustainability (U.S. Partnership for Education for Sustainable Development, 2013) and raise awareness for ESD in school (Müller *et al.*, 2021). Schroth and Helfer (2017) acknowledge that the standard is applied to all levels of education, from kindergarten to high school, and that it addresses a variety of SD-related issues such as the ecological system, economic system, social and cultural system, personal and collective action, and intergenerational responsibility. ESD is integrated in public and private schools, on university campuses, and in formal and informal education (Rowe *et al*., 2015; Müller *et al.*, 2021).

Education for Sustainability (EfS) is nationally recognised in Australia and New Zealand, and the initiatives are found in schools in both countries (Taylor *et al.,* 2015). The Australian government integrated the principle of sustainability into the curriculum, which can be found in the Australian Curriculum, Assessment, and Reporting Authority (ACARA) policies and in the sustainability curriculum framework (DEEWR, 2009; Australian Education for Sustainability Alliance, 2014; Smith and Watson, 2019). These EfS initiatives in Australia are diverse, including support from schools, educational stakeholders, individuals, and communities, while in New Zealand, EfS initiatives are supported by local governments and non-governmental organisations (Taylor *et al.,* 2015).

In Asia, Japan also develops the curricula for SD and embeds them in the subject syllabus starting from the preschool level, making schools an essential sector in promoting SD (MEXT, 2008; Fredriksson *et al*., 2020). Furthermore, the whole school strategy to promote SD is prevalent across the continent. According to Ichinose (2017), the number of UNESCO Associated schools in Japan, including public and compulsory schools, is increasing considerably.

Approximately half of these schools are at the primary school level. As environmental issues increase, the environmental policies are established, and ESD is considered in educational reform in China with a greater emphasis on environmental issues (Müller *et al.*, 2021). Han (2015) reports various types of ESD schools in China, such as an ESD Experimental School, the ESD Example School, and the National ESD Example School. The concept of ESD is not only taught in these schools but also incorporated into their planning and strategic approaches (Han, 2015). In Hong Kong, a teacher handbook for promoting SD is published to promote SD learning starting from primary schools and environmental education is also encouraged to be taught in school (Müller *et al.*, 2021). Green schools are also implemented in Hong Kong as well as in Indonesia (Iwan and Rao, 2017).

The government has established SD-related legislation in South Korea, a nationwide ESD promotion strategy, and a national curriculum (Kwon and Lee, 2019). The ESD concept is encouraged and implemented in education to raise awareness for SD (Sung and Choi, 2022).

According to UNESCO, promoting youth for SD is one of the key priority action areas (UNESCO, 2020). The policies and initiatives highlight the significance of ESD through practical implementation to prepare the new generation with the knowledge, awareness, and behaviour for SD. Moreover, ESD advocates recommended including environmental, social, and economic issues and introducing the SDGs as a global framework. There are many strategies for ESD integration into educational settings that can promote SD learning, especially in young students. Frameworks and strategies are described in later sections

2.3.2 Beyond Environmental Education

As the environment is accounted for as a part of the three pillars of sustainable development, ESD, which includes environmental issues, may overlap with Environmental Education (EE). EE is thought to affect children's and adults' environmental conduct. A growing body of studies and the absence of observable changes showed that this assumption was invalid and that EE needed to do more than educate children about the natural world to affect their behaviour and attitude (Taylor *et al*., 2015). EE is the educational process that emphasises the relationship between the environment and humans, using interdisciplinary approaches, including problem-solving approaches, with knowledge, understanding, attitudes, skills, and commitment to environmental problems and considerations.(UNESCO-UNEP, 1983, cited in Pavlova, 2013). Monroe (2012) indicates that EE in school often teaches students science-based information about ecosystems and conservation. On the other hand, ESD is more focused on the change in behaviour towards social, economic, and environmental issues in educational settings and aims for the quality of life of human beings (UNESCO, 2005, cited in Pavlova, 2013).

Based on EE, a more sustainable life can be promoted by teaching attitude, knowledge, behaviours and values (Sanchez-Llorens *et al.,* 2019). Clearly, environmental knowledge alone is insufficient to bring about SD; values, attitudes, and behaviours also contribute. Using an integrated approach and interdisciplinary knowledge (Peters and Wals, 2013), such as natural science and social science, ESD encompasses issues such as democracy, gender equity, and human rights, thus making ESD more comprehensive than EE (UNCED, 1992; Danish Ministry of Education, 2003). Based on SD concepts, UNESCO (2005) characterises ESD as encouraging lifelong learning, being culturally and geographically relevant, addressing local needs, attitudes, and conditions, and recognising global consequences within official, informal, and non-formal education. Pavlova (2013) asserts that ESD focuses on the human condition apart from environmental conditions and EE.

ESD prioritises preserving natural resources over maintaining a rich environment to ensure the quality of people's lives and that of future generations. However, Monroe (2012) argues that while ESD equips individuals to address, resolve, and avoid environmental problems, EE is currently designed with the same goal. Pavlova (2013) argues that EE and ESD must align and synchronise instead of being opposed to each other, as human-environment relationships are found to be crucial. Despite concerns that extending beyond EE to ESD might focus too much on humans need which then potentially lose sight of the fact that humans are a part of nature as the focus shifts from environment towards human centre (McKeown and Hopskins, 2007).

EE and ESD could provide quality education by enhancing comprehension of multiple views, communication, envisioning and evaluating possibilities, information collection, synthesis and interpretation, and preparation for complex challenges (Monroe, 2012). UNESCO (2022) advocates ESD as a quality, transformative education that encompasses creating changes in knowledge, skills, attitudes, and values and involves morality, fairness, care, and justice. To effectively integrate ESD with STEM education and achieve the goal of SD learning, ESD frameworks and practices that effectively promote knowledge, skills, attitudes, and values are identified in the following sections.

2.3.3 Framework for ESD

Achieving SD requires the integration of SD principle. Mensah (2019) summarised the principle of SD as the systematic integration of environmental, social, and economic concern in decision making processes across generations. To anchor ESD and pursue SD goals, the concepts of SD along with competencies serve as foundation to assist practices and curriculum for an effective ESD. These frameworks provides guidelines to promote sustainable citizens by addressing critical components and principle that promote learning, value, attitude, and skill and involve sustainability issues. As, Vare and Scott (2007) categorised ESD into two models: a knowledge-driven learning model following the experts, and a critical evaluation of the expert's perspective on SD.

The combination of those two models informs the significance of raising awareness by fostering knowledge, and enhancing ability to critically analyse the issue through reflective and collaborative processes (Vare and Scott, 2007). Wals and Lenglet (2016) asserted that promising approaches to creating sustainably-minded citizens must provide students with the opportunity to learn not only facts about the issue but also sustainability issues regarding these facts, public concern, and deliberation through collaborative learning and the outcome of collective action. Since shifting societal attitudes and fostering public awareness via educational initiatives are crucial for SD (Taylor *et al.,* 2015), the pillars of SD, SDGs and competencies for sustainability provided significant advantages for embedding ESD into educational practices, which are outlined below.

2.3.3.1 Pillars of Sustainable Development

The three pillars of SD are known as the dimension of SD, which include social, economic, and environmental, as shown in Figure 2a. It was mentioned in Agenda 21, which was released in 2002, and integrated into the educational approach to teaching SD during the decade of ESD (2005–2014) (DESD, 2005). The literature study of Mensah (2019) report that the discourses around SD are based on this pillars. Thus, when ESD adopted those three pillars of SD, the centre of the ESD integration framework was established, as shown in figure 2b.

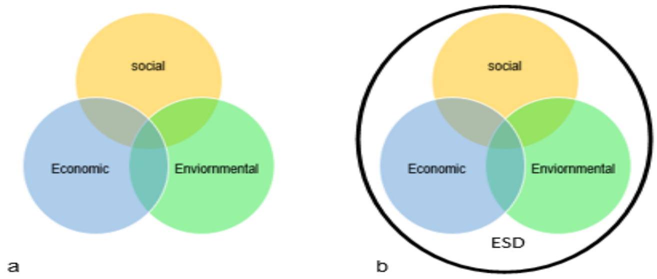


Figure 2 Three Pillars of SD and Conceptual Core for ESD
(esdteachers.bangkok.unesco.org)

The figure 2 illustrates the integration of SD concept as holistic approach within ESD. Mensah (2019) state the concept of SD is built upon economic sustainability, social sustainability, and environmental sustainability. By emphasised these three pillars, sustainability become simpler to comprehend (Weber *et al*., 2021). Therefore, SD can be strengthened as the three pillars of SD are considered in education. In early childhood education, this pillar of SD is adopted as experts believe it can ensure sustainability where the environment focusses on ‘about’, 'in', and ‘for’ the environment with broader aims, relates human activities to society, and draws on the impact of the environment (Hedefalk *et al*., 2015). Nevertheless, it has faced criticism for its inadequacy in addressing sustainability challenges (Eilks, 2015). So, It is important to consider when promoting the principles of SD, those who make decisions must always keep these pillars' interconnectedness, synergies, and tensions in mind (Mensah, 2019).

In 2008, UNESCO included a culture pillar as another component of SD. Due to the significance of culture in relation to human action, Hawkes (2001) stated that the culture pillar involves wellbeing, creativity, diversity, and innovation. Sharvina *et al.* (2017) stated that the cultural component is distinct from the social pillar because culture is a different reference point for enhancing vitality. Makrakis *et al.* (2012a) embedded the four pillars in the curriculum design of climate change education for children's rights (Makrakis *et al.,* 2012b). This highlights the significance of cultural value in conjunction with the economy, environment, and society in the pursuit of SD. Although the notion of SD must consider the requirements of future generations (Sharvina *et al.,* 2017), it can be applied to all areas of environmental sustainability in this study's context. The culture can be integrated if the environmental issues can be linked to local traditions or cultures to show students how culture relates to other pillars. Burmeister *et al.* (2012) agree with this viewpoint and assert that the ESD must consider both natural and man-made environments to comprehend social, political, ecological, economic and cultural dimensions on a local and global scale.

2.3.3.2 Sustainable Development Goals (SDGs)

The SDGs are an encouraging global framework for achieving SD by 2030, addressing all SD issues at the core causes (Mensah, 2019). They provide an inclusive and transformative framework for organisations to address a wider range of global issues and instil positive changes by directly confronting inequalities and injustice rather than perpetuating existing social and economic disparities (Vaccari and Gardinier, 2019). As shown in Figure 3, the SDGs encompass a variety of sustainability issues.

Sustainable Development Goals (SDGs)		SDG9	**Industry, Innovation, and Infrastructure:** Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
SDG1	**No Poverty:** End poverty in all its forms everywhere.	SDG10	**Reduced Inequality**: Reduce inequality within and among countries
SDG2	**Zero Hunger:** End hunger, achieve food security and improved nutrition and promote sustainable agriculture.	SDG11	**Sustainable Cities and Communities**: Make cities and human settlements inclusive, safe, resilient, and sustainable.
SDG3	**Good Health and Well-being:** Ensure healthy lives and promote well-being for all at all ages.	SDG12	**Responsible Consumption and Production**: Ensure sustainable consumption and production patterns.
SDG4	**Quality Education:** Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.	SDG13	**Climate Action:** Take urgent action to combat climate change and its impacts.
SDG5	**Gender Equality:** Achieve gender equality and empower all women and girls.	SDG14	**Life Below Water:** Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
SDG6	**Clean Water and Sanitation:** Ensure availability and sustainable management of water and sanitation for all.	SDG15	**Life on Land:** Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
SDG7	**Affordable and Clean Energy:** Ensure access to affordable, reliable, sustainable and modern energy for all.	SDG16	**Peace, Justice, and Strong Institutions:** Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels.
SDG8	**Decent Work and Economic Growth:** Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.	SDG17	**Partnerships to Achieve the Goal:** Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Figure 3 The Details of SDGs (United Nations, 2015)

The details of SDGs in figure above clearly demonstrate that SDGs agree with the global sustainability dimensions, highlight links between these dimensions that are relevant, and offer a manageable framework for ESD (Weber *et al*., 2021). In the latest UNESCO assembly in 2021, the SDGs continue to place emphasis on globally implementing ESD policy and practices. To promote a successful implementation, educators are provided with guidance on how to address the SDGs and their learning objectives for achieving them (UNESCO, 2017). The learning objectives cover cognitive, socio-emotional, and behavioural domains, which help educators define each goal pertaining to knowledge and thinking skills, social skills, and action competencies (UNESCO, 2017) to ensure that SDGs support students' learning about sustainability through a variety of topics and approaches.

While a comprehensive dashboard for transitioning to SD is provided through the SDGs, including their targets and indicators, scholars like Constanza *et al.* (2016) argue that the SDGs are the initial steps towards sustainability, but they are not exclusive and unmeasurable. Kopnina (2020) notes concern about SDG integration that may prioritise economic sustainability over human and non-human relationships, with less mention of dealing with overconsumption and increasing populations. This issue cautions that focusing too much on economic and social growth could impede SD, as economic growth causes biodiversity loss, climate change, resource depletion, and environmental abuse. In a world with finite resources, the SDGs may not be enough to ensure environmentally sustainable lives and protect other species (Washington, 2018). Additionally, in their literature study, Mensah (2019) found the challenging aspects including trade-offs and tension for making decisions on what is achieved and potential lost, particularly in the short run. Nonetheless, achieving one SDG can help address some other goals as one issue solve and improve the others, and it balance agenda of SD and targets (Mensah, 2019; Leal Filho *et al.*, 2020).

Because SDGs encompass issues for sustainability, they connect with the environmental issues that students face on a daily basis. their relevance necessitates the implementation of several strategies to tackle them, while also enhancing students' global awareness. Therefore, economic, social, and environmental sustainability must be balanced to achieve SD, country needs to consider the trade-offs and find way to manage them (Mensah, 2019). Additionally, capacity building is crucial as knowledge alone cannot reach a successful implement of SDGs (Albareda-Tiana *et al*., 2018). Educational initiatives developer need to apply skills, tools and carry out the task to accomplished the goals (Leal Filho *et al.*, 2020). The following section highlights the competencies for sustainability which help in equip individuals with knowledge, skills, attitudes and values needed to overcome SD challenges.

2.3.3.3 Competencies for Sustainability

To effectively address the global issues targeted by the SDGs, youths require crucial competencies to positively and responsibly impact the world and actively create changes (González-Salamanca *et al*., 2020). ESD can promote SD by fostering cross-cutting competencies to address various sustainability concerns (Rieckman, 2018), making competency a pivotal element in guiding the progress of education towards SD (Adomßent and Hoffmann, 2013). Recently, competencies have gained attention as critical references for curriculum and course development (Wiek *et al*., 2011). This trend is driven by the perceived lack of relevance of current educational provisions and the need to develop ‘change agents.’ As a result, ESD circles are increasingly focusing on ‘competence’ and ‘competency’ (Mochizuki and Fadeeva, 2010).

Competency encompasses knowledge, skills, attitudes, values, motivation, and commitment, which should be promoted when implementing ESD (Rieckman, 2018). Competencies are multifaceted and involve knowledge, skills, and attitudes for completing tasks and solving problems, and sustainability competencies are defined as complexes of knowledge, skills, and attitudes for completing tasks and solving problems regarding sustainability issues in the real world (Barth *et al.*, 2007; Wiek *et al.*, 2011; Wiek *et al.*, 2016). Jegstad and Sinnes (2015) claim that the development of competencies that are regarded as relevant to contributing to SD is a significant outcome that can be achieved through ESD.

Ojala (2016) indicated that the conceptualisations of ‘sustainability competence’ in ESD range from more prescriptive to more complex. Different competencies are discussed in Education for Sustainable Development Goals and Learning Objectives. Among those, the eight core competencies are illustrated as essential to successfully integrating ESD into teaching and learning to create sustainable citizens (UNESCO, 2017). UNESCO (2017) provides a view of how specific learning objectives regarding the 17 SDGs relate to competencies. The specific learning objectives include 1) cognitive domains related to knowledge and thinking skills that help understand the SDG goals and how to overcome them. The second domain is the socio-emotional domain. This domain comprises learners' social skills, such as collaboration, and emotional skills to develop individuals, such as self-reflection skills. Lastly, the behavioural domain describes action competencies (UNESCO, 2017). An example of the relationship between specific learning objectives for the SDGs and critical competencies for SD is found in Figure 4.

Specific Learning Objectives for the SDGs	Key Competencies for Sustainability
The **cognitive domain** comprises knowledge and thinking skills necessary to better understand the SDG and the challenges in achieving it.	**Systems thinking competency**: The abilities to recognize and understand relationships; to analyze complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.
	Anticipatory competency: The abilities to understand and evaluate multiple futures—possible, probable, and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
	Normative competency: The abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge, and contradictions.
The **socio-emotional domain** includes social skills that enable learners to collaborate, negotiate, and communicate to promote the SDGs as well as self-reflection skills, values, attitudes, and motivations that enable learners to develop themselves.	**Strategic competency**: The abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield.
	Collaboration competency: The abilities to learn from others; to understand and respect the needs, perspectives, and actions of others (empathy); to understand, relate to, and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.
	Critical thinking competency: The ability to question norms, practices, and opinions; to reflect on own one's values, perceptions, and actions; and to take a position in the sustainability discourse.
The **behavioral domain** describes action competencies.	**Self-awareness competency**: The ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.
	Integrated problem-solving competency: The overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive, and equitable solution options that promote sustainable development, integrating the above-mentioned competences.

Figure 4 Learning Objectives and Key Competencies for Sustainability *(UNESCO,2017)*

Figure 4 is UNESCO version of competencies for sustainability that interlink with fostering cognitive, behaviour and socio-emotional development and there are many different sets of competencies for sustainability. Learning competencies in school must be considered when implementing ESD. Timm and Barth (2021) indicated that teachers can promote SD competencies at the individual level by designing meaningful educational settings. ESD competencies must be implemented for students to become aware, responsible, and the intended learning outcomes must place emphasis on students' learning while discussing ESD, particularly when integrating sustainability into formal education curricula (Moshizuki and Fadeeva, 2010). Riekman (2018) stated that competencies enable and empower individuals to think about their current and future social, cultural, economic, and environmental consequences from local and global perspectives. Thus, different sets of ESD competencies that are deemed to be essential for ESD integration in education must be explored.

UNESCO 2015 suggests that students can only develop these competencies from life experiences, as they cannot be taught (Rieckman, 2018). However, based on the significance of these competencies, scholars provided different approaches for cultivating them. Approaches such as problem-based learning, project-oriented learning, service learning, simulation, and case studies, are recommended for higher education (Tejedor *et al.,* 2019). It was found that some competencies are less focused on in schools, such as future thinking or anticipatory competency, as reported in Sweden (Ojala, 2016). However, the sustainability discussion can serve as a space for practise competencies for SD. An example of that is when students respond to the questions that target cultivating the ability to articulate their own opinions in an impartial manner while also comprehending the viewpoints of individuals from various backgrounds (Komasinski and Ishimura, 2017). As scholars suggest different key competencies to achieve SD, this study necessitates the integration and application of these competencies for sustainability. The summary of competencies defined by scholars are presented in Table 2.

Competencies	Descriptions
System thinking	• Understand relationship and able to analyse complexity of inherent of social - environmental system (Wiek et al, 2016; UNESCO,2017;Senge, 2006 in Grandisoli and Jacobi,2020) • Comprehend how systems are embedded within different domain and scale (UNESCO,2017) • Capable to analyse SD issue across different domains/ sector/ scales (Wiek et al, 2016) • Applying systems concepts such as cause-effect structures, feedback loops, structuration,(Wiek et al, 2016) • Able to describe the need for systemic thinking in sustainability problem solving/ (Wiek et al, 2016) • Able to describe how different professional activities contribute to, or solve/mitigate sustainability problems(Wiek et al, 2016)
Anticipatory (Future thinking)	• Understand and capable to evaluate multiple futures (UNESCO,2017) • Able to create visions for the future, to apply the precautionary principle, to assess the consequences of actions, and to deal uncertainty (Wiek et al, 2016) • Able to anticipate how SD issues might evolve over time (Wiek et al, 2016) • Able to create and craft sustainable and desirable future visions with evidence (Wiek et al, 2016)
Self-awareness	• Able to reflect on one's own role in local – global society, continually evaluate and further motivate one's actions, and deal with one's feelings (UNESCO,2017)
Critical thinking	• Capable to question norms, practices and opinions; reflect on own one's values, perceptions and actions; and take a position in the sustainability discourse' (Wiek et al, 2016; UNESCO,2017)
Integrated problem-solving	• Able to apply different problem-solving strategies to SD issue (Wiek et al, 2016; UNESCO,2017) • Construct viable, equitable, and inclusive solutions through the integration of problem analysis, assessment, visioning, and strategy formulation by integrating competencies. Wiek et al, 2016) • Able to describe the need for integrated problem-solving activities and how each competencies enable this effort to foster sustainability (Wiek et al, 2016)
Normative / Value thinking	• Able to understand and reflect on the norms and values that underlie one's actions and to negotiate sustainability values, principles, goals and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions' (UNESCO,2017) • Able to specify, compare, apply, reconcile, and discuss sustainable values, principles, goals, and targets based on justice, equity, accountability, etc. in visioning, assessment, and evaluation (Wiek et al, 2016)
Strategic	• Able develop and implement innovative actions at the local level (UNESCO,2017) • Able to develop and test systemic interventions actions strategies for SD, accounting for unintended consequences and effects; able to create plans, mobilise resources, and collaborate to overcome challenges and barriers to reach envisioned outcomes; describe the desire strategic thinking in sustainability problem-solving (Wiek et al, 2016) • Able to position activities that contributes SD (Wiek et al, 2016)
Collaborative	• Able to learn with team and understand significance of teams and stakeholder (Wiek et al, 2016; UNESCO,2017) • Understand and respect the needs, perspectives and actions of others (empathy, be sensitive to others (empathic leadership), deal with conflicts in team, communication, pluralist (trans-cultural) with sympathetic understanding, discussion, negotiation, and leadership. (Wiek et al, 2016; UNESCO,2017) • Able to facilitate collaborative and participatory problem-solving, start, facilitate, and promote teamwork (Wiek et al, 2016; UNESCO,2017)

Table 2 Key Competencies for Sustainability and Descriptions From Scholars

The table above indicates different descriptions of competencies for sustainability from different studies. One of the study is from Wiek *et al.* (2011) reviewed the literature on sustainability competencies in higher education and identified five key competencies: systems thinking, anticipatory, normative, strategic, and interpersonal. Adomßent and Hoffmann (2013), suggest that the most significant competences are systemic thinking, anticipatory thinking, and critical thinking, as these are followed by acting equitably and ecologically, cooperating in heterogeneous groups, and having empathy and the ability to modify one's perspective. Academics universally recognise that students should be trained to acquire these specific competencies (Redman and Wiek, 2021). They propose an eight-key competency framework for ESD across all disciplines to accelerate SDGs progress.

The study by Levchyk *et al.* (2021) highlights the cultivation of SD in primary school students by adopting several approaches based on integrated ESD with media education, in which empowerment is the main focus. They argue that human responsibilities are a significant outcome of SD learning through collective participation and collective responsibility in school. Furthermore, Jegstad and Sinnes (2015) also note that scholars should highlight ESD competencies and lived experiences in educational programmes. They provided teacher with key competencies to promote ESD in K-12 chemistry education. Frisk and Larson (2011) provided example of competencies integrating through several approaches, such as discussing the interconnection of issue for systems thinking, and using visioning and forecasting to promote future thinking.

The study of Zeegers and Clark (2014) also promote system thinking by observe students understanding of complex system using topics such as sustainable energy, food security and providing student with knowledge from invited speakers and supporting materials with activity such as debates. Evidently, providing learning environments that consider these competencies enables students to develop each dimension by themselves. The Organisation for Economic Co-operation and Development (OECD) established its own competency framework called global competence (Asia Society/OECD, 2018). Like UNESCO’s competencies, the OECD aims to prepare individuals with the fundamental skills for the globalised world, approaching this goal from a different perspective. Both the OECD and UNESCO are looking ahead to 2030, and their approaches are similar, but their theoretical orientations and frameworks are different (Vaccari and Gardinier, 2019).

The definition of global competence according to the OECD (2018b) is the ability to examine local, global, and intercultural issues, understand and appreciate others' perspectives and world views, interact openly, appropriately, and effectively with people from different cultures, and act for collective well-being and sustainable development. Education for global competence has also become an OECD priority to advance social and economic development (Vaccari and Gardinier, 2019). Unlike the ESD competencies, which focus more on addressing sustainability and environmental issues for a more sustainable future, the OECD global competence seeks to promote international understanding and citizenship. However, the OECD stated that global competence can help promote the SDGs. Teaching global competence can foster a generation that cares about global issues and addresses social, political, economic, and environmental challenges (Asia Society/OECD, 2018). Nevertheless, Levchyk *et al*. (2021) identified a deficiency in the evaluation of sustainability competencies. This constraint presents a significant obstacle for this study in terms of observing the progression of students in each competency.

Overall, the pillar of SD emphasises the holistic perspective of SD. The SDGs indicate the scope and objective for tackling issues, and SD competencies can support ensuring learners' responsible thinking and action. In order to comprehend the matter at hand and equip students for forthcoming challenges, individuals must cultivate the knowledge, value, attitude, and competency necessary to confront such intricate concerns, specifically the ability to render decisions predicated on logical reasoning as opposed to intuitive estimations (Austin, 2020). These competencies were developed to assist people in becoming sustainable citizens. This requires not only individual competency but also their connection with values, motivations, and opportunities (Rieckman, 2018). Following that, competencies for SD must be considered.

2.3.4 ESD Pedagogy: How Different Studies Deliver ESD

> *Sustainability didactics refers to teaching and learning, and the design of learning environments or spaces, that enable learners: to see the world more holistically, to see the local manifestations of global phenomena but also the global manifestations of their own choices and actions, to consider different time perspectives, past-present-future but also to consider short and long term effects, to help them understand systems and systems dynamics, to help them deal with complexity and uncertainty, to help them navigate socio-scientific disputes, anticipate probable futures and imagine and articulate more desirable ones, and, finally, to engage them in change and transformation to move beyond awareness and the threat of paralysis by becoming overwhelmed.* (Wals *et al.,* 2015, p. 17)

'Beyond the Unreasonable Doubt' by Wals *et al.* (2015) presents sustainability didactics, a pedagogical approach that promotes a holistic comprehension of sustainability. This approach to transformation prioritises the integration of holistic thinking, engagement with socio-scientific issues, and empowerment to effect transformative change, while emphasising global-local interconnections. Cultivating students with knowledge of SD and attempting to establish the best practices for equipping students with SD skills is needed.

As indicated by Wals *et al.* (2015), sustainable pedagogy shapes students' development and existence in the world based on certain expectations and limits, such as fairness, justice, democracy, and ecological fragility. ESD pedagogies align with the contributions of ESD: the enhancement of quality education to encourage students' engagement in questioning, analysis, critical thinking, and informed judgements (Laurie *et al.,* 2016). In the view of Tejedor *et al.* (2019), pedagogical strategies for sustainability involve negotiated and adaptable procedures to facilitate teaching and learning. Due to these frameworks, which serve as guidelines for the planning, implementation, and evaluation of ESD programmes and initiatives, SD pedagogies were constructed in different ways (Grandisoli and Jacobi, 2020). These pedagogies emphasise transformative learning, shaping students into change agents (Burns *et al*., 2019; Grandisoli and Jacobi, 2020). An example of studies in the table below presents the variety of models, frameworks, and learning approaches that promote ESD.

Framework	SD focus	Approach	Disciplines	Participants	Student level	Study
Theoretical model						
Socio-scientific issue -science curriculum	3 pillars for SD, competencies, SSI issue	Inquiry- based learning	Chemistry	N/a	Secondary level	Jegstad and Sinnes (2015)
Competence, learning, intervention, assessment	Knowledge, attitude, skills and action	Action oriented	Inter-disciplinary	N/a	All level	Sinakou *et al.* (2019)
Theoretical and practice						
Burns' model ecological based	Ecological principle	Thematic, experiential, place-based learning	Leadership	Students	Higher education	Burns (2015)
Competences based learning	5 key competencies	Problem and project-based learning	Science	Students	Secondary level	Wiek *et al.* (2015)
Competence based	ESD competencies	Competency-problem solving	Biology	Students	Secondary level	Kay *et al.* (2014)
Issue-oriented instructional model	Socio-scientific issue	Inquiry- based learning	Biology	Students, teachers	Secondary level	Jackson *et al.* (2023)
Action competence in SD (acisd)	Action competence and SDGs	Self-direct, project- based learning	STEAM, arts	Students, Family	K-12	Kalla *et al.* (2020)
Erasmus+ project - environmental sustainability	Environmental sustainability	Multi-disciplinary, partnership, whole school	Multi-disciplinary	Students, Teachers, School Stakeholders	K-12	European commission *et al.* (2021)
Esd-stem4sd	Environmental Knowledge	Play-based learning	STEM	Students	Early Childhood Education	Campbell and Speldewinde (2022)
Sufficiency Economy Philosophy	Moral, Ethical and SD learning	Sufficiency-based curriculum	Cross-disciplinary	Students	School level	Dhamapiya and Saratun (2016)
Sustainability backpack	Holistic understanding of SD	Inter-disciplinary	Natural science and Social study	Teachers	Primary level	Munkybye *et al.* (2020)
STEM BCG	Bioeconomy, Circular Economy, Green Economy	Project-based learning	STEM	Students	Primary level	Ruengrung (2022)
ESD competence	System thinking	Technology based learning	Science	Students	Primary level	Clark *et al.* (2017)
Co – constructing ESD	Leadership and partnership	Whole school approach	Cross-disciplinary	Students, School Stakeholders, Community	Primary level	Nuamcharoen and dhamathiti (2018)
key component of sustainable pedagogy	Knowledge, Attitudes, Values, Skills, Behaviours	Active learning and multi stakeholder	Whole school	Students, School Stakeholders	Secondary level	Grandisola and jacobi (2020)
Community of empathic enquiry	Ecological System View, Empathic Enquiry	Whole school approach, cross disciplinary	Cross-disciplinary	Students, Teachers, Community	Primary level	Smith (2015)
Whole school approach	Value of environment, community, planet	Whole school approach, community partnership	Cross-disciplinary	Student, school Stakeholder Community	Primary level	Kuzmina *et al.* (2020)
ESD – media education	Competencies	Inquiry- based learning	Cross-disciplinary	Students	Primary level	Levchyck *et al.* (2019)
Stem4sd	SDGs, Scientific thinking	Inquiry- based learning	Stem	Students	K-12	Pahnke *et al.* (2019)
SDGs	SDGs, Noise pollution	Problem-based learning	Physics	Students, Teachers	Primary and Secondary	Costa (2023)
ESD Learning Objective, competencies	SDG 11	Project based learning	Design	Students	Secondary	Del Cerro Velázquez and Lozano Rivas (2020)
Competencies for sustainability	SDG 12	Project based learning	Cross-disciplinary	Teachers	Higher education	Albareda-Tiana *et al.* (2018)

Table 3 The Summary of Literature Study of Studies with ESD frameworks (2014-2022)

Table 3 shows that studies indicate that ESD implementation varies across different target groups, incorporating various approaches such as classroom-based, whole-school, and place-based learning, competency-based learning, problem-based learning, project-based learning, and inquiry-based learning. Additionally, among many contributions to SD, SDGs are commonly integrated into educational practices.

Okubo *et al.* (2021) state that despite the complexity and ambiguity of the SDGs, it is crucial to note that educational initiatives do align with these goals. For example, Costa *et al.* (2023) are also raising awareness regarding SDGs 11 and 17 in the educational programme for students in school to learn about noise pollution. SDG 11 is also integrated into art classrooms, where students learn to design for sustainability (Del Cerro Velázquez and Lozano Rivas, 2020). These initiatives demonstrate the interconnection of SDGs and classroom knowledge and inform the development of classroom practices in the eco-urban technical project. Students were trained to be ‘sustainable citizens’ (Del Cerro Velázquez and Lozano Rivas, 2020) through competencies as a learning approach and the achievement of SDGs as a learning objective. This framework is proven to have positive results in increasing students' awareness of sustainability. Interestingly, the study of Albareda -Tiana *et al.* (2018) adopted project-oriented learning and hands on workshop through workshops based on SDG12 for pre-service teachers. Students learn about and work on SD issues regarding food choice, food waste, and sustainable consumption, and develop competencies in research and sustainability.

Furthermore, competencies for sustainability were agreed to be critical components and embedded in many practices. It confirms the scholars value competencies for promoting SD (Albareda-Tiana *et al*., 2018; Clark *et al.*, 2017; del Cerro Velázquez and Lozano Rivas, 2020; Geden *et al*., 2019; Giangrande *et al*., 2019; Grandisola and Jacobi, 2020; Levchyck *et al*., 2021; Ojala, 2016; Rodríguez-Aboytes and Nieto-Caraveo, 2018; Tejedor *et al*., 2019; Wiek *et al*., 2016). Among these studies, primary school students are presented with a focus on fostering competencies for SD such as system thinking (Clark *et al*., 2017) and a set of competencies, for example, diagnostic competency and law competency (Levchyck *et al.,* 2019). Rodríguez-Aboytes and Nieto-Caraveo (2018) provide the assessment aspect of competencies for sustainability. In their study, assessment tasks were developed to assess high school students' achievement of competencies in Mexico. These examples provide role of competencies for achieving SD at school level.

Scholars also suggest several approaches to foster competencies. For instance, the instruction involve facilitating students' comprehension of the connection between issues' causes and effects (Clark *et al*., 2017), using this causal problem analysis to practise system thinking. Demssie *et al.* (2022) combine variety of approaches such as filed trip, collaborative learning and mobile learning to fostering system thinking competence and assess the ability to identify the dimensions of system involving 3 pillars of sustainability. Future thinking or Anticipatory competence could be incorporated by deliberating on future perspectives (Ojala, 2016; Geden *et al*., 2019). Students can demonstrate self-awareness competency, according to Giangrande *et al*. (2019), when they participate in reflections. Wiek *et al*. (2016) also demonstrated the implementation of competency-based education in three case studies that implemented novice, intermediate, and advanced levels of competencies, all of which were designed to be adapted for high school, undergraduate, and graduate levels. The backword design (Wiggins and McTighe, 2005) was employed to operationalize competencies and create a pedagogy to convey key competencies while briefly discussing measuring competency acquisition. Additionally, rubrics are developed for assess students competencies in educational programme (Albareda-Tiana *et al*., 2018; Rodríguez-Aboytes and Nieto-Caraveo, 2018)

One obvious example of the integration of competencies for SD with active learning and multi-stakeholder social learning is reported. Grandisoli and Jacobi (2020) adopted key components established by different scholars, comprising: system thinking skills, foresighted strategy, critical and reflexive thinking, stakeholder engagement, and group collaboration. This provides different aspects of how to construct the pedagogy from different theoretical perspectives and how to put it into practice together with the evaluation process of the intervention (Grandisoli and Jacobi, 2020). Their study demonstrated the flow of teaching and learning, starting with the identification of ESD issues, which is waste management, and encouraged stakeholders to work together and form partnerships for the project and find solutions at the end of process.

Grandisoli and Jacobi (2020) claim that the study is successful by providing the opportunity for a longitudinal evaluation that involves the effects and impact of the pedagogy. These educational methods emphasise the strategies of Peter and Wals (2013), which are: 1) consider learning as more than knowledge-based; 2) provide quality of interaction with others and the environment in which learning takes place; 3) focus on real issues essential for engaging learners; 4) regard indeterminacy as a central feature of the learning process; and 5) consider learning as cross-boundary and not confined to the dominant structures and spaces that have shaped education. In their study, linking political, cultural, territorial and economic factors in the practice illustrated the sophisticated integration aside from the three pillars of SD, as most sustainability criteria focus on environmental or ecological issues. With these strategies, implementation helps provide direction for constructing pedagogical activities for this research.

The study by Redman and Wiek (2021) identified how many competencies were implemented in research. System thinking is the most widely adopted competency, followed by interpersonal or self-awareness, normative, anticipatory, and strategic competence, respectively. They also encourage more research to be conducted, including: 1) research and development of new competencies; 2) operationalization of the framework across disciplines, learning environments, and global contexts; and 3) testing the framework in real-world problem-solving settings (Redman and Wiek, 2021). This research endeavours to promote knowledge and skills within primary science education, where specific competencies are emphasised.

In addition to the framework for ESD, many other strategies were illustrated and informed on how pedagogical intervention can be implemented following their own goals to promote sustainability knowledge, create social learning, and foster skills. Students centre, encourage agency and autonomy, and reflection (Pahnke *et al.*, 2019). More examples are found in the

Erasmus+ project by the European Commission, Directorate-General for Education, Youth, Sport and Culture (2021), where practices regarding science education for environmental sustainability were highlighted with themes encompassed SD issues such as sustainable food choice, biodiversity, carbon emission reduction and climate change. The whole school approach, multidisciplinary and participatory approaches were adopted across the European Union.

Among many strategies promoting SD competencies, Tejedor *et al*. (2019) suggested problem-based learning (PBL) as one of instructional approach wherein students engage in small-group discussions with the guidance of an instructor to acquire the skills of information retrieval and analysis in order to resolve complex issues by identifying solutions (Tejedor *et al.,* 2019). Aside from learning skills, Bessant *et al.* (2013) also agree that PBL has the potential to enhance students' understanding toward SD issues as well as awareness of sustainability. These activities require students to discover solutions through collaborative efforts and in-depth investigation (Wiek et *al.*, 2014). As a result, in addition to knowledge, skill development can be encouraged, according to Wiek *et al*. (2014), through opportunities for practical application and collaboration with others. Brundiers and Wiek (2013) assert that PBL helps students understand the problem and enables them to construct knowledge.

Problem-based learning is similar to the other strategy, project-based learning. Brundiers and Wiek (2013) indicated they share some common characteristics, such as using real-world problems to engage students, placing students at the centre of learning while the teacher is a coach, and multiple types of knowledge that can be applied. Project-based learning prioritises student engagement and stimulates creativity and cooperation through three phases: 1) Definition/Planning/Research, 2) Implementation/Production 3) Evaluation/self-evaluation (Tejedor *et al.,* 2019). The case study in the project offers real-life situations with one or more problems to discuss, analyse, propose solutions to, and answer questions about (Tejedor *et al.,* 2019). Brundiers and Wiek (2013) recommend project-based learning as it is a self-directed learning orientation where students can develop evidence for solutions and provide outcomes as choices for solutions and products. In Thailand, project-based learning is employed with the Bio-Circular-Green Economy (BCG) model, emphasising the importance of economic, social, and environmental aspects in the context of local food to enhance students' problem-solving skills and STEM learning (Ruengrung, 2022).

Another approach is inquiry-based learning, which encourages students to inquire into complexities and learn to confront complex situations in a constructive manner. Pahnke *et al*. (2019) suggest that the integration of STEM inquiry-based learning and ESD can be beneficial for students as it corresponds to students' curiosity, their desire for exploration, and their aspiration to comprehend the world. Integrating inquiry-based learning with disciplines such as science education, students learn SD while scientific processes, knowledge and skills, and awareness are enhanced (Jegstad and Sinnes, 2015; Austin, 2021; Jackson *et al*., 2023). It was also implemented with gifted students to learn about the issue of mining, which is a local issue relevant to students (Morris *et al*., 2021).

Place-based learning is yet another approach that promotes SD by integrating local environment and community into learning process. It is commonly employed in environmental education (Lozano *et al*., 2017). This approach involved outdoor learning where learning activities are held in natural settings, allowing students to relate theoretical concepts with real-world experiences, promoting the relationship and connection between students and nature and enhancing their understanding of place and responsibility for SD (Li and Shein, 2023; Selby, 2017). They use playful interactions with nature to break down the cognitive/emotional, nature/culture, and knowledge/experience binary and connect learners directly with the world (Austin, 2020).

There are no single approach to reach to effective ESD initiatives. For example in Higher education, various strategies are identified as effective approach to promote competencies for sustainability such as case studies, lecturing, PBL, community learning, simulation and place-based learning (Lozano *et al*., 2017; Tejedor *et al*., 2019). To sum up, there are many strategies suggested by scholars in the education setting to integrate ESD (UNESCO, 2013; UNESCO, 2018b), as shown in the Table 4 below.

Approach	Descriptions	Uniqueness	Example	Studies
ESD curriculum	ESD is embedded in the national curriculum , national standard, in school curriculum.	School to national level	ESD curriculum in USA, Australia, Japan Sweden, Norway , Thailand	Schroth and Helfer (2017), Australian Education for Sustainability Alliance (2014), DEEWR, (2009), Edwards and Cutter-Mackenzie (2011), Smith and Watson, (2019), Didham and Ofiei-Manu (2012)
Cross curriculum	ESD is integrated by learning such subjects and disciplines, ESD concepts are bl ended into them.	Embedded in single to multiple discipline	Erasmus+ project, System thinking and electricity unit. SDG11 and Drawing, STEM4SD , SDGs integrated course, ESD in gifted programme	European commission (2021), Clark *et al.* (2017), Del Cerro Velázquez and Lozano Rivas (2020), Okubo *et al.* (2017), Jackson *et al.* (2023), Campbell and Speldewinde (2022), Ledwith *et al.* (2017), Eilks (2015), Levchyk *et al.* (2019), Morris *et al. (*2021)
Whole school approach	Apply in whole institution level and involved students and school-stake holders and community.	involve various stakeholders in school and able to adopt different approaches	Eco school, Green school, Bansankong's rubbish project, Food for life, Zero waste project, Sufficient Economy Philosophy, STEM4SD	Kuzmina *et al.* 2017, Asia pacific for cultural centre for UNESCO, 2012, Iwan and Rao (2017), Lee and Suwicha (2020), Dhamapiya and Saratun (2015), European commission *et al.* (2021), Pahnke *et al.* (2019), Grandisola and Jacobi (2020)
Informal curriculum	Collaborating with the public sector and stakeholders to co-produce ESD practises or conducting learning outside of school.	Partnership with public and private sector, not limit within school	Nishinomiya city, Japan , Root and Shoot (Australia),	Yoshizumi and Miyaguchi, (2005)

Table 4 Different Approaches for Delivering ESD and Examples of Study

Table 4 illustrates various approaches, offering practical ideas for integrating ESD with STEM education in any educational context. Promote ESD requires education ‘about’ and ‘for’ SD as the former is the knowledge-based; instead, the latter emphasised skill and value as it places learners at the centre as active participants (Austin, 2021; Gajparia *et al*., 2022). Overall, scholars demonstrated the necessity of incorporating different sets of competencies and foci into this research, with a particular emphasis on the process of implementing them and the trajectory to cultivate and observe students' competency development. However, since the research focuses on primary school students, it is important to consider age-appropriate and engagement approaches when implementing various strategies to promote ESD through STEM. In the following section, ESD for young children is discussed.

2.3.5 ESD for Young Children

> *Even children in the third grade can learn through Education for Sustainable Development, because ESD develops their ability to address open questions, to consider various scenarios for the future and to act competently.*(Clausen, 2009, p. 27)

The ESD learning course in Denmark is as an example of a learning strategy that engage third-grade students in discussions about the different living lifestyles of children in Guatemala and Denmark (Clausen, 2009). Building on the perspective from the previous section and this example, and considering that ESD has a broad target audience, it is important to emphasise the promotion of SD learning from a young age. Learning ESD at an early age promotes attitude and value (Samuelsson, 2011) and foster lifelong learning (Siraj-Blatchford *et al*., 2010). In terms of their maturity to learn, Samuelsson (2011) argues that they are capable of comprehending and creating meaning from their experiences and environment. Serret and Earle (2018) suggest that by upper primary age, children are able to ask questions and made connection from local, to national and to global level regarding issues such as global warming and government policy. These capabilities prepare them to engage with the complex SD issues, integrating their previous knowledge, experiences and surroundings.

Numerous studies centre their attention on promoting SD learning during this developmental stage, underscoring the significance of young children as agents capable of transformative change and fostering sustainability (Clark *et al.*, 2017; Levchyk *et al.*, 2021; Taylor *et al*., 2015). Some countries, such as Japan and Australia, agreed to adopt ESD in early childhood and primary curricula (MEXT, 2008; DEEWR, 2009; Hedefalk *et al.,* 2015). This includes integrating education for environmental sustainability into natural science courses or incorporating it into subjects related to civil education or citizenship education at the primary school level (European Commission *et al.,* 2021). This demonstrates the educational policy emphasise on ESD to foster young citizens, regarding ESD capacity to facilitate transformative learning and teaching for change in young children.

ESD benefits students in several ways. ESD makes their learning content more relevant, the school curriculum more meaningful, enhances students' engagement by adapting ESD to local themes and goals, and helps students recognise their social roles (Laurie *et al.,* 2016; Panhke *et al.*, 2019). This demonstrates that ESD improves learning, inspires students to be responsible and aware, and empowers global citizens to meet 21st-century challenges. With these benefits, introducing ESD at an early level is essential in terms of preparing them for an uncertain future and equipping them with the ability to work with others and accept other perspectives (Samuelsson, 2011; Hedefalk *et al*., 2015). Similar to the study of Hill *et al.* (2014), where the ESD initiatives of educators were explored (Hill *et al.,* 2014), further supports that educators agree with ESD practice to start early. Hedefalk *et al*. (2015) suggest that teaching and learning for sustainability education that reaches the objectives of SD are still limited. To reach this level, the practice must provide action activities and learning processes involving decision-making.

To promote ESD in young students, which is the target level of this research, Kopnina (2012) stated that the different implementation of ESD in the case study between elementary and higher education levels is the practice's goal. The former level focuses on awareness of the environment, but the latter focuses on skills and knowledge for green production and economy as per UNESCO guidelines (Kopnina, 2012). So, at the younger level, the issues for learning are less complex and target the attitude and perception toward SD. Torkar (2014) added the issue should not burden for young children for their learning and experience with nature as well as their enjoyment are crucial.

In early childhood education, Hedefalk *et al*. (2015) identified ESD practices with two distinct definitions: one is teaching in, about, and for the environment, and the other is teaching relating to three dimensions: economic, social, and environmental. The former definition teaches about nature and natural systems, such as planting trees and knowing the water cycle. At the same time, the latter follows the UN sustainable development framework and relates to the connection between human behaviour and its effect on society and the economy. Students are capable of considering environmental issues, social impacts on humans and living organisms, and economic perspectives informed by their cultural experiences, according to Samuelsson (2011). The most common practices for young children are related to food, energy, play space, and gardening, and their opinions collected represent the concept of SD in terms of knowledge of nature only and focusing on natural resources (Hill *et al.,* 2014). This reminds me that SD concepts regarding social, political, and economic aspects are understandable by students.

At the primary school level, ESD is embedded both in the classroom and throughout whole school practices. Laurie *et al.* (2016) reported that ESD is embedded in primary curricula in Sweden and Scotland, while other countries in their research have seen an increase in school projects regarding ESD. An example is the eco-school programme which incorporates global citizenship, water, and waste management (Boeve-de Pauw and Van Petegem, 2018). In the UK, Finlayson (2018) notes the implementation of a whole school approach that integrating concepts of care for oneself, other and the environment into their ESD practices. Similarly, a climate change curriculum that takes climate change into account, was conducted in primary schools in the UK, Ireland, Turkey and Germany using a whole school approach (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2021). The whole school approach works throughout the entire school, regardless student level.

An example of classroom practice is found in a third-grade classroom in Denmark. Students learn life quality, history and empathy from a story of a Guatemalan boy (Rolls *et al.,* 2015). Students are engaged with community learning by interviewing local people and drawing conclusions on the posters that reflect natural resources in different time periods (Rolls *et al.,* 2015). This case provides an important insight for more success in ESD implementation by encouraging students to reflect on their thoughts and promoting communication. These capabilities were also emphasised in the study by Munkebye *et al.* (2020). Munkebye *et al.* (2020) report on implementing an ESD multidisciplinary learning unit based on social study and natural sciences in Norwegian classrooms. The program adopted a holistic approach and involved SD issues in subjects aimed to enhance student competencies such as expressing their view, making arguments, and raising awareness and understanding of SD.

In addition, Hedefalk *et al*. (2015) content that problem-solving, democratic justification, and meaningful action towards the environment can be approach for ESD, suggesting that the environmental issue and facts can be effectively incorporated into ESD. However, few studies provide the activities that enable students to perform environmental protection and uphold the idea of democracy (Hedefalk *et al*., 2015). Levchyk *et al.* (2021) conducted one such study, where students develop competencies for sustainability through experiential learning and reflection, demonstrating collective participation and responsibility. Several approaches in the ESD–media education learning programme, including game and project work, were implemented with topics like water, garbage, and plants.

Extracurricular activities is also reported. Many STEM projects engage students in primary school interested in learning about environmental issues and climate change, providing future and community perspectives and moving toward actions. Moreover, in the study of Pahnke *et al*. (2019), a STEM camp and fabrication lab in Thailand at Sirindhorn Science Home for Children provided students with STEM4SD activities based on the SDGs. Students were targeted to have meaningful experiences, foster creativity, construct concepts of the world, face challenges, nurture curiosity, learn metacognitive skills, and be inspired. Primary school students take part in the programme by learning about issues such as climate change through active engagement in game-based learning and exploration (Panhke *et al.,* 2019).

Policy, research, and practice place significance on promoting ESD at a young level, encouraging primary school students to learn about SD from various approaches. They can learn from environmental knowledge by being active participants in learning. The student's engagement in reflecting on their voices and participating in discussions is the approach to promoting SD learning. These insights inform the development of pedagogical activities for this study; however, SD competencies are less mentioned at this level.

2.3.6 ESD in Thailand and The Philosophy of Sufficiency Economy

Before exploring ESD in practice, Thailand's education system needs to be understood. The national Ministry of Education (MOE) is in charge of general education policy, which includes mainstream and vocational education, including the majority of state and private educational institutions (OECD/UNESCO, 2016). The Office of the Basic Education Commission (OBEC) is responsible for mainstream education, covering primary level (grades 1 – 6) and secondary level (grades 7–12). At the same time, the Office of the Vocational Education Commission (OVEC) is in charge of vocational education and training. Furthermore, the institute for the promotion of teaching science and technology (IPST Thailand) is responsible for supporting professional development, curriculum and assessment in science, mathematics, and technology standards (STEM education), as well as gifted education for science and mathematics (OECD/UNESCO, 2016; IPST, 2020).

Before 2019, higher educations were governed by different governmental agencies, such as the Ministry of Public Health and the Office of Higher Education Commission (OHEC). Since 2019, universities and other higher institutions are under the Ministry of Higher Education, Science, Research, and Innovation (MHESI, 2020). For ESD integration In Thailand, sustainable development goals are the framework for developing the country under national policy. According to The National Strategy (2018-2037), which is Thailand's first 20-year policy to achieve the vision of 'a developed country with security, prosperity, and sustainability under the Sufficiency Economy Philosophy' (National Strategy Secretariat Office, 2018), the focus is on sustainable natural resource management, climate change, sustainable economic growth in business, the tourist industry, consumption and production, waste management, sustainable agriculture, and maintaining social equality and well-being among Thai citizens.

However, there appears to be no official ESD curriculum or standard in mainstream Thai education. After the United Nations promoted the SDGs in 2015, 193 countries were given a global framework to achieve sustainable development by 2030 (United Nations, 2015). Thus, Thailand must also incorporate these objectives into its policies and practices as a member country of the UN. Recently, the country's main focus has been on SDG4 (quality education), as also stated in Thailand's 20-year National Strategy (Office of the National Economic and Social Development, 2018; OEC, 2021).

The implementation of the national strategies focusing on SDG4 can be seen in the country's policies, addressing quality and equality in education. In practice, school-aged children get a free 15-year education (OECD/UNESCO, 2016). In addition, the Ministry of Education announced that compulsory education, starting from elementary education (preschools - 3 years old) to primary education (grades 1 – 6) and lower secondary school (grades 7 – 12), is mandatory for all children in the country, regardless of nationality or migratory status. It was found that 83 per cent of those who graduate from primary education are enrolled in secondary schools, and 76.2 per cent of children aged 3 to 5 have access to high-quality early childhood education (Voluntary National Review, 2017).

The national strategy also addresses teaching and learning to foster 21st-century skills and lifelong learning as well as increase competent workers (Office of the National Economic and Social Development, 2018). The education plans of both mainstream and vocational schools follow the SDGs pertaining to quality education and lifelong learning.

Based on SDG 4, the Ministry of Education of Thailand has announced Thailand's national education plan for 2017–2037 and determined the National Scheme of Education's strategies, which use the following six strategies to fulfil the vision, objectives, and educational concepts: (1) national security; (2) national competitiveness enhancement; (3) human capital development and strengthening; (4) social cohesion and just society; (5) eco-friendly development and growth; and (6) public sector rebalancing and development (Office of Educational Council, 2017). To emphasise this, strategy 5 focuses on educational administration to enhance the quality of eco-friendly life. The Office of the Educational Council indicates that the aims are to focus on the learner, curriculum, and research regarding promoting awareness of the environment, morals and ethics, and the implementation of SEP for an eco-friendly life (OEC, 2017).

For other SDGs integration, an attempt was mainly made in higher education. Many universities have started adopting SDGs in their curricula, such as postgraduate courses (sustainability.chula.ac.th, no date). In 2019, the higher education policy and practise related to ESD were established under the name of the Thailand Environmental Education for Sustainable Development (EESD) Partnership. Since the stakeholders from four universities are joining together to build up the network under the cooperation of the Ministry of Natural Resources and Environment of Thailand to promote ESD at national and international levels (UNESCO Bangkok, 2019), this partnership could lead to a positive direction for future education transformation and bring more efficient ESD implementation in higher education in Thailand.

In addition, UNESCO provides guidelines and examples of practises in teacher education. The Southeast Asia ESD teacher and educators' network is formed to collaborate with teachers, institutions, and universities dedicated to promoting Southeast Asia (UNESCO Bangkok, 2019). Members collaborate to include ESD in teacher education, conduct ESD activities, and share regional best practices. Consequently, this generated the research idea to study the integration of ESD within the existing Thai national curriculum at the primary level by developing an alternative approach for implementation in primary schools. Thus, there is little evidence on teaching and learning for SD in early childhood and primary education that promotes SD, especially integration with the SDGs, and competence for SD.

However, ESD practice was found to be a whole school approach at a younger level. Bansankong Primary School in Chiang Rai is an example of successfully raising SD awareness. The school started the rubbish initiative, and students collaborated with the community to learn about waste and share their expertise (Asia Pacific for Cultural Centre for UNESCO, 2012). With the powerful collaboration of school stakeholders and community members, this project enhances awareness of waste management in their community as a basis for SD (Asia Pacific for Cultural Centre for UNESCO, 2012; Nuamcharoen and Dhirathiti, 2018). However, the ESD practices that focus on empowering youth and supporting educators in primary schools are still scarce, especially in SDG integration and professional development.

Even though there is no official ESD curriculum, in Thailand, the SD initiatives are governed by the nation's distinctive sufficiency economy paradigm with the concept of the 'Philosophy of Sufficiency Economy' that was advocated by His Majesty Bhumibol Adulyadej, Thailand's former king in 1974 (Mongsawad, 2010; Didham and Ofei-Manu, 2012). Sufficiency Economy Philosophy (SEP) offers a comprehensive approach to achieving a balanced development between rapid economic progress and the establishment of self-reliant communities (Mongsawad, 2010; Didham and Ofei-Manu, 2012; UNESCO, 2013). Dharmapiya and Saratun (2016) indicated that the aim of promoting SEP within the Thai education system is to foster the cultivation of sufficiency thinking among students from a young age to equip them with the necessary skills to lead a self-sufficient and harmonious lifestyle.

The SEP has underpinned Thailand's national curriculum. Its goals align with the SD concept with a focus on social, economic, cultural, and environmental factors by following the middle path of Buddhism that avoids extreme life, SEP emphasises moderation, reasonableness, and self-immunity, which are key to promoting the outcome (UNESCO,2013). Focusing on environmental issues, the SEP targets immunity toward environmental changes by starting with oneself. Barua and Tejativaddhana (2019) argue that SEP provides more benefits for global society. SEP is relevant worldwide in the 21st century due to economic uncertainty, climate change, and unsustainable resource use, and it protects society from globalisation's harmful impacts and prioritises wellness over wealth building, creating a more balanced and SD path (Barua and Tejativaddhana, 2019). SEP was already promoted by OBEC Thailand to be integrated into mainstream education to equip students with moral-led knowledge (Bureau of International Cooperation, 2008). According to Didham and Ofei-Manu (2012), based on the National Educational Plan, SD content is clearly identified in the eight primary subject areas, with content topics and learning requirements closely related to ESD. However, the concept of SD is taught separately among those subject areas. For example, environmental sustainability aspects were taught in science subjects, while economic aspects were taught in social studies, religion, and culture subjects. More opportunities to foster holistic perspectives of SD in the science classroom are needed, along with skills to tackle uncertain challenges.

According to the Basic Education Core Curriculum (A.D. 2008), instead of having an ESD standard, as shown in Table 5, the goals of learning are partly related to sustainability issues, encompass morals and ethics as well as life skills as an influence of SEP (Ministry of Education, 2008; Dhampiya and Saratun, 2016). According to educational reform, education in Thailand is directed towards the management of education and the structure of the curriculum, operating within the SEP framework (Nuamcharoen and Dhirathiti, 2018). Under the SEP framework, 40% of surveyed sectors must provide ESD, including the national curriculum, elementary, secondary, and non-formal education (Didham and Ofei-Manu, 2012). According to Benavot (2014), Thailand's curriculum structure allows schools to create locallybased content, up to 30% of the total curriculum, and this brings advantages for schools to address local ESD issues, such as sustainable lifestyles, livelihoods, and self-sufficiency. Dharmapiya and Saratun (2016) indicate that currently, more than 14,000 Thai schools out of nearly 40,000 effectively implement the sufficiency-based curriculum. The objective was to attain a comprehensive integration of various aspects of quality of life, including social, economic, and environmental dimensions (Nuamcharoen and Dhirathiti, 2018). For example, the reservation of the environment as part of environmental protection is a global community as part of global citizenship, applying SEP to maintain economic status under sufficient resources (Didham and Ofei-Manu, 2012). Problem-solving is acknowledged with awareness for environmental protection, but other key competencies for sustainability are not directly highlighted. However, there are only a few reports of students perspectives regarding SD, especially in science education and STEM education (Lee and Ruwicha, 2020; Ruengrung, 2022).

Relationships in the development of learners' quality according to the Basic Education Core Curriculum	
Vision	
The Basic Education Core Curriculum is aimed at enhancing capacity of all learners, who constitute the major force of the country so as to attain a balanced development in all respects – physical strength, knowledge and morality. They will fully realize their commitment and responsibilities as Thai citizens and members of the world community. Adhering to a democratic form of government under a constitutional monarchy, they will be endowed with basic knowledge and essential skills and favourable attitude towards further education, livelihood and lifelong learning.	
Goals	
1. Morality, ethics, desired values, self-esteem, self-discipline, observance of Buddhist teachings or those of one's faith, and applying the principles of Sufficiency Economy Philosophy. 2. Knowledge and skills for communicating, thinking, problem-solving, technological know-how, and life skills. 3. Good physical and mental health, hygiene and preference for physical exercise. 4. Patriotism, awareness about a democratic way of life and form of government under a constitutional monarchy 5. Awareness of the need to preserve all aspects of Thai culture and Thai wisdom, protection and conversation of the environment, and public-mindedness with dedication to public service for peaceful and harmonious coexistence.	
Learners' key competencies	**Desired characteristics**
1. communication capacity 2. thinking capacity 3. problem-solving capacity 4. capacity for applying life skills 5. capacity for technological application	1. love of nation, religion and the monarchy 2. self-discipline 3. avidity for learning 4. applying principles of sufficiency 5. dedication and commitment to work 6. cherishing Thai nationalism 7. public-mindedness
Learners' quality at basic education level	
Learning standards and indicators	**Learner development activities**
1. Thai language 2. Mathematics 3. Science 4. Social Studies, Religion and Culture 5. Health and Physical Education 6. Art 7. Occupations and Technology 8. Foreign Languages	1. consulting activities 2. student activities 3. activities for social and public interest

Table 5 Summary of Thailand's Basic Curriculum A.D. 2008 (Ministry of Education, 2008)

According to SEP, Thai students may have an understanding of sustainability from this approach. However, there are only a few reports of student perspectives regarding SD, especially in science education and STEM education. It was suggested by Promboon *et al.* (2018) that the potential for attaining the SEP will be considerably enhanced by the development and implementation of a high-quality, rigorous STEM education system. Even though SEP has already been embedded in the Thai curriculum since 2008 (Dharmapiya and

Saratun, 2016), ESD still needs to be encouraged, expanded, and integrated into mainstream education (Nuamcharoen and Dhirathiti, 2018). Models and interpretations of the SEP from diverse perspectives and sectors have arisen, but systematic study is needed to explore its variation of application, and how the concept can be implemented into strategies, policies, and action plans is also crucial and must be explored further (UNESCO, 2013). This research sees the potential of competencies to address these gaps as an alternative approach for ESD at the primary school level.

Nuamcharoen and Dhirathiti (2018) add another approach to promoting ESD in the country by using co-construction theory in schools, which was implemented in Bansankong School, in which a partnership between school stakeholders was created and a whole school programme was designed.The outcome of the framework was that the approach effectively addressed communal issues, such as poverty and illiteracy, as a result of fostering both students' academic and life skills (Nuamcharoen and Dhirathiti, 2018). However, the study reports the issue of the budget needed to operate the approach in schools to achieve more promising SD learning (Nuamcharoen and Dhirathiti, 2018).

According to the research and practises of ESD in several countries, educational policies and ESD curricular or ESD cross-curricular play an essential part in encouraging ESD practises and research. For example, in Sweden, the national curriculum embeds ESD. Research on ESD found many ESD initiatives in schools (Fredricks and Eccles, 2008; Hedefalk *et al*., 2015; Olsson *et al.,* 2016; Svalfors, 2017). It is because scholars report that teaching about environment, especially in environmental education in Thailand is not teach as a distinct subjects (Bhandari and Abe (2000) cited in To-Im and Klungklueng, 2012; Asares and Krishnan 2014), not challenging and engaging practice (Laiphrakpam *et al.*, (2019), and not encourage for critically examining the issue (To-Im and Klungklueng, 2012).

To promote ESD in primary schools in Thailand, the integration of ESD into certain subjects within the existing national curriculum could be a viable, especially due to the way it incorporates SEP concepts (Ministry of Education, 2008). As science subjects provided environmental knowledge, according to Thailand's primary core curriculum, students can learn about economic or social perspectives from other subjects such as social studies, religion and culture, and geography (Ministry of Education, 2008). Although environmental conservation activities regarding soil, water, and others can be implemented through a whole school approach according to scholars, by following the SEP (Dhampiya and Saratun, 2016). Teaching by integrating SD in classroom can also help to striving to create a more sustainable citizens.

To this end, To-im and Klungklueng (2012) address the need of strategies regarding environmental education with powerful instrument for create the changes through the SD. ESD integration through the science curriculum is highly likely suitable for teaching primary students. The content can be tailored to match their level of understanding, in line with the country's education policy. The potential of science knowledge is discussed in later section.

2.3.7 Environmental Sustainability Issues

When considering real-world issues, it is important for young students to learn about the environment that are relevant to their lives and their classroom knowledge. Mackey (2012) contents that children as an active citizens can raise their voices and participated in solving the issue, involve in seeking knowledge, expressing ideas, and making decisions within the contexts appropriate to their level. Tailoring learning tasks to align with students' interests, needs, and sense of self-worth can make the content more engaging and relevant to them (Stuckey *et al.,* 2013). Following this view, global sustainability issues encourage critical and introspective thinking in students, helping them relate their lives to those around the world (Bourn *et al.,* 2016). Additionally, as many parents want to help their children succeed in life, SD and a strong economy are equally important to ensure that their children attain prosperous careers and futures (Stuckey *et al.,* 2013). These themes also allow students to positively connect with social issues, fostering a perspective geared toward a better future (Bourn *et al.,* 2016).

To provide students with skills such as problem-solving, according to Glancy and Moore (2013) problems, or issues, especially in the classroom, real issue must be taught and should be challenging and provide rich context for them to encounter. Environmental sustainability is regarded as a wicked issue that has no one single solution to resolve, is involved with stakeholders and conflict from global perspectives, and provides a unique challenge (Murkatroyed, 2010; Yearworth, 2015; Broen and Broen, 2019).

The real-world complex issue that interlinked with society and science, can also serve as ill - structure problem (Holder *et al.*, 2017). The ill-structured problems, as defined by Jonassen (1997), involved unclear and unique issue, have no one correct answer, offer multiple ways to resolve them, and are uncertain and inconsistent in principle, concept and rules, requiring argumentation and personal belief. Therefore, the complex nature of real-world environmental sustainability issue makes it meaningful for learning, as students can gain concepts and skills. The ill-structured problem allow for multiple solutions to resolve, especially when they consider multiple solutions related to social, economy or geological data (Holder *et al.,* 2017). Students are also encouraged to find argument for support their claims (Hmelo-silver and Barrow, 2015) and allow application of advance PSS (Kim *et al.,* 2019). Teachers can also empower students by motivating them to have optimism and a vision for the future, foster in them a sense that they are capable of creating global change, reduce the causes of climate change and global warming, and understand the significance of environmental protection (Skamp *et al*., 2013).

Many studies provide evidence that integrated ESD through science education can be done by teaching environmental knowledge. An issue-based approach is a useful method of structuring the curriculum to develop such concepts in a manner that supports constructivist pedagogy and the integration of cognitive and affective skills in science with clear connections to environmental issues (Littledyke, 2008). In the previous section, Socio-scientific issue presented the integration between scientific knowledge and controversial issues in society including climate change and energy issue (Burmeister *et al*, 2012). Based on Wendlandt Amézaga *et al.* (2022), knowledge is crucial as factor for attitude and behavior toward SD. Additionally, In order to address intricate issue and advocate for their solutions, student must depend on their prior knowledge and personal belief (Holder *et al.,* 2017). However, knowledge alone is not enough for pro-environmental behaviors (Kokkinen, 2013). Additionally, global sustainability issues cannot be resolved solely through the application of scientific knowledge, so that value regarding diverse cultural and contextual backgrounds and perspectives must also be taken into account (Manabu, 2018).

As this research is focused on primary school students, the science knowledge is regarding environmental aspects. Among SD issues, environmental sustainability is more likely to be relevant to students at this age. The European Commission *et al.* (2021) defined learning for environmental sustainability as a form of education that raises students' awareness, sensitivity, and knowledge of the environment and its complex relationships with social and economic systems, as well as encourages concern, motivation, complex systems, and critical thinking abilities to help students recognise and handle environmental issues.

Environmental sustainability issues extend beyond protecting the environment. Understanding the environmental sustainability issue involves examining it within the social and economic context while also evaluating the comprehensive skills required for achieving SD (European Commission *et al*., 2021). In order to incorporate the topic of environmental sustainability based on Thai science standards, the model proposed by Burmeister *et al*. (2012) suggests incorporating critical reflection. Burmeister and Eilks (2012) suggest a discussion of the issue within the SD dimension, encompassing social, economic, and environmental factors. This emphasises the importance of the three pillars of SD that must be incorporated and highlights the importance of student participation in the decision-making process (Eilks, 2015).

Global environmental issues were the focus to provide perspective of issue as its vary in context and culture, which can be embedded into practice, such as climate change adaptation, disaster preparedness, the green economy, social justice, and global alliances (Laurie *et al*., 2016). The global perspective enable students to explore the complex interconnection between global and local issue. Concurrently, Incorporating natural and local environmental issues into the learning scenarios highlights their significance as major problems faced by Thailand in the last decade. An example of this is the flood commonly occurring in the rainy season. In 2011, the most catastrophic flood, the worst in 70 years, hit Thailand. This flood lasted for seven months, from July to January, and spread around the country from northern to southern Thailand, causing the deaths of 728 people and affecting nearly 13 million others. Many lost their homes, agricultural resources, and jobs. The industry section for the electronic global supply chain was severely disrupted, resulting in an economic loss of approximately 30 billion US dollars (Bank of Thailand, 2012; Gale and Saunders, 2013).

Given Thailand's seasonal monsoon climate, flooding has become an annual occurrence, with reports indicating that floods have hit Thailand every year since 2011 (Hydro and Agro Informatics Institute, 2019). This calls into question the capacity of the Thai people, government, and community to address this issue. In addition to flooding, Thailand also faces hardship with the severe issue of deadly PM2.5 air pollution, which becomes a controversial issue during the winter season (Pongpiachan, 2016). Landslides are also common in mountainous areas in the north, northeast, and south of Thailand. As Thailand is in the tropical zone, heavy rain and deforestation are the sources of this phenomenon, causing problems such as blocked roads, houses, and life devastation. A case in Mae Hong Sorn Province in July 2018 reports that a landslide affected transportation and destroyed the electrical system, leading to electricity outages and school shutdowns (Thaipbsworld, 2018).

Recent occurrences that have had an impact on the lives of local residents include bushfires. In the beginning of 2020, Thailand's bushfire situation is getting more serious, as reported by the detection of the satellites. Bushfires cover the area of eight northern provinces of Thailand, leading to deforestation and an air quality change in the cities nearby (GISDA, 2020). In Chiang Mai provinces in 2020, the bushfire devastated Suthep-Pui National Park, which contains 10% of Thailand's hotspots. The causes of this phenomenon are attributed to human behaviour, such as cutting and burning for farming, as well as droughts, which are identified as the primary sources of the fires (GISDA, 2020).

In addition to these aforementioned catastrophic issues, plastic and microplastic issues, water pollution, water scarcity, and mangrove destruction are also extremely challenging for this country (Pollution Control Department, 2019). These issues offer students the complexity, foster engagement, promote comprehension of the issue and allow them to see practical solutions in action. However, it must be concerned that asking students about these topics in both local and global level, can make them feel frighten, upset, discomfort and hopeless (Nicol *et al.,* 2019; Quinn *et al*., 2015), especially young students (Nordensvaard, 2014; Austin, 2020). To teach students and learn regarding the issue, ‘hope’ is essential and must be promoted (Ojala, 2012; Wals, 2015; Austin, 2020) and actions that students can make as well as how they should avoid the issue are recommended under teacher judgement (Quinn *et al*., 2015). Accordingly, competencies embedding can also be advantages in equipping students with the skills and attitude necessary to overcome the challenges and recognise their potential to cope with the issue.

Many concerns with environmental sustainability show the importance of changing human conduct. Students have the right to understand the significant concerns confronting the world, as well as the realisation that they may be able to help and change the future (Austin, 2020). As issues are particularly relevant for Thai students, learning scenarios can incorporate social and economic components to boost students' learning through SDG integration, the notion of SD, and competencies as well as awareness for SD.

2.4 STEM Education

As introduced in Chapter 1, STEM education is an interdisciplinary approach incorporating science, technology, engineering, and mathematics, that yields benefits for students. STEM education support learning across disciplines (Smith *et al.*, 2022). From the lens of researches and practices, the advantage of STEM are as follows;

1. Providing an excellent learning opportunity for a deeper grasp of that transdisciplinary knowledge and conceptual learning (Honey *et al*., 2014). STEM is an effective tool to demonstrate the implementation of several concepts and connections of knowledge made by students, integrate multidisciplinary knowledge including science, technology, engineering, and mathematics, which is applicable to solving problems in the daily life

(Bethke Wendell and Rogers, 2013; Portz, 2015), as well as promote academic achievement (Yu *et al*., 2020)

2. Enhancing students' essential skills, including problem-solving, analytical thinking, critically reflecting and creativity, prepares them for their future academia and career (STEM Education Thailand, 2014; Sriwibunrat and Onthanee, 2018; Pahnke *et al*., 2019; Khamngoen and Srikoon, 2021; Lakanukan *et al.,*2021).
3. Promoting learning motivation, affection, and value of learning (National Academies of Sciences, 2022), helping students connect to the real world and introduce them to STEM careers, and following STEM pathways (Margot and Kettler, 2019), and promote social-emotional development (Ozkan and Kettler, 2022)
4. Promote innovative teaching of the STEM discipline such as Mathematics education (Fitzallen, 2015) and Engineering education (English, 2016).

The advantage of STEM education made this an effective approach for promoting problem-solving skills (PSS). STEM education and problem-solving skills are discussed in the following section.

2.4.1 STEM Education and Problem-Solving Skills

The OECD (2104) emphasises the significance of PSS in empowering students to tackle and overcome obstacles, particularly non-routine cognitive challenges. Scholars support that STEM education are not only boots students' learning motivation and developing STEM literacy, but also fostering their awareness of how to effectively apply STEM knowledge to solve real-world issues in the problem-solving process (Lai, 2018; Lou, 2011).

Due to the research objectives, this study aims for promote ESD, enhancing the problem-solving skills (PSS) of gifted science students through STEM problem-solving activity. Thai scholars have reported an enhancement in PSS among Thai students through STEM activity (Khamngoen and Srikoon, 2021), especially in young gifted individuals (Lakanukan, 2021). However, to foster PSS, comprehension of PSS is vital for effectively implementing it in real-life scenarios, emphasising the importance of practical problem-solving experiences over theoretical assumptions (Sangwan and Singh, 2018).

Scholars suggest that PSS is a combination of processes, skills, and attitudes. Gagne (1970) defines problem-solving as the process through which a learner discovers a solution for a unique circumstance, leading to the acquisition of new knowledge. Jonassen (1977) describes problem-solving as complex activity requiring the cognitive and procedural knowledge, motivation and attitude, metacognition and knowledge about self. Mourtos *et al*. (2004) identify problem-solving as a process involving ill-defined issues, entirely new problems, no explicit statement of the issue, multiple solutions, unclear algorithms, the integration of multidisciplinary approaches, and the application of communication skills. OECD (2013) used Meyer's (1990) definition of problem-solving for PISA in 2012, which describes it as a cognitive processing aimed at changing a given circumstance into a desired condition when no solution is currently available.

In addition to the process, a set of skills is involved. Watts (1991, p. 41) indicates that PSS, coupled with creative skills, encompasses 'the ability to diagnose the features of a problem, formulate hypotheses, design experiments to test them, and evaluate the results; the ability to draw on relevant ideas and use materials inventively'. To solve complex problem, Costa (2000) contents that students performance during the process requires strategic reasoning, insightfulness, perseverance, creativity and craftsmanship. The OECD (2014) notes PSS involve interdisciplinary, scientific reasoning and higher-order thinking. English (2023) highlights the significance of the way of thinking in STEM based problem-solving promote PSS, and propose framework including critical thinking, system thinking, design based thinking which can contribute to innovative thinking. Attitudes are also crucial, along with cognitive components, as learners must be motivated and believe in their capacity to become effective problem solvers (Foshay and Kirkley, 1998). This multifaceted understanding of PSS, encompassing processes, skills, and attitudes, will guide the research in enhancing problem-solving skills among students.

Watts (1991) suggests PSS must be taught at an early stage of life, and simple issues can be used. Mourtos *et al.* (2004) suggested that the use of open-ended problems at the first step for improving PSS, increasing student confidence, and increasing student engagement. Wood *et al*. (2000) add specific steps for problem solving, including engaging students with motivation, defining the problem, exploring the problem, planning the solution, implementing the plan, checking the solution, and evaluating and reflecting. Jonassen (1997) suggest that educators can support students' problem solving by using real world issue, introduce constraints, engage them with cases, support them with knowledge, encourage reflection and reasoning, provide scaffolding, and assess solutions. Therefore, teachers can highlight the context, and significance of each problem, and assist in reinforcing the discussion with students to enhance their ability to apply the skill in other contexts.

Different instructional strategy can be employed to foster the PSS. Integration of STEM disciplinary knowledge, skills and attitude of problem solvers can be promote through methods such as inquiry-based learning, problem-based learning (PBL) and project-based learning (Hite and Thompson, 2019). In Thailand, the government and non-governmental agencies have developed STEM strategic approaches and introduced inquiry-based problem-solving methodologies with varying teaching phases (Sutaphan and Yuenyong, 2019).

PBL can be considered a component of context-based learning, as stated by Overton (2016). Context-based learning is a strategy that involves tackling real-world issues through real-world scenarios. Rose *et al.* (2012) argued that context-based learning involves the application of problem-based, student-centred approaches in practical activities that are based on meaningful and relevant contexts related to real-world problems. Studies by Yu *et al.* (2014) have demonstrated the improvement of problem-solving skills through context-based learning such as simulation, film, and real context by design. They highlights that context based learning allows students taking into account the social and real-life contexts in which they are learning. From this perspective, problem- based learning use the problem as context for students to learn and create solutions toward real world situations. PBL involves engaging students in interdisciplinary projects, taking part in daily activities, and collaborating with students, especially in small groups, to find solutions (Segalas, 2010). In a group, students can work with ill-structured problems, generate their solutions, evaluate ideas, and make decisions and reflections (Dadd, 2009).

PBL is challenging with open-ended questions and it places students at the centre of their learning. Smith *et al.* (2022) highlight keys of PBL is the problems nature and its contexts. The used of open-ended problem can encourage student to construct explanation (Hmelo-silver and Barrow, 2015) and offers the student the opportunity to solve problems and find strategies by accumulating ideas and information (Maker *et al.,* 2015). The illustrated problem which discussed previously in earlier section offers several benefits which is appropriated to be integrated into PBL learning (Barrows, n.d. cited in Savery, 2006). Although, PBL requires extra resources and cost, students can gain transferable skills as well as content knowledge and technical skills and they are not allowed to be passive learners in PBL (Dadd, 2009). Teachers can step back from control as facilitator and allow students to take responsibility for their own learning by employing scaffolding such as modelling, coaching, fading back from support to develop student autonomy (Hmelo-silver and Barrow, 2015). In STEM-PBL challenges, students are exposed to authentic, real-life problems presented in a multimedia format that mimics the problem's context and solution (Massa *et al.,* 2012; Portz, 2015). Students can apply STEM knowledge, gain STEM knowledge as well as attitude toward STEM learning (Lou *et al*., 2011). With these benefits, STEM and PBL successfully provide problem-solving scenarios.

Inquiry-based learning (IBL) is another approach in STEM learning. Similar to PBL, IBL also focus on student centre and found to be involved with solving global problems (Bruner and Prescott, 2013). IBL is driven by students' curiosity and questioning, while PBL begins with problems. IBL allows students to have significant autonomy in responsible for their own investigations by posting questions, review information, plan their investigation, and focusing on learning approaches (McMullen and Fletcher, 2013; Sotirou *et al.*, 2017). Scholars propose that STEM inquiry-based learning can be employed by adhering to the 5E model (Bybee, 2006), which encompasses engaging, exploring, explaining, elaborating, and evaluating, and 6E mode (Barry, 2014) which enriching is employed before evaluating. Moreover, Deak *et al.* (2019) assert that inquiry-based learning must undergo a variety of processes to reach its final claims. Additionally, teacher can use learning materials to inquire knowledge by offering students the opportunity to engage with the subject matter and take responsibility for their own learning, thereby facilitating the experience of self-determination in the learning process (Conradty and Bogner, 2019). To adopt the IBL, many strategies can be employed, such as e-learning by using a smart phone and computer to integrate with technologies (Deak *et al*., 2019). Benefits of IBL for students are include enhancing STEM knowledge, acquiring and scientific process skills, learning motivation, and STEM awareness (Attard *et al.,* 2021; Bruner and Prescott, 2013; Lai, 2018).

To enhance students PSS and promote STEM learning, Smith *et al.* (2022) note that they need opportunity to explore STEM fields and engage with STEM disciplines in different ways. However, scholars indicate that when integrating STEM in education, mathematics and engineering are often marginalised compared to science and technology (English, 2019; National Academies of Sciences, 2022). Mann and Mann (2017) suggested that opportunities to engage in engineering design activities provide positive developments from step-by-step and problem-solving practices. More importantly, students can apply their science and mathematics knowledge when solving engineering problem (Silvering, 2019). This raise the important of engineering role in STEM. Moreover, STEM education research with a special focus on engineering is relatively rare compared to those with a focus on mathematics and science, as well as integrated STEM, which combines two or more disciplines (English, 2016; Li *et al.,* 2020). Currently, in preschools and primary schools, the allocation of resources and prioritisation of science and engineering education is insufficient, particularly with regards to engineering (National Academies of Sciences, 2022).

Considering the importance of engineering, this thesis emphasis on engineering as a key component in integrated STEM interventions within primary education. Despite both PBL and IBL are approach for STEM education, PBL approach is adopted because PBL allow students address real world challenges, through collaborative problem-solving which align with engineering principles and practice. By using 'environmental sustainability issue' at the starting points, this research focussing on enhancing PSS through the incorporation of EDP and EHoM. Unlike the IBL where student investigate and inquire learning on their own selected topics or working on their own way to solve the problem, this research focus on example of SD issues that usually occur in Thailand such as landslides, flood, drought and plastic pollutions in the river and ocean.

2.4.2 STEM Education for Learning SD

STEM education are mostly incorporated science and mathematics contents and develop students understanding of technology and engineering (Silvering, 2019). STEM disciplines are crucial for addressing global concerns, recognising the changing nature of environmental issues, and preparing the workforce for the twenty-first century (Bybee, 2013). Hopkinson and James (2009) highlight that embedding STEM with SD aims to enhance students awareness about the relationship between their field of study and SD, the potential consequences of their actions, and the skills they can use to contribute to society and the environment. Students with STEM knowledge, skills and understanding, are able to comprehend sustainability issue and challenges (Campbell and Speldewinde, 2022). Students need engaging and powerful experiences that integrated these to effectively understand the issue (Roehrig *et al.,* 2012).

As Bourn *et al*. (2016) argue, merely promoting learning about topics such as climate change, global poverty, and gender equality is insufficient. It is also important to consider how children learn about these issues, what shapes their views and behaviours, and how teachers and students can adopt a more critical and engaged approach to learning (Bourn *et al*., 2016). Achieving SD learning requires tackling issues that are socially significant and addressing them from a variety of perspectives, which necessitates adopting a comprehensive strategy (Burmeister *et al.,* 2012). This section discuss how STEM education can promote ESD through the incorporating with disciplines in details in the next section.

2.4.2.1 Potential of Science Knowledge

In STEM, science serves as foundation knowledge to solve engineering problem. Cunninghame and Kelly (2017) argue that scientific principles grounded as important elements for engineering design. To integrate STEM with ESD, despite having an ESD curriculum, cross-curricular integration can be an option. As part of STEM education for promote SD, science is a tool for integrated SD concepts (European Commission *et al*., 2021). Science subjects can integrate ESD concepts, as well as several other subjects, such as social studies, agriculture studies, and business (Esd.bgk, 2019; IDOS, 2019). It plays a pivotal role in empowering students to make decisions regarding SD issues for example climate empowerment. However, traditional science education is incapable to achieve the desired changes (McKeown and Hopskin, 2010). Quinn *et al.* (2015) point out that encouraging a change in attitude towards sustainability requires more than just scientific knowledge.

Science for sustainability involve value and ethics. In some perspectives, science possesses both negative and positive value, as it can contribute to unsustainable practices while also serving as a means for sustainability (Quinn *et al.*, 2015). It is essential to consider that the instruction of science for sustainability may provide conflicting perspectives and values among both educators and students in the classroom. Aside from value, environmental ethics must remain at the centre of ESD due to the severity of ecological issues, problematic development, and problem growth (Kopnina, 2012). An ethical approach must be taken when the ESD principle is embedded in decision-making (Quinn *et al*., 2015). Baker *et al*. (2018) indicate the significance of environmental ethics education in fostering students' awareness of SD issues as well as promoting knowledge and skills for finding solutions and protecting the environments. It means that the ethics shape students' decision-making processes when dealing with the SD issue. Taking values-and ethics-driven strategies that prioritise students' participation, involving decision making, can be an approach to promoting SD such as in Chemistry education (Burmeister *et al*., 2012).

However, science knowledge is crucial as foundation for making decision for sustainability. Numerous scholars advocate for the inclusion of scientific information in conjunction with ethical considerations (Austin, 2021; Feinstein and Kirchgasler, 2014). Austin (2021) states that ESD and science education overlap, identifying the areas of education 'about' environment, 'through' environment, and 'for' the environment. Subject areas of science promote interdisciplinary learning in the context of ESD, Eilks (2015) asserts that interdisciplinary entails the integration of varied ideas from fields such as chemistry, biology, physics, economics, social sciences, and the humanities to address societal concerns. Science education provides a deep understanding of scientific knowledge (Austin, 2021), which is a source of concepts and facts for shaping pro-environmental habits (Littledyke, 2008). As one of the models to promote ESD through science education, Burmeister *et al.* (2012) suggest that science and technology curricula should incorporate sustainable scientific content. This argument is supported by Thailand's science standards, which adopted SEP. These standards lay the foundation for ESD by presenting environmental facts and impacts. This includes basic ecological knowledge about humans and other living things, and the 3R approach mentioned earlier.

To integrate science with ESD, the link between scientific concepts and sustainability concepts is crucial (Quinn *et al.*, 2015). Example of that is connecting idea about food chains, food webs to local ecology destruction or investigating properties of substance with rubbish investigation and see how waste and renewable resources can be manageable (Quinn *et al.*, 2015). This example provide lens to integrate key concept of science and ESD in primary curriculum.

Science education should be a cornerstone of ESD because of its emphasis on helping students acquire scientific knowledge and an appreciation of the world around them (Austin, 2021). Scientific inquiry, such as questioning, investigating, and evaluating, is a knowledge pathway, that helps students gain understanding, question the issue and explore to find answers (Pahnke *et al*., 2019, Austin, 2021). This argument is supported by a study by Ruengrung (2022) which demonstrates that using scientific knowledge regarding food preservation, nutrition, and toxin is part of the knowledge-enquiring process. Based on the BCG model in his study, students discuss learning in relation to the bioeconomy, circular economy, and growth economy as approaches to striving for SD (Ruengrung, 2022).

Moreover, to promote ESD with science knowledge, environmental-related issues were embedded in terms of socio-scientific issues (SSI) (Austin, 2021). The SSI was purposed as one of the models that science education can address through ESD (Burmeister *et al.,* 2012), and the analysis of this model suggests that the integration of socio-scientific issues enhances SD learning due to its exceptionally high SD learning potential. It also establishes rigorous SD learning standards as the means to achieve SD. It promotes learning for sustainability, along with the use of sustainable science and technology implementation. Burmeister *et al.* (2012) contend that through this strategy, students gain the knowledge and skills necessary to participate in societal decision-making so that they can help shape a sustainable future. Through discussion and debate of SSI issue, critical thinking skills can be foster (Zeidler and Nichols, 2009). This strategy's strength is its skills-centric nature, which places a strong emphasis on ESD.

SSI covers a wider range of scientific and societal topics, including ethical and moral issues, allow students to participate in discussion and engage in dialogue and debate (Zeidler and Nichols, 2009), are commonly integrated in science curricula regarding K-12 education

(Burmeister *et al*., 2012; Feinstein and Kirchgasler, 2014). To engage students in discussions introducing the concept of SD in this research, environmental sustainability is emphasised, as it is the most mentioned environmental aspect in the science curriculum, and at the same time, environmental sustainability allows for discussions on economic and social aspects. According to the Burmeister *et al.* (2012) model, SSI is embedded in context-based approaches. This model prioritises the acquisition of scientific knowledge while also promoting reflection about social conflicts related to the practical application of that knowledge (Eilks, 2015). The topic of SSI in science education is intriguing when considering sustainability, as SD encompasses complex problems that are ill-structured (Austin, 2021).

To promote SD, economic dimension must be emphasised. Ghosh and colleagues (2019) described environmental sustainability as encompassing a wide range of issues extending from the local to the global level. This includes global concerns such as greenhouse gases, climate change, and energy, as well as local issues such as soil erosion, water management, soil quality, and air and water pollution.

Scholars provide examples of study used environmental issue for learning science. Ledwith *et al.* (2017) incorporate oil spill phenomenon and ask students in Ireland to construct clean-up tools and clean the oil using a scientific approach. Such an approach demonstrates a good example of environmental issues in teaching and learning science. Unlike environmental education, environmental facts are taught to provide knowledge about the issue and enhance students' awareness. Similarly, Costa *et al.* (2023) used the noise pollution issue for students learning towards SDG11, awareness of the issue, and knowledge of physics regarding frequency for primary and secondary school students. These examples demonstrated the real-life issue of guiding the implementation of science education, and STEM education integrated with ESD, in young Thai students.

According to the SEP which is a Thai ESD framework, Didham and Ofei-Manu (2012) claim that it is embedded within the science discipline in four content areas regarding ESD: 1) the study of living organisms and their vital processes; 2) the interrelation between life and their surrounding environment; 3) the concept of energy and its various manifestations; and 4) the evaluation of the Earth. It is evident that the environmental aspects of SD are already embedded in the curricula. Based on the analysis of Thailand's science standard (A.D. 2008, revised version, A.D. 2017), the Thai science curriculum focusing on primary science standards can be integrated with ESD through this cross-curricular practice (IPST, 2017). To emphasize, the core content of the fourth- to sixth-grade science curriculum (primary school) consists of 4 learning areas, including 1) biological science, 2) physical science, 3) earth science, astronomy, and 4) technology, which provide students with prior knowledge about sustainability issues.

Additionally, ESD must not only deliver with science but also enhance 21st-century skills. Eilks (2015) argues that by exclusively focusing on acquiring knowledge, learners will fail to grasp the intricate relationship between science, technology, and society, which will hinder the cultivation of essential skills required for engaging in sociocentric discussions. Those skills, such as critical thinking, problem-solving, creativity, acollaboration (CERI, 2008; Trilling and Fadel, 2009; Bell, 2010; Joynes, 2019; Burmeister *et al*., 2012), are essential for the future. As skills are crucial for SD learning, science education equips students with the tools they need to make informed decisions about their lives and take part in making decisions that affect them as individuals, members of society, and citizens of the world (Austin, 2021) and provides cognitive and affective domains in caring for the environment and responsibility (Littledyke, 2008).

In this research, students at upper primary school level are the main focus. The learning content based on Thailand's science standards for grades four to six include biological science strand, which is beneficial for student as they learn the foundation for SD (Didham and Ofei-Manu, 2012). The topics taught at this level involved facts regarding the environment, ecosystems, relationships of organisms in the ecosystem, the understanding of the local environment, global disasters, global weather and climate, as well as the consequences of living things and the environment (IPST, 2017). Additionally, the basic science standard in Thailand aims to enhance 'learner quality', which encompasses skills and competences, and states that students who complete sixth grade will possess several learner qualities, some of which pertain to knowledge and awareness of sustainability (IPST, 2017). However, to enhance students' knowledge, skills, attitudes, and values, they require support and guidance towards ethical and responsible behaviours. (OECD, 2018b). This research aim to motivate students to critically assess the SD issues and articulate their reflections on sustainability actions and solutions.

2.4.2.2 Potential of Mathematics

Mathematics is a crucial discipline in STEM, functioning as a language for other disciplines and serving as the foundation for the STEM fields (Schmidt and Huang, 2007). Integrating mathematical learning becomes meaningful as it becomes connected, focused, and relevant which can be done through content or context integration with the support of science, technology, and engineering (Stohlmann, 2018). Mathematics contents for STEM integration are involved number and operation, measurement, data analysis, geometry, and linear and quadratic equations such as the application of statistic concepts for decision making about renewable energy sources (Costa and Domingos, 2019; Stohlmann, 2018). These suggest the integration of mathematic in STEM problem-solving activities in multiple of ways.

Mathematics can integrate several topics. In German primary schools, interdisciplinary learning encompasses topics such as eating habits, exercise, and health issues (Williams et al., 2016). Students are able to collect data, categorize food into types of nutrients using the Excel program, and ultimately create food data based on their personal diet. This real-world experience helps improve students' motivation and increase their performances, as well as promote interdisciplinary mathematics (Williams *et al.,* 2016).

The issue of SD has received insufficient attention in mathematics education (Renert, 2011). This could be attributed to the limitations of interdisciplinary mathematical integration (Williams *et al*., 2016), particularly in STEM fields (Fitzallen, 2015). English (2016) suggests that mathematics plays a more significant role in classroom activities than in STEM education research, which primarily focuses on science. Williams *et al*. (2016) argue that we do not sufficiently address the interdisciplinarity of theoretical and conceptual tasks, nor do we adequately explore the disciplines with which mathematics interacts. This necessitates giving math educators more opportunities to contribute to math integration. Significantly, it is crucial to conduct further research on integrated STEM with a focus on mathematics (Becker and Park, 2011; Fitzallen, 2015; Stohlman, 2018).

Based on the study of Benett *et al*. (2014), students perceived negative attitude regarding learning mathematic activity as the context of learning is irrelevant in their perspectives. Williams *et al*. (2016) contend that the integration of mathematics in interdisciplinary learning should not be restricted to STEM integration but should also encompass other disciplines across the curriculum. Accordingly, integration with SD offers mathematic learning a meaningful and relevant for student and promote mathematic education. Significantly, Mathematic education is valuable for promoting ESD (Vásquez *et al.*,2023) and achieve SDGs (Lafuente-Lechuga *et al*., 2020). Lafuente-Lechuga *et al.* (2020) note that mathematics offer a mean of confronting with reality and solving everyday issues. Serow (2015) indicates that mathematic is advantage for equips students for exploration of sustainability issues by equip students with essential skills for working with data as well as prediction. By teaching mathematics this way, students can deepen their understanding of sustainability and social justice.

As supported by Stohlmann (2018), global and environmental issues can serve as topics for mathematics learning, with an emphasis on engineering design challenges, mathematical modeling, and game-based and open-ended integration with technology. Local and global issues can serve as the context for mathematics in primary education, thereby connecting both disciplinary and non-mathematics content (Nicol *et al*., 2019). Twohill and Shúilleabháin (2021) also present the integration of mathematics with inequality for 9- to 12-year-old students to learn about fairness and profits while learning number operation and percentage. Nicol *et al*.'s 2019 study also illustrates how mathematical concepts can help students understand social issue contexts like food waste, water waste, and food security. Hamilton and Pfaff (2014) provide an example of integrating Arctic sea ice data with linear regression, illustrating the integration of SD issues with statistical concepts, enabling students to observe peak melting rates and compare ice extent across different months. Additionally, Lafuente-Lechuga *et al.* (2020) showcase the use of mathematics in addressing SDGs issues like school dropout (SDG4), poverty reduction in sub-Saharan African countries (SDG1), and planning for renewable energy investment (SDG9).

As a result, students can observe the practical applications of mathematics and develop a positive outlook on the learning process, as they can recognise the usefulness and have a positive value and attitude towards learning mathematics (Lafuente-Lechuga *et al.,* 2020). More importantly, it helps to transform students' perception of mathematics, from a disjointed process of memorisation and repetition to a valuable instrument for analysing and comprehending complex and real-world phenomena (Greenstein and Russo, 2019). Since mathematics offers a powerful means of addressing SD issues in the classroom, teachers should continue to develop curricula that make mathematics meaningful by tackling real-life challenges and contributing to societal improvement (Hamilton and Pfaff, 2014).

Aside from SD issue, Mathematics skill can be used to integrated for learning sustainability such as Modelling. Mathematic modelling includes problem understanding as a component of its theory; as Ferri and Mousoulides (2017) suggest, students are able to develop solutions for complex and interesting real-world issues. Modelling process enables students to find a solution and interpret the activity in a meaningful manner, identify, assess, and test their ideas, as well as present and share them (Ferri and Mousoulides, 2018). Example of that is the integration of mathematical models of climate change, energy or biodiversity with economic model to see the impacts of issues (Rehmeyer, 2011). These illustrate the role of mathematical modelling in solving SD issues. Apart from mathematic modelling, Ningsih and Juandi (2017) indicate high school mathematic materials which can be linked to issue in real life such as statistics, build space, systems of linear equation for students to learn ESD concept through the sustainability pillars.

Hamilton and Pfaff (2014) suggest integrating Sustainable Development (SD) with mathematics by utilizing SD context, real-life place-based examples, emphasizing system thinking and future design, recognizing ethical and affective aspects, and fostering skill development. A teacher can employ curriculum analysis to assess the materials suitable for embedding the ESD concept (Ningsih and Juandi, 2017) and collaborate with students to create mathematical problems that address issues like social justice (Nicol *et al.,* 2019). These strategies not only address scientific knowledge and concepts but also encourage students to apply mathematical skills and concepts to solve SD issues through STEM problem-solving interventions.

2.4.2.3 Potential of 'Engineering and Technology'

In addition to the science and mathematics concepts that provides the basis for learning SD, 'engineering and technology' can be integrated to promote learning for SD. According to Finegold and Jones (2016), engineering and technology hold considerable importance for both society and individuals in facing social and environmental challenges. Based on study of Ritz and Fan (2015), integrating technology and engineering in learning activities can enhance natural context experiences for the application of scientific and mathematical concepts to address real-world challenge.

Hence, engineering can be integrated with SD learning through STEM practises that engage students with design-based learning that requires students to learn engineers concepts and principles, and follow how engineers solve the problem to enhance PSS. Mourtos *et al*. (2004) define engineers as individual who are problem solver by combining analytical, experimental, computational or design work to solve problems. The engineering profession is innovative and forward-thinking, and engaging engineering provides students with the opportunity to effect global change while positively impacting the lives of others (Mann and Mann, 2017).

To promote engineering to advance ESD, engineering practices in STEM educational research are investigated. Because engineering is crucial as natural integrator in the form of EDP for learning content related to other discipline as Moore *et al.* (2014) indicate, this serves as integrator for ESD. While EDP is an engineering principle that had been incorporated in numerous STEM study, there are few examples integrating EDP with SD issues at school level. Karahan and Ünal (2019) promote students' learning for SD by designing eco-friendly

STEM projects. In their study, primary gifted students reflected on their learning process using a case study design regarding issues such as the management of rainwater surfaces and developed critical thinking as well as their perspectives regarding SD, including financial and environmental perspectives. Another example is the study of Abdurrahman *et al*. (2023), where EDP was integrated into renewable energy and students were asked to design vacuum cleaners. Students are promoted with system-thinking skills while learning renewable energy and physics (Abdurrahman *et al.,* 2023). Aside from environmental-related issues, EDP can be integrated with malnutrition and consumption. Analogue rice is produced in STEM-EDP learning activities to promote problem-solving skills and promote learning of physics, chemistry, and biology through social issues (Koes-H *et al.*, 2021). By integrating inquiry-based learning with EDP, innovative artefacts for preparing to address the PM2.5 issue in Thailand can be produced (Lakanukan *et al.*, 2021). Lakanukan *et al*. (2021) found that students demonstrated their problem-solving abilities through problem identification, problem-solving design, improvement, and communication. Their research suggests that environmental issues in Thailand can be incorporated through EDP; however, neither SD education nor student reflections on SD are elicited or integrated. The details of EDP are illustrated in the following section.

Aside from EDP, scholars indicate how engineering can incorporated with SD. Yearworth (2015) proposed that engineers gradually engage in projects that involve sustainability-related projects that are categorised as wicked and messy for engineers working with issues in the real world that are relevant to sustainability. Engineering learning about SD issues is found in an activity of the Royal Academy of Engineering (2020), in which it was designed for high school students to discuss topics about climate change, water shortages, and plastic issues, and students were asked to create a water bloom to collect plastic. Hands-on engineering learning was integrated with energy saving and carbon emission reduction so that primary students learn from hands-on experiences and plan solutions to the issue, which yield positive results when they apply their knowledge from the intervention at home (Lee *et al.,* 2013). In their work, students conduct hands-on learning using several tools to create an energy-saving house, such as the placement of LED lights and water conservation equipment. Their performance is investigated, and students gain positive outcomes regarding knowledge, attitude, and behaviour (Lee *et al.,* 2013). Interestingly, to integrate engineering with SD learning, Segalas (2010) identified different strategies to promote engineering for SD, role playing is also an advantage for developing skills in addition to PBL learning.

Technology can also advance sustainability. Unlike engineering, technology which is human made (Forbes *et al*. 2021), is the end point of science and mathematics application through engineering process. It serves as tools or process to solve problems. Technology is interconnected with human development, and was viewed as providing negative and positive impacts for society and sustainability (Eames *et al.,* 2015). Technology helps human reaching its full potentials and offers numerous advantages, including improve medical services and food production systems, enhance education as well as elevation of life quality by addressing the SD challenges (Eames *et al*., 2015). Conversely, technology can negatively affect the earth, so it is imperative to consider technological application in a sustainable manner (Eames *et al*., 2015). Teaching Technology can help students see the outcome of engineering practice and appreciate the knowledge of science and mathematics knowledges. According to González-Salamanca and Salinas (2020), the use of technology as a resource, tool, scaffolding, and object of knowledge can have significant impacts on enhance higher order abilities such as skills for the 21st century. For ESD advancement, technology assists educator by providing novel teaching strategies, accelerating the innovation process in education, enhancing learning experiences, expanding access to resources and skills (Sung *et al*., 2020).

In order to effectively integrate engineering and technology and ensure that STEM-based activities align with research objectives, prioritising the instructional design is the utmost importance. Ritz and Fan (2015) note the strategies that integrate both engineering and technology through technology and engineering activities, to enhance natural context experiences facilitating the implementation of science and mathematics to address real world challenge. For engineering focusses, Tank *et al.* (2015) argue that a more precise delineation of the engineering practises, values, and skills that ought to be incorporated by educators remains imperative to guarantee that students are informed about and engaged in the practical application of engineering concepts. However, teaching engineering concepts and skills is challenging because it requires different sets of concepts and skills from scientist, and it is difficult to separate concepts and skills in engineering practice (Katehi *et al.*, 2009). Educators can help K-12 student tackle the issues of understanding engineering concepts and skills by adhering to common principles such as providing sufficient classroom time, engaging student in iterative design activities, sequencing level of difficulty to learn concepts, and integrating tools (Katehi *et al*., 2009).

For integrating technology, design and artefacts creation is taught in technology education. (Rizs and Fan, 2015). Students can be enhanced with conceptual knowledge and its application to real world through hands on nature of integrating technology with engineering content and principle and application of mathematics and science (Rizs and Fan, 2015). It need to be recognised how technology can be involved by three key idea/outcomes. According to Eames *et al*. (2015), technology knowledge and principle can be embedded, students must be enhance with skills and technological practices, and students must comprehend the nature of technology and its impacts on society and environment. These perspectives can guide the design of learning activity which incorporating technology into learning for SD.

In summary, integrating STEM disciplines are promising for the advancement of ESD. However, strategies play crucial role to ensure the acquisition of SD knowledge and skills. For example, the study by Pahnke *et al*. (2019) gives suggestions on how to incorporate STEM for SD. These suggestions include using inquiry-based learning, promoting a whole-school approach, encouraging independent thought, aligning with the SDGs, strengthening evidence-based argumentation, supporting diversity, and giving students the power to use STEM skills and reflective reasoning to solve difficult sustainability problems (Pahnke *et al*., 2019). However, as this research aimed to promote engineering and SD concepts and competencies, as suggested by scholars, relevant STEM problem-solving frameworks that address engineering are presented as follows:

2.4.3 Engineering Design Process (EDP)

According to Han and Shim (2019), EDP entails design activities that take into account all the information required to clearly describe a problem, generate ideas and their solutions, develop those ideas into high-quality product concepts, and determine the needs of the customer. Engineers provide explicit, unambiguous, and specific descriptions of client needs at the problem-defining stage to identify what they want, assess whether the requirements are feasible, and determine what function will be added to the product (Han and Shim, 2019). By elevating engineering design to the same level as scientific inquiry in all science classrooms and emphasising engineering design's fundamental concepts and technological applicability timelines, science and engineering can be integrated into science education (NRC, 2013). So that, engineering design is regarded as one key element together with the science practice of the Next Generation Science Standards framework, core discipline ideas and cross cutting ideas (NRC, 2013). This inclusion is adjusted to be appropriate to the students' grade level. An example of that is that as the NRC (2013) indicates, third to fifth grade students are focused on developing abilities to engage in more systematic and creative engineering. Therefore, while engaging with problems, students encounter various constraints and criteria, including the availability of supplies and the required time for student work. Additionally, they experience failure, which is integral to finding improved solutions (NRC, 2013).

There are many frameworks for employing EDP in an educational setting. The NGSS framework, for instance, integrates EDP into science and engineering practices through eight methods: 1) Asking questions (for science) and defining problems (for engineering), 2). Developing and using models, 3) Planning and carrying out investigations, 4). Analysing and interpreting data, 5) Using mathematics and computational thinking, 6) Constructing explanations (for science) and designing solutions (for engineering), 7) Engaging in argument from evidence, and 8) Obtaining, evaluating, and communicating information (NRC,2013). To place a greater emphasis on engineering, the Engineering is Elementary (EiE) programme offers a good example, encompassing five steps: problem identification, information seeking, solution design and planning, testing and evaluation, and finding solutions to a particular problem (EIE, 2016). Similarly, NASA also has its own EDP in which six steps are involved, and 'experiment' is found as an additional step compared to EiE (NASA, 2011). IPST also has its own version of EDP, which includes problem identification, searching for information, solution design, planning and development, testing, evaluation and improvement, and presentation (IPST, 2014). Different frameworks of EDP are illustrated in Figure 5.

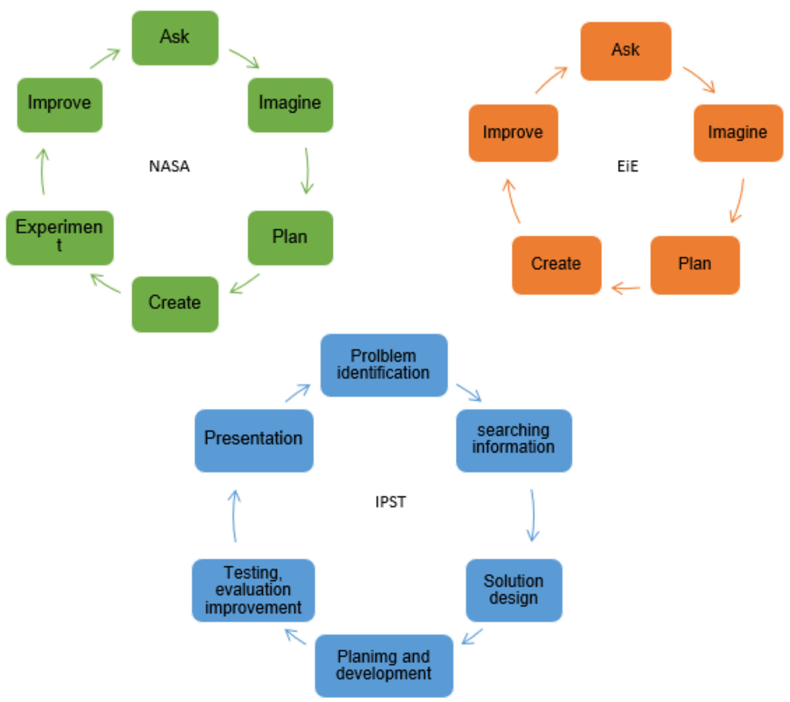


Figure 5 Different Versions of EDP from NASA (left), EiE (right) and IPST(Bottom)

Many scholars provided students with engineering experiences in order to create problem-solving opportunities. Examples of work that put the model into practice are found in the study of Hutsamin and Bongkotphet (2020), who adopted NASA's EDP in their research to develop student problem-solving competencies in grade 10 students in Thailand. The outcome of the EDP can be any form of solution, especially the product, which clearly demonstrates that the problem is solved, which refers to Han and Shim (2019) description of the goal of the EDP as the creation of a product that meets world demands and is oriented towards real-world application, economics, ethics, and legality. The products, designs, or artifacts are evidence to explain how they generate ideas through planning and problem-solving, such as shoes in shoe design (English, 2019), energy-saving houses in energy-saving units (Lee *et al*., 2013), and face masks in PM 2.5 activity (Lakanukan *et al*., 2021). Additionally, students can also generate knowledge on their own while being active investigators. Interacting with artifacts, models, or prototypes facilitates students' making sense of information, enables them to articulate their ideas, and fosters a desire for further learning (Reiser *et al*., 2017). The study by Dailey (2017) shows that year 4 students use EDP to address water shortages in habitats, focusing on water transportation as a solution. This exemplifies the effective use of embeding ESD with STEM in primary classrooms to tackle sustainability issues, particularly in enhancing the knowledge of gifted students about earth systems, gravity, and engineering design. This approach could potentially broaden the understanding of SD and its associated competencies.

In addition to fostering problem-solving skills, EDP can support student collaboration. The Edible Car Programme was introduced to students as a means of offering scenarios for problem-solving in Hite and Thompson’s (2019) research, which examines student global competences. In order to encourage students to create edible lunar vehicles, the EiE's EDP was used in the study (Hite and Thompson, 2019). Lucas and Hanson (2014) also suggested that EDP is a signature pedagogy that offers team sports environments that are beneficial for enhancing Engineering Habits of Mind (EHoM), especially for creative problem-solving. Another example is the magnetic train activity inspired by the EIE Maglev activity (EiE, n.d.). The activity allows children to discover the magnet's power, learn the magnetic forces in different ways, and use their knowledge to invent their own magnetic trains. The programme demonstrates that STEM education significantly enhances scientific knowledge, with engineering being integrated as the practical application of science understanding.

2.4.4 Engineering ‘Habit of Minds’ (EHoM)

Engineering Habits of Mind (EHoM) plays importance role in STEM education as it benefits in providing individual insights of how engineers find solutions to a problem, promote ‘engineering’ through STEM approaches and improve engineering education. According to Tank *et al.* (2015), integrated STEM learning environments require professional engineering skills like communication, cooperation, and EHoM. Unlike the EDP, which practices the designing process, the EHoM rather focuses on practicing the cognitive skills that engineers adapt when facing problems. The EHoM framework offers insights into problem-solving by emulating engineers' habits, including their activities and thoughts from the initial encounter with a problem to the development of a final solution (Morgan and Kirby, 2016). By practicing EHoM, students are equipped with attitudes, cognitive skills and knowledge needed for tackling engineering challenges. Understanding of engineering profession and their characteristic can also be enhance from EHoM (Bianchi and Chippindall, 2018).

EHoM are defined differently by scholars, Tank *et al.* (2015) indicate EHoM as values, attitudes and thinking skills related to engineering. A set of Engineering Habits of Mind was characterised by Katehi *et al.* (2009) implementing in the United States including 6 keys EHoM; system thinking, creativity, optimism, collaboration, communication and ethical considerations. This set of EHoM was implemented to promote students learning STEM knowledge and skills such as problem-solving skills, thinking skills and creativity at preschool, high school and higher education level (Lammi and Denson, 2017; Lippard *et al.*, 2019; Karatas-Aydin and Işıksal Bostan, 2023). Additionally, Lucas and Hanson (2016) define EHoM as what engineers think and how they act when encountering a problem and solving it can improve engineering education by engaging students with these processes. Unlike Katehi *et al.* (2009), EHoM characterised by the Lucas and Hanson (2014) includes six elements including system thinking, problem finding, creative problem solving, visualising, improving and adapting as listed in the descriptions shown in Figure 6.

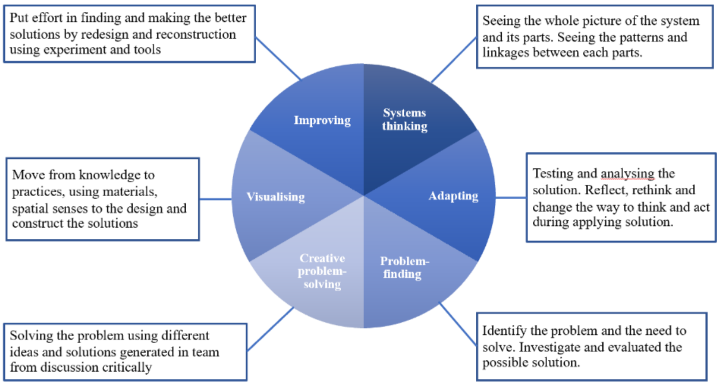


Figure 6 Elements of EHoM Developed by Lucas and Hanson (2014)

Based on figure 6, these 6 EHoM can be divided into a total 12 subunits and are designed with a core engineering mind to ensure thing work and improvement while taking ethical considerations into account (Hanson *et al*., 2018). As the STEM activity provided space for using cognitive knowledge regarding STEM to solve the problem, the implementation of EHoM can be observed during EDP, tinkering and working with professional engineers (Lucas and Hanson, 2016). NRC (2009) also proposed strategies for promoting EHoM, through approaches which are Ad Hoc infusion, standalone course and fully interconnected STEM programme.

Scholars have provided an illustration of EHoM practices. Lucas *et al.* (2014) provides a precise scenario showing how they follow each element. A young girl demonstrates her system thinking ability when comparting the overflow water from a bath to a stream that runs down a hill. Another example is when children make a paper glider and keep adjusting the angle of the glider flops to make it fly. This demonstrates that young children can learn system-thinking habits from small-scale scenarios. This small and gradual change shows the improving habits of students in solving problems (Lucas *et al.*, 2014). EHoM can be implemented with extracurricular activity for a small group of gifted children, while working with materials and instrument support. The case of Redeemer Primary School in Blackburn has successfully provided the whole school engineering curriculum and it was reported that students developed systems-thinking and improved problem-solving skills to tackle several real-life situations, and exhibited their potential through their workpieces (Lucas *et al.*, 2014). Research also demonstrates that young children can practice EHoM as it introduce at preschool level to promote engineering skills (Lippard *et al*., 2019), and gifted student at primary school level can display EHoM in an engineering -based eliciting activity (Karatas-Aydin and Işıksal Bostan, 2023). Teachers can also provide learning experiences for students to practice EHoM by working with engineers through active student-centred approaches and real-world tasks (Hanson *et al.* 2021) and observe students practicing EHoM from reflections on their teaching activities (Hanson *et al*., 2018).

Unlike EDP that is widely emphasised in STEM research to facilitate engineering integration, Engineering thinking especially EHoM focus in STEM activity is still scarce. Wheeler *et al.* (2019) indicated that there are more research needed for observed students learning EHoM. Finegold and Jones (2016), found that in their study, the schools should encourage the development of EHoM. EHoM is one approach that is effective to introduce engineering as Hanson *et al.* (2022) suggest that students should be exposed to engineering in particularly at primary school level to develop their knowledge of engineering and boost their desire to work in STEM fields. Habits of Mind can be cultivate from experiences when habits are employed and students are engage and practice which leads to reflection, evaluation and future application (Costa and Khallick, 2009). Therefore, teacher can enhance EHoM through 4 steps including; develop understanding of habits, creating climate for habits to flourish, choosing teaching strategies and building engagement in learning (Lucas and Hanson, 2017).

STEM approach which provided problem-solving opportunities and developed students' PSS, it may contribute to promoting SD learning. According to the criteria indicated for suitable learning opportunities for SD by Rowe (2007), one of the criteria is the need to allow students to multiply classroom knowledge and express themselves in action. With this condition, enhancing engineering thinking through EHoM is likely to provide those opportunities for young learners.

2.5 Collaboration : Promoting Collaborative Skills

Traditional learning with specific knowledge is not enough for living in the 21st century. In a competitive future where human workforces are replaced by technology and robots, students need to learn skills that help them succeed. Collaboration is, among other skills, needed for lifelong learning in the future (Häkkinen *et al*., 2017; OECD, 2018a). Collaboration, in addition to problem-solving skills, is embedded in EHoM as a skill needed for creative problem solving (Lucas and Hanson, 2014). Collaboration is widely recognised as a useful skill essential in the twenty-first century (Laal and Ghodsi, 2012; OCED, 2017). Collaboration is also significant as one of the key competencies for sustainability. UNESCO (2017, p. 10) indicates that collaboration competency is 'the abilities to learn from others; to understand and respect the needs, perspectives, and actions of others (empathy); to understand, relate to, and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.' Jegstad and Sinnes (2015) assert that students need to comprehend and appreciate collaboration because it enables them to tackle the challenging tasks more effectively than individual effort.

Skills for collaboration are often defined in different ways, and studies pertaining to collaborative skills often revolve around the behaviour expressed during the research process. For example, Gillis and Ashman (1996) evaluated the outcome of teaching collaborative skills by studying behaviour, interaction, and achievement. Additionally, Counsell *et al.* (1999) provided a term that is likely to describe collaborative skills as the abilities to accomplish problems through joint responsibility actions, as these are needed for collaboration. In their study on training students in these collaborative skills, Prichard *et al.* (2006) mentioned that these skills include behaviours that assist others, as well as the use of relevant language. Ritter *et al.* (2020) evaluated the collaborative skills of preservice teachers by using the subscales concept regarding the definition of Counsell *et al.* (1999), which include the concepts needed for successful collaboration such as goal orientation, task accomplishment, cohesion, and assumption of responsibility (Ritter *et al.,* 2020). Since collaborative skills are observed through various student behaviours, the definition has not yet been explicitly established (Prichard *et al.,* 2006). Behaviours were observed as collaboration in Phelix (2012) regarding social and cognitive behaviours such as friendliness, influence, cooperation and reliability. Strom and Strom (2011) indicate that students can evaluate the contribution of their teammate, articulate their viewpoints and justify their efforts in groups.

The various types of behaviours mentioned above and collaboration skills are also recognised as group working skills. According to Blatchford *et al.* (2007), group working skills are the ability to work in a group. These elements of collaborative skills can be characterised as accepting another opinion, giving elaborate explanations, asking for assistance, helping, negotiating, coordinating group work, listening attentively, and giving feedback (Le *et al.,* 2018). Apparently, these skills equip students with the ability to work with a variety of people. By being flexible, adaptable, sharing thoughts and responsibilities, and respecting each other's values, an effective contribution can be made to achieving a common goal (Partnership for 21st Century Skills, n.d., cited in Trilling and Fadel, 2009). Johnson and Johnson (1989) stated that students must be taught interpersonal and group skills as meticulously as academic skills through provided opportunities and specifically prepared lessons for this purpose. This study agrees that they are essential for learning.

Collaborative skills are linked with problem-solving ability, and collaborative problem-solving skills (CPS) are more specific and focus on problem-solving. OCED (2017) defines CPS as the competency to actively participate in a collaborative process when multiple individuals work together to solve an issue by sharing understanding and effort, combining knowledge, skills, and efforts to obtain a solution. CPS appears to refer to the ability to solve a problem in a collaborative setting. The development of CPS is a process in which individuals become interdependent with the collective capabilities of a group (OECD, 2017).

Moreover, the PISA (2015) has identified that communicating, managing conflict, organising a team, reaching consensus, and managing progress are skills needed for students. These skills can be assessed in project-based learning in schools and other collaborative settings (OECD, 2017). To assess students' ability to solve a problem in a collaborative situation, Pisa (2015) developed core collaborative problem-solving competencies, including 1) establishing and maintaining shared understanding; 2) taking appropriate action to solve the problem; and 3) establishing and maintaining team organisation. These competencies were used to evaluate individuals' collaborative problem-solving skills in collaborative tasks (OECD, 2017). This gave me the idea to evaluate collaborative skills in a collaborative setting through observing students behaviours in groups

2.5.1 Establishing Groupwork for Collaboration

Collaboration, collaborative skills, or collaboration skills are found in research and interventions related to student group work. Blatchford *et al.* (2003) define group work as the condition whereby students are working together within a group. Group work is recommended for classroom implementation, as it offers more benefits than individual work (Blatchford *et al.*, 2003). According to the OECD (2018), the utilisation of group-based cooperative project work is seen as a pedagogical approach that fosters the development of global competency, enhancing students' collaboration abilities and reasoning skills. Supported by the SPRinG programme, the outcomes are positive students' behaviours and improved interaction and cognitive skills (Blatchford *et al.,* 2006; Blatchford *et al.,* 2007). The study of Baker *et al*. (2009) also found evidence of using small group work to enhance the social abilities of young children (Baker *et al.,* 2009). As stated by Glancy and Moore (2013), teamwork is considered a crucial element for effective STEM learning because it fosters communication and metacognition.

Effective group work can be organised. Chiriac and Gramstrom (2012) identify two types of group work: cooperative, when a student is working in a group, and collaborative, when students are working together. Both cooperation and collaboration are terms that describe the situation of group learning or working with two or more people (Dillenbourg, 1999). The definitions of these terms overlap. However, the way they learn or attempt to do something together is different. Rockwood (1995) characterised cooperative learning as a close-end assignment. To cooperate, working or learning produces common knowledge or a product. According to Dillenbourg (1999), this process involves evenly distributing tasks among the group members. According to Chiriac and Frykedal (2011), each team member completes their assigned task before combining these individual contributions to produce a team product. Slavin (2015) stated that cooperative learning is advantageous for students to learn academic content by working together in small groups in the classroom (Slavin, 2015).

Collaborative learning (CL), as opposed to cooperative learning, is an instructional approach wherein learners engage in group work with the objective of collectively achieving a common purpose (Dillenbourg, 1999; Johnson and Johnson, 1999). Roschelle and Teasley (1995), as referenced in Phielix (2012) describe CL as the mutual engagement of individual for solving problem through the coordination of members' contributions. The outcome of collaboration, such as the group product produced by members that work together and help each other is collaborative work (Chiriac and Frykedal, 2011; Chiriac, 2014). Unlike cooperative learning, collaborative learning is more implemented and open (Rockwood, 1995) because knowledge from collaborative learning is shared between group members (Dillenbourge, 1999; Chi and Wylie, 2014). The learning outcome is produced as a group from the ideas generated naturally from social interaction among students, including group discussions. Collaborative learning improves student learning and should be used in teaching and learning. Laal and Ghodsi (2012) categorised the benefits of collaborative learning into four different aspects: social, physiological, academic, and assessment. Students can develop learning skills such as critical thinking, problem-solving, and academic achievement (Laal and Ghodsi, 2012). The study of Piaget and Vygotsky supports the idea that learning with peers can develop students' learning abilities (Le *et al.,* 2018). So, collaborative learning is widely recommended as a great tool in an educational setting as it helps students handle real-life situations from socialising and dealing with team members (Le *et al.,* 2018). For solving the problem, the output from the collaboration approach is greater than that of the individual (Schwartz, 1995; Aronson and Patnoe, 1997; Dillenbourg, 1999).

Researchers indicate the importance of collaborative skills in relation to collaborative learning. According to Le *et al*. (2018), the absence of collaborative skills in students is a crucial factor in determining the effectiveness of collaborative learning, leading to several issues such as low coordination, poor team member coordination, and low-quality discussions. Popov *et al.* (2012) assert that a lack of collaboration skills affects communication within a group. It was found that, even though the teacher considers group work as an approach for learning collaborative skills, teachers are likely to prefer using less group work regarding the concerned subject knowledge outcome (Chiriac and Frykedal, 2011).

Task management, assigning roles, and team development can help students overcome challenges, gather ideas, solve problems, and achieve their goal. The group task is essential to ensure students interact and help each other achieve the given task (Blatchford *et al.*, 2007; Cohen and Lotan, 2014; Kutnick *et al.*, 2014). To achieve the task, member roles are created, and students can play different roles within the group. Cohen and Lotan (2014) recommended giving roles to ensure team members know what to do and rotating the roles can offer the opportunity to assume each position and contribute productively to the group. Especially for gifted and talented development, Kaplan (2014) recommended that, in fact, gifted students strive hard to define themselves as achievers. It is important to understand the key skill of collaboration, which is understanding that one's involvement in a well-constructed project may showcase rather than diminish one's potential.

Evidently, managing group work position leading to positive outcome. Therefore, assigning roles in small groups is one of the strategies (Bond, 2013) to balance students' achievement and relationships with peers (Smith, 2017). Additionally, the stages of team development outlined in Tuckman's five-stage model of group development (Tuckman, 1965), can be incorporated into lesson plans starting from the forming stage, storming stage, norming stage, performing stage, and adjourning stage.

In order to advance collaborative skills of gifted students in this research, it is recommended that groupwork experiences must consider all contribution of gifted individuals and allow them to learn positive interaction as well as higher order thinking skills and interpersonal skills application under the safe environment (Patrick *et al*., 2005). Moreover, according to Bächtold *et al.* (2023), students' reluctance to collaborate in groups is associated with a lack of motivation for their studies, particularly, regarding the knowledge taught. Therefore, the learning activity can be adapted, as scholars suggest, to support students' collaboration within their group. This can begin engaging lesson plan, carefully plan in group management as well as provide challenging tasks for them to find team solutions, brainstorm and perform the solutions to achieve the goal.

2.6 Summary

This thesis examines the impact of STEM problem-solving integrated with ESD on students' knowledge, awareness, and skill development. It examines various learning theories, focusing on sustainability, problem-solving, and collaboration. The chapter critically evaluates and discusses theories, frameworks, and practises aimed at promoting students' SD learning and skill development. STEM education is examined as a method of learning that enhances students' understanding and skills, particularly in problem-solving. Collaboration is highlighted as an essential skill for the 21st century, which is essential to promoting SD learning and problem-solving ability. The chapter informs educational intervention development and empirical study, particularly focusing on gifted science students. Gifted education, STEM-based activities, and conceptual frameworks are discussed in the next chapter.

CHAPTER THREE: LITERATURE REVIEW (2)

The previous chapter encompassed a literature review on ESD, STEM education, and teamwork. Nevertheless, these pieces of information were inadequate in elucidating the construction of instructional interventions designed to investigate student knowledge and skills. This chapter aims to fill this gap by doing a comprehensive assessment of the existing literature on gifted education and specifically focusing on gifted science students. The objective is to develop a solid foundation of knowledge about this specific group. In addition, the study also examines the use of STEM problem-solving to improve gifted learning. It then explores STEM activities designed to foster SD learning in gifted science students. At the end of this chapter, the chapter presents models for combining SD and STEM instruction, which will be used as the basis for developing the lesson plan for the intervention in this study.

3.1 Giftedness and Science Gifted Student: Definition and Characteristics

This research aims to foster knowledge and awareness of SD and promote problem-solving skills and collaboration in gifted science students. The prioritisation of addressing the requirements of gifted students arises from a dedication to cultivating inclusiveness and advancing equitable educational prospects for all individuals and ensure equality education (Ozkan and Ketler, 2022). ‘Gifted’ students are commonly referred to as individuals that possess exceptional ability. The construct of ability encompasses both cognitive and non-cognitive capacities. Renzulli (2012) states that gifted education is built on the universal notion that some students outperform their peers in cognitive, leadership, creative, and artistic areas.

In Thailand, gifted students are supported by schools and organisations to foster their exceptional intellectual and non- intellectual capabilities. The objectives of programming and service are to remove obstacles that impede their educational experiences and guarantee that they also receive customised support and enrichment opportunities. This emphasis on inclusivity is consistent with the overarching educational objectives of establishing a setting in which every student, irrespective of their capabilities, is equipped with the necessary skills and resources to achieve their maximum potential and promote lifelong learning.

As chapter 1 briefly details, the target group of this study must be defined to create an intervention that meets their needs, benefits their learning, and reaches the research goals. Researchers suggest that policies and practises play a crucial role in shaping the conceptualization of giftedness and in providing support to gifted students. As stated in ONEC

(2018), the definition is usually based on policy, need, and social value. The definition helps guide educational provision to identify the students to get the support they need and provides a practical framework to understand the field and not limit the educational opportunities of students who are gifted and talented in any area (Anuruthwong *et al*., 2014). Differing interpretations of gifted terminology are found in such programmes, aligning with their own conceptions of giftedness. In addition to the term 'gifted', several gifted-related programmes employed terms such as 'able', 'highly able', 'high ability student', 'talented', or 'gifted and talented', ‘brilliant’, ‘expert’, ‘precocious’, ‘genius’, prodigy’ to refer to students who are outstanding performer or demonstrated exceptional academic performance or possessed high intellectual abilities (Ozkan and Ketler, 2022; Subotnik *et al*., 2011; Wai *et al*., 2022).

The National Association for Gifted Children (NACG) agrees that a definition of giftedness is necessary; according to the complexity of giftedness itself, the direction must go beyond a focus on identification criteria and ensure that students with gifts and talents receive the comprehensive support they deserve in schools (NAGC, 2019). To develop provisions for gifted students and gifted programmes in a particular context, countries, states, and organisations issued their own definitions that led to a unique way of managing resources to meet their needs and ensure equity in getting the proper support when it is needed.

3.1.1 Conceptualised of Giftedness

It is widely recognised that giftedness has many definitions. One robust example of the giftedness definition is from Joseph S. Renzulli, who established the schoolwide enrichment model in the United States. Renzulli (1978) defined giftedness as the behaviour that expresses the interaction of three essential human characteristics: unique or general ability at above-average levels, high dedication to work or motivation, and a high level of creativity. The gifted and talented students can develop the interaction of those three characteristics; they need support and opportunities from the irregular educational programme (Renzulli, 2005; Renzulli 2014). Renzulli also emphasised that gifted behaviour can be identified when three clusters interact together; the unequal expression of those clusters may not be identified as gifted. For example, high achievement is impossible without task commitment, as shown in figure 7.

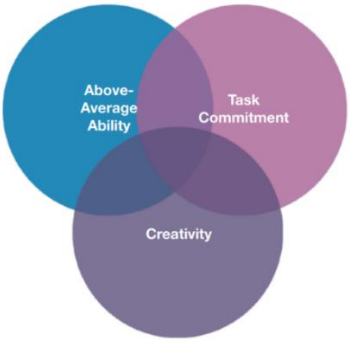


Figure 7 Renzulli’s Three-Ring Conception of Giftedness (Renzulli, 1978)

Additionally, based on this concept, Renzulli specify gifted students in two domains, schoolhouse giftedness or creative productive giftedness. The first one is express their talent in the school subjects through school test or cognitive assessment while the latter one is the individual who have potential to be create knowledge and product (Renzulli and Reis, 2021). His conceptualisation of giftedness provided the provision direction for potentially gifted children during the school years (Subotnik *et al*., 2011).

Besides, Gagné (1985) clearly defined the distinction between ‘gifted’ and ‘talented’ due to their natural ability, trained or untrained since they were born. The gifted are born with this natural competence of intellectual, creative, social, and physical competence, while the talented are trained and develop knowledge and skills to enable them to perform at a higher level (Gagné, 1985). Gifted individual are top are 10% of populations, are born with natural abilities called aptitudes, while talented individuals demonstrate outstanding masteries through the development of knowledge and skills (Gagné, 2011). In his differentiated model of giftedness and talent, one can develop talent through learning and practice, ranging from high aptitude to well-trained and systematically developed skills characteristic of a particular form of human capacity performance (Gagné, 2004).

Similarly, Sternberg (1984) provided a gifted definition as intelligence based on his ‘triarchic theory’ that can describe cognitive characteristics under three types of intelligence: analytic type, creative type, and practical type. This definition provided a view of giftedness based on cognitive ability. Gifted with general ability and conceptualised as intelligence are identified using IQ (Silverman, 2009). Sternberg (2005) described the successful intelligence include ability to accomplish one's life goals, capitalise personal strengths, adapt to one's environment, and effectively integrate analytical, creative, and practical abilities.

Gardner (1993) said that giftedness is a sign of early biopsychological potential in any of a culture's domains. The word ‘gifted’ is used to describe someone who makes quick progress and shows promise in a task area, and people can be gifted in any area where intelligence is thought to be important (Gardner, 1993). Similar to Gardner, Heller (1991) defined giftedness as multidimensional in reference to the Munich model of giftedness, which assumes that the gifted comprise intelligence, creativity, social competence, musical skills, and practical abilities. Gardner and Heller propose that definitions of giftedness must be conceptualised multidimensionally, encompassing more than just intelligence or cognitive abilities. However, Gardner believes that people cannot only express general intelligence, which is only related to cognitive ability, but intelligence can be divided into different kinds. His theory about multiple intelligences supports the idea that gifted students can exhibit proficiency in eight distinct types of intelligence, including linguistic, logical/mathematical, spatial, bodily-kinesthetics, musical, interpersonal, intrapersonal, and naturalist intelligence (Gardner, 1983; Davis *et al.,* 2011).

In the talent development Model of Subotnik describe giftedness as a transformative process in which certain characteristics facilitate talent development into competencies and expertise leading to academic productivity or artistic excellence (Jarvin and Subotnik, 2015). This perspective indicate that gifted is not static trait that can evolved though the development process to acquire higher level of competence and achievement. Subotnik *et al.* (2011) highlight that giftedness reflects societal values, is demonstrated through achievements in adulthood, results from an interplay of biological, educational, psychological, and psychosocial factors and these attributes are considered exceptional.

For practical implementation in supporting students, many countries adopted their own definition of giftedness, and have developed provisions based on these definitions. An illustration of those was found in different publications regarding gifted education in various countries. In the United States, where federal definitions are provided, NACG defines ‘gifted’ and ‘talent’ as a high level of performance compared to other students at the same age, in the same background, and with the same experiences (NAGC, 2013). Furthermore, the definitions of gifted varied among different states, as NAGC reported the 50 states’ definitions of giftedness (NAGC, 2013). Some define gifted as students with high learning abilities or who perform at an outstanding level at school; others focus on intellectual ability; and some include creativity in their definitions (NAGC, 2013). The identification of gifted students may be based on students’ academic achievement and performance, with IQ tests used for the identification process and those who demonstrate high performance receiving support.

As there is no universally accepted definition of giftedness, Mcgrath (2017) revealed that in the context of Ireland, ‘Gifted’ is commonly used to denote students whose IQs rank within the uppermost 10, 5, 3, or 2 percent of the distribution of possible scores (Mcgrath, 2017). In the

United Kingdom, the terms used to identify those students are different. Taber (2007a) delineates the terminology employed in gifted and talented provision that gifted refer to high abilities students in academic while talented are high ability in creative subjects such as music and sport. Terms also present at national level even though the national gifted programme was currently unavailable. Even though, the term 'most able' (Ofsted,2013) is found, there is currently no national definition (Koshy *et al*., 2018). The definition of gifted is also different among other commonwealths. In Wales, 'more able and talented' is used instead of gifted to describe learners who need curricular extensions and enhancements in all subject areas to reach their full potential (Welsh Government, 2015). While in Scotland, the 'able learner' is regarded as the student who has additional needs (Scottish Network for Able Pupil, n.d.).

Similar to the view of gifted in the UK, in Finland, they view gifted as talented. It is more acceptable in Finland to talk about talented development rather than giftedness because the word 'gifted' is considered to be 'taboo' (Tirri, 2017). Tirri (2022) suggests that the perception of giftedness as a fixed quality among Finnish students should be reconsidered using alternative terms to describe individuals with exceptional abilities.

Accordingly, NACG states that students with gifts and talents can come from all racial, ethnic, and cultural groups, as well as all socioeconomic backgrounds, and they may have learning and processing impairments (NAGC, 2019). To fulfil their full potential, they need access to relevant learning opportunities and different services based on their changing needs in order to develop socially, emotionally, and in their areas of talent (NAGC, 2019). Without support and development, they may unable to achieve their full potential when they are growing up as -104

Learning the characteristics of giftedness is important and helpful for exploring the needs of gifted students, the types of gifted students, and providing suitable educational settings for them. The Department for Education and Skills (2006) provided the gifted characteristics as additional information to help educators observe their students' giftedness. These characteristics are referenced in the research of Joan Freeman. Some of those characteristics shared similarities to the study of Silverman (2003), which are fast learning ability, an extensive vocabulary, a good memory, a long span of concentration, perfectionism, similar to older people, having humour, enjoying reading books, being able to solve puzzles, intelligence, maturity, and an intense curiosity. Additionally, characteristics such as perseverance and observational ability are also noted (Silverman, 2003). Another different characteristic provided by the Department for Education and Skills (2006) in referring to Freeman (1998) is having strong leadership, expressing strong opinions and viewpoints, being quickly bored by what they perceive as routine or essential tasks, showing a strong sense of leadership, and not necessarily being well-behaved and well-liked by others. However, these characteristics do not necessarily mean that these students are gifted. Silverman suggests that more evidence from other sources of identification is needed to identify giftedness, such as classroom performance observation or any achievement outside the school context (Silverman, 2003) to help teachers provide further support for their learning (Department of Education and Skills, 2006).

In Thailand, Anuruthwong (2008) explained the conceptions of the definition of giftedness that are explored in Thailand's educational context. In her study, more than 15 worlds described 'giftedness', such as 'Me weaw', which refers to a person who was born talented, or 'Chalard', which refers to a person who has the intellectual capacity or has a high IQ according to their personal background and beliefs (Anuruthwong, 2017). In Anuruthwong (2017), the word 'Kwam Samart Piset' has been stated in the Thailand national educational plan since 1991, which means having exceptional abilities, referring to the definition of giftedness in the Thai educational system (ONEC, 1991 cited in Anuruthwong, 2017). Gifted OBEC is a programme established by the Office of Basic Education Commission (OBEC) with the purpose of defining the characteristics of giftedness or talent that represent higher ability than average people or have the potential to develop into a talented person in the future. The term 'Kwam Samart Piset' was also found in the identification programme and the guidelines of the Office of Basic Educational Commission where policy and practice are aimed at students with high ability (OBEC, 2019; OBEC 2022; OEC 2022).

Apparently, giftedness or exceptional talent is rooted in cultural, environmental, political, and historical settings, reflecting societal ideals and requirements at a specific moment (Maker, 2021). Giftedness is encompassed by various definitions, which highlight its presence in multiple domains, such as academic and non-academic areas (e.g. Renzulli, 1978; Gardner, 1983; Gagne, 2011). Based on many scholars conceptualised their gifted students and provide appropriate programming and service for them. This study restricted to science-gifted students. To ensure the STEM intervention meet their needs and provide provision for them. This research conceptualised giftedness based on their characteristic and potential. Gifted students in this research refers to students who express their superior cognitive potential in learning science, having high aptitude in science, and have interest in the subject when compared to their average-ability peers. They are also identifies by the local school gifted schemes. This definition leads to formulating an instructional curriculum tailoring to support their ability in learning STEM especially a science focus and the recruitment of research participants in this research.

3.1.2 Gifted in Science

Based on gifted conceptualisation, discipline-specific type of giftedness is one facets of gifted diversity (Jarvis and Henderson, 2015). Students who are gifted in science typically express a strong interest in the subject. This interest should be carefully considered when developing programmes to support them, ensuring that their specific needs and interests are adequately addressed. These students are distinct in their talents, interests, passions, and learning challenges (Ozkan and Kettler, 2022). Considering the area of science education and STEM, gifted students prefer science and mathematics as their primary courses and supporting measures were established to promote STEM disciplines through education and public engagement activities, particularly among girls (Mcgrath, 2017). Obviously, it is important to comprehend the requirements of individuals with advanced cognitive abilities in a broad sense, to address their distinct needs and gifted students must give research projects that correspond with their personal interests (Ozkan and Kettler, 2022).

Understanding their characteristics and learning styles is also crucial. It is important to identify their individual abilities, and tailor learning experiences to suit their unique learning styles (Terry *et al.,* 2008). To ensure the inclusion, gifted students possess different needs (Renzulli and Reis, 2018). Gifted students have specific characteristics which Ozkan and Kettler (2022) identified as follows: 1) they desire autonomy, 2) they can feel constrained in regular curriculums and teaching approaches for average students, 3) they can learn complicated concepts faster and more thoroughly than their peers, 4) their ability to understand and generalise ideas and engage in in-depth debates demonstrate their cognitive capacities. Intelligence and academic potential distinguish gifted individuals from others.

According to Anuruthwong (2017) characteristics of gifted students include, for example, giftedness in science (or realistic talents) which is classified as a subtype of giftedness. Those individuals possess not only an inclination towards the subject but also the capacity to conduct scientific research with ingenuity (Cho and Park, 2006). They are more capable than the average group of comprehending and describing natural phenomena, recognising similarities and differences, systematising and organising information, thinking critically, synthesising, reasoning, and conducting experiments. (Anuruthwong *et al.,* 2014). Gifted students often exhibit different characteristics (Taber, 2007) as shown in Figure 8. These characteristics offer a clear picture of the learning style of a gifted student in science and can be used as a guideline for teachers to observe and plan for their learning.

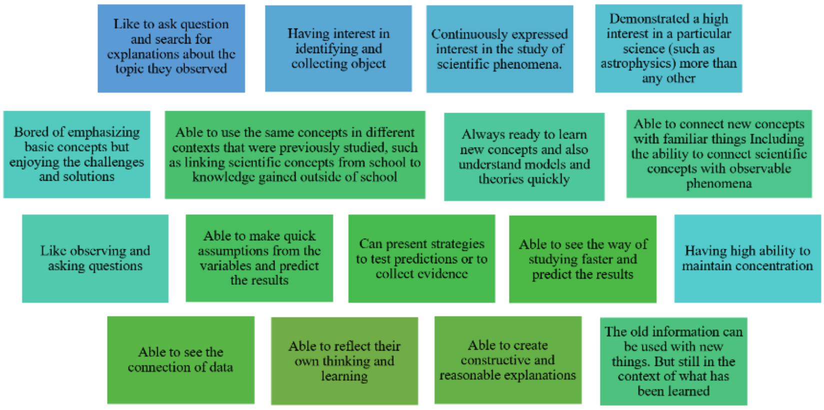


Figure 8 List Of Science Gifted Learners' Characteristics (Taber, 2007a)

In the Thai context, Anuruthwong *et al*. (2014) also provided characteristics of giftedness in science, that can be observed and assessed through behaviour. In addition to Taber, other characteristics can be found, such as having a deep understanding of nature and being able to invent or create scientific works better than people of the same age and in the same context (Anuruthwong *et al.,* 2014). Gifted students in science also often express commitment, and motivation in the science field (Shim and Kim*,* 2005).

It is necessary to develop an appropriate educational model in order to develop programmes for gifted education, by considering the characteristics of scientifically gifted students characteristics (Shim *et al.,* 2001; Shim and Kim 2005). By possessing knowledge of these characteristics, as well as their usefulness in identifying gifted students for the purpose of developing a provision plan, it becomes possible to create an appropriate educational environment that effectively fosters their engagement in high-level learning (Taber, 2007a). Additionally, Lee (2021) suggests that the selection process should be improved by considering the candidates characteristics to match their individual abilities. Therefore, the pedagogical approach must meet students' needs when considering gifted curriculum to offer students with optimal experiences (Van-Tassel Baska and Baska, 2021) and avoid lessening their ability and not suiting their characteristics, so it can reach the aim of enriching their ability and potential in learning science. Abdurrahman *et al.* (2019) provide an example of this by providing students with enrichment programs for those who are exceptional in science lessons to enhance skills for 21st century.

In Thailand, in the educational policy regarding gifted education, the primary core curriculum (A.D. 2008) provides educational provision for special target groups. Significantly, the Basic Education Core curriculum can be adapted to suit the settings and contexts of the target group, as long as the quality achieved meets the standards (Ministry of Education, 2008). The adjustment must meet the Ministry of Education's requirements and be carried out following the Ministry's standards.

IPST Thailand organised the nationwide gifted programme to select students to participate in the enrichment programme. IPST (2018) proposed the indication of gifted characteristics in science, designed to serve as a guideline for developing scientific activities at the primary school level. The indicator comprises two indications of gifted characteristics: a science-based expertise indicator and a conduct indicator demonstrating scientific aptitude. Those areas are detailed as shown in the table 6.

Type of indication	Indicators	Definition and level of indicators
science-based expertise indicator or Skills	S1.Data Collection and Management Skills	Ability to pursue knowledge, encompassing data reading and data management S1B) Basic Data Collection and Management Skills S1H) Advanced Data Collection and Management Skills
	S2 Experimental skills	The ability to make assumptions, define and regulate variables, Select equipment, measurement, gather information, and the ability to resolve any mistake or inconsistencies in the experiment S2B) Basic Experimental skills S2H)Advance Experimental skills
	S3 Information Assessment Skills	Abilities to evaluate information. to derive a pattern, a concept, or a conclusion from data S3B Basic Information Assessment Skills S3H Advance Information Assessment Skills
	S4 Communication and information presentation skills	Knowledge transfer abilities. patterns or inferences drawn from information supplied to others S4B)Basic Communication and information presentation skills S4H) Advance Communication and information presentation skills
conduct indicator that demonstrates scientific aptitude.	A1 scientific attention behaviour	This indicator indicates scientific interest. A1L1) Attention Behaviour Level 1 (Keywords: Know, Doubt) A1L2) Attention Behaviour Level 2 (Keyword: Understand, Explain)
	A2 knowledge Application behaviour	Denotes a grasp of scientific information that may be applied A2L1) Implementation Behaviour Level 1 (Keyword: Link) A2L2) Implementation Behaviour level 2 (Keyword: applied, predicted)
	A3 knowledge creation behaviour	Capacity to use the information to produce new knowledge is indicated by the behaviour of developing a body of knowledge A3L3 Knowledge Creation Behaviour (level 1) (Keyword: Assessment) A3L2 Knowledge Creation Behaviour (level2) (Keyword: Synthesis, Creativity)

Table 6 IPST's Gifted Science Characteristics Indicator
(Translated From Handbook for Teachers (IPST, 2021)

In the last few years, IPST Thailand has started integrating gifted science characteristics into its identification process. Since 2018, indicators of gifted science characteristics have been used as the blueprint for constructing test items. The item established to identify the students as part of the IPST talent development programme is constructed using Thailand science standard learning content. These characteristics were assessed, rather than the amount of science knowledge they demonstrated, which determines the characteristics they exhibited.

In addition, in 2021, in the teacher training programme, the gifted science characteristics were used as the framework for developing enrichment activities to support gifted science students in schools, which are the partners of the science and mathematics talent development programme. Unlike the escalated enrichment camp, where intensive knowledge is provided, IPST Thailand recognised that learning competency and skills are more critical following the OECD recommendations. IPST believes that students can seek knowledge by using various techniques in this innovative era, and skills are more critical for their learning in the future.

Following the broad characteristics of gifted science students (Anuruthwong *et al.,* 2014; Taber, 2007a) and the IPST's indicator, It guides enrichment intervention designed for them. This research conceptualises the concept of gifted science students as those who perform better in science subjects than average and assume a particular interest in science and STEM, engaging students with characteristics regarding gifted indicators. With no intention to assess or identify the scientific ability of individual students, the study utilises the characteristics of academically gifted individuals to develop instructional strategies that cater to their requirements in the context of ESD and STEM education.

3.1.3 Gifted and Talented Development

All students need support, including gifted students, as Subotnik *et al.* (2011) emphasises the significance of programme that enhance gifted students' talent and their abilities. It is not only their right to learn what they need to learn according to equity in education but also to maintain their capacity and increase their ability to reach the full potential. According to VanTassel-Baska *et al.* (2021), students need specialised instructional learning to meet cognitive and affective demands. As stated in the differentiated model of giftedness and talent proposed by Gagné (2011), it illustrates how a person's natural abilities, also known as gifts, can be developed into talents via the application of learning and practice. In this section, how to nurture gifted students is discussed through different existing gifted programme. The study of gifted programme can broaden the will to support students with knowledge and skills from various effective practices. This information is helpful for making decisions on designing conceptual frameworks and pedagogical activities in the future

Gifted curriculum and instruction are important, as it is what gifted students learn. There are three major types of approaches identified by many scholars in this field: acceleration, differentiation, and enrichment (Kim, 2016; Robinson and Dailey, 2014). Acceleration, as Kim (2016) stated, is traditionally the primary method for nurturing gifted students during the early years of gifted education, but it has adverse effects on the socioemotional requirements of gifted students. Even though, a meta-analysis supports the idea that both academic achievement and social emotional development benefit from this type of support (Steenbergen-Hu and Moon, 2011). Acceleration, by its definition, refers to a kind of educational intervention predicated on progress through academic programmes at rates faster than or at ages younger than one's classmates (Pressy, 1949 in Steenbergen-Hu and Moon, 2011; Kim, 2016). It means the acceleration focuses on fast-paced learning with an expected outcome in cognitive achievement (Renzulli and Reis, 1997). This approach is based on the premises that gifted students can perceive information rapidly than peers and they always mastered at highest level in their domain (Subotnik *et al.*, 2011). They can access to the content earlier, skip to higher grade or early access to placement courses (Subotnik *et al.*, 2011).

Unlike acceleration, which focuses on fast-paced learning, differentiation or flexible grouping is agreed to be more effective than instruction in the whole classroom environment (Robinson *et al.*, 2007). For mixed ability classroom, differentiation is purposed as students are diverse in abilities, prior knowledge and interests (Reis and Renzulli, 2018). One piece of evidence is found in a cluster group of gifted learners; Robinson *et al.* (2014a) stated that the implementation of a rigorous and differentiated science curriculum provided a positive outcome as the students with high ability were not mixed with low ability learners by enhancing scientific concept and subject understanding as well as methodological. To develop students understanding of differentiation, many models were developed, for example, Kaplan's models by Kaplan (1986) where four steps are focussed on including: content, process, product and learning environment, that focus on a certain theme (Kaplan (1986) cited in Ronksley-Pavia, 2010). Differentiation was also used to promote gifted students in several way; promoting individuals in the classroom to ensure the inclusive education of Finnish students (Tirri and Kuusisto, 2013) and promoting SD in Australia (Smith, 2015). Example of that is the use of variety of materials and assignments as well as independent learning (Laine and Terri, 2016).

The most complex options, in addition to earlier types of gifted programs, Enrichment is comprised of many forms, goals, and specific outcomes to be selected, making it impossible to review the effectiveness of the option (Robinson and Dailey, 2014). It is an approach to nurturing students with both academic and socio-emotional needs (Kulik, 1992). Kim (2016) added that enrichment programmes involve the development of in-depth knowledge and proficiency in a subject to foster gifted students' higher cognitive functions and creative output. Her study about meta-analysis reported that the results demonstrate enrichment programmes impacted middle school students in terms of their socioemotional growth (Kim, 2016).

The enrichment programme, agreed by many scholars, provides benefit as it allows for student investigation, integrated in-depth materials on a subject, tools for the development of higher-level thinking processes and skills, integrating independently chosen self-projects, offers genuine products or services for a target market in real-world (Renzulli and Reis, 1997; Fiddyment, 2014; Kim, 2016; Reis and Renzulli, 2018; Reis *et al*., 2021). Enrichment and enrichment pedagogy are founded on two main principles, according to Reis *et al.* (2021); they are centred on the interests and skills of children, and they are guided by theories that inform the selection of enrichment activities by teachers or the choice of curricular opportunities that align with relevant content and curriculum for enrichment purposes. Students can engage with more depth from learning topics such as robotics and human anatomy that are not instructed at the sophistication level or in typical classroom.

Aside from the three types of strategies for gifted curriculum above, it can be distinguished by the philosophical aspect of developing a curriculum suitable for them. Van Tassel-Baska and Stambaugh (2008) provided different philosophical orientations for gifted curriculum, such as cognitive process development, technology, personal relevance, social change enhancement, academic reasoning and understanding development, and career preparation. The philosophical perspective on curriculum plays a crucial role in shaping the necessary research and practical measures aimed at facilitating the advancement of talented students through targeted approaches. The divergence of viewpoints among professionals who engage with gifted students exists over the content of their instruction and individuals possess robust philosophical viewpoints regarding programmes designed for gifted education (Van Tassel-Baska and Stambaugh, 2008). This informed that different development model for gifted and talented children worldwide, based on their own definition and approaches of identification, target providing opportunities for nurturing and enhancing the abilities of gifted children, enabling them to achieve their unique educational demands.

In the United States, the public law states the guidance to provide education for the gifted following the Gifted Students Act signed by President Obama (U.S. Department of Education, 2005). State agencies' authorisation of elementary and secondary education allowed widespread gifted programmes to depend on state support. Many programmes developed for gifted learners are identified and differentiated by the state’s or programme’s definition of giftedness. For example, in Van Tassel-Baska and Brown's (2007) study, a comparative study among different models of gifted development was done. Eleven models were analysed according to their efficiency in applications and practices. An example of a model is Renzulli’s Schoolwide Enrichment Model (SEM), which is widely used as an example of an enrichment option. With a strong emphasis on enhancing learning for all students through high levels of engagement, there are more than 2,500 schools that have adopted and provided learning experiences that are tailored to each student's interests, learning preferences, and preferred means of expression (Renzulli, 2014b). On the other hand, Van Tassel-Baska’s Integrated Curriculum Model (ICM) (Van Tassel-Baska and Brown, 2007) was developed based on evidence regarding quasi-experiments and experimental research and problem-based science was implemented to promote high-order thinking (Van Tassel-Baska *et al.*, 1998). The implication also provided significant positive results in linguistic ability, attitude of teachers, motivation of students, and critical thinking in various research studies related to ICM in school.

In the UK, there are many gifted programmes run by schools and universities. Even though a programme at the national level in England was closed in 2011, initiatives was done by local authorities and school (Dimitriadis, 2016; Koshy *et al*., 2018). Also, gifted programmes operated by the university were found, such as the Ascend Project: Able scientists are collectively experiencing new demands. This project develops activities to promote the school's science curriculum and creates teaching materials that were put into an experiment. This was a SEP-funded project from 2004–2005 run by the Faculty of Education at the University of Cambridge working with secondary schools in Cambridge to develop and nurture talented students at the KS4 level (years 10–11, age 14–16) and is supported by the Gatsby Technical Education Projects science promotion programme (Taber, 2007a).

In Wales, NACE National Education for More Able Learners is an independent agency that promotes talent learning, provides resources and advice to whole schools, and works in conjunction with the Welsh Government (Welsh Government, 2015). Gifted education is still promoted at the school level. Additionally, gifted education is still a highlight. In Scotland, Special Needs Ability Pupil, or SNAP, is a programme operated by the University of Glasgow. Scotland gifted education have also emphasis the rights – based approach following inclusive education that provide implication and opportunity for gifted young students (Sutherland and Stack, 2014).

In Europe**,** the trend of individual talent development is decreasing among European countries, according to several factors, such as focusing on the benefit of society rather than the individual. This immigration situation brought to Europe a mixture of cultures and beliefs, a change of attitude towards exceptionality, and the formation of the countries of Europe and the European Union, as described in the study by (Tourón and Freeman, 2017) **.** So, most gifted and talent development programmes are generally not dependent on government policy. For example, the Centre for the Talented Youth of Ireland (CTYI) in Ireland is operated by Dublin City University (Ledwith *et al*., 2017). The students were identified using IQ criteria and attended enrichment classes with mixed grades for their enrichment development (Mcgrath, 2017). Aside from that, the Saturday class offered education in areas that are not typically covered by the school's curriculum and provided students with the opportunity to learn about things to which they would not normally be exposed in the classroom (O'Reilly, 2013).

In Scandinavia, where education focuses on education for all, gifted development exists in terms of individual development support by private organisations (Tourón and Freeman, 2017). Instead of focusing on the identification of those talents, educational goals are personalised and child-centred to assist each child is reaching their potential organisations (Tourón and Freeman, 2017). Similar to Finland, where equity education is implemented, gifted students were underemphasised. However, the shift toward promoting individual needs in gifted education practice occurs in classroom settings as a choice for teachers to implement in their own interests to support gifted students (Tirri, 2022). According to Terri (2022) different strategies were found, including differentiation practices such as providing individual advancement tasks with difficulty levels and problem based, and enrichment approaches such as summer camps, competitions and school clubs.

Gifted education is still the main focus in Asian countries. It indicated their education policy and practice are related to country investment and prosperity (Chan, 2017). Many special schools are established for serving talented students, such as super-science high schools in Japan, Seoul Science High School for gifted students, and the Korea Science Academy of KAIST in South Korea. There are many government institutions and programmes for gifted students, such as the Special Class for the Gifted Young in China, the PERMATA Pintar National Gifted Centre in Malaysia and the Gifted Education Programme (GEP) in Singapore (Chan, 2017). These programmes share common aims and is responsible for selecting and developing these students. South Korea also provides supports with advanced enrichment and intensive training for students in science-gifted high schools, selected through nationwide process (Lee, 2021). Additionally, gifted student with special need and those from socioeconomic disadvantaged background are the focus in Taiwan, where they are identified and counselled by schools (Yu *et al*., 2020).

For a variety of reasons, national policy is involved in gifted education because it influences the methods used to nurture and cultivate their talent for the development of human capital. As stated by Sumida (2017), fostering the interest of exceptional students in science and mathematics is crucial for the advancement of science and technology in the nation, and this can be accomplished through effective education. To fully advance students potential, gifted curriculum must be designed with gifted students at the forefront, otherwise, they will not benefit optimally (Van Tassel-Baska and Baska, 2021).

Additionally, Gifted education teachers enhance students' higher-order thinking and suit their requirements with extensive disciplinary content, creative thinking, and individual research (Yu *et al*., 2017). Many strategies are suggested to promote gifted students such as problem-based learning, interest-based learning pedagogy, curriculum compacting, project-based learning, open-ended choice, and the application of creative productivity to students learning (Reis *et al*., 2021). Among those strategies, motivating students to learn is the key idea, providing them with learning opportunities that are both challenging and interesting (Reis *et al*., 2021). Van Tassel-Baska and Baska (2021) also highlight that gifted curriculum must include five elements which are acceleration, complexity, depth, challenge and creativity. On the other hand, if the curriculum is redundant for the child or if it is below that student's level of preparation, the brain will not be inclined to engage or respond, and as a result, it will not release the levels of dopamine, noradrenalin, serotonin, and other neurochemicals that are necessary for optimal learning (Van Tassel-Baska and Stambaugh, 2008). Beyond cognitive support, gifted students also need emotional support and opportunity for social participation. In the next section, gifted education in Thailand is discussed along with provision support gifted science students in particular.

3.1.4 Gifted in Thailand Context, and Programme for Science Gifted Students

Earlier, Thailand's national educational policy also regarded giftedness and talent as part of educational development. An example of the national gifted programme is the OBEC gifted programme, sponsored by the Office of the Basic Education Commission (OBEC), a Thai governmental agency under the Thai Ministry of Education (MOE). Gifted OBEC follows Gardner’s definition of eight multiple intelligences. It helps to identify gifted students in Thailand to measure the ability of students of different varieties to join a school gifted programme, and it suggests that school teachers assess the students using multiple tools regarding those intelligence areas (OBEC, 2019). This programme supports the secondary school to run a gifted school programme for several disciplines, including languages, science and mathematics, art and music, and in 2019, OBEC opened the electronic system to identify gifted or talented students for adoption by the student, schools, and parents (OBEC, 2019).

The school must be the place that provides education that reaches international standards, develops thinking skills, is moral and ethical, and provides technology and career opportunities for students (OBEC, 2022). In ONEC (2018), the number of gifted students in 502 schools under the Office of Basic Education Commission is 5,488 students that identify as gifted in all varieties, and among those students, 671 are accounted for at the primary level, surveyed by ONEC in 2016. In addition, only 12.04 percent of the overall number are gifted science students, while the biggest proportion of gifted areas are in sport and music, which are 24.40 percent and 20.61 percent, respectively (ONEC, 2018).

To promote gifted education following national policy, OBEC guidelines were provided for schools to develop students to reach their potential by establishing special science and mathematics classrooms. The special classroom is the class that provides educational management and promotes potential teaching for students with special abilities, under the authorization of the Educational Service Area Office, according to the OBEC guidelines (OBEC, 2022). The classroom can be opened by focusing on several disciplines, including science, mathematics, languages, sports, music, art, and technology. The special classroom option is the most selected for nurturing gifted students from school management perspective and students in these classroom are selected through the process based on academic achievement (Anuruthwong, 2017). The example of a gifted programme for science is stated in Chapter 1.

According to ONEC (2018), the educational management for gifted science in Thailand was described to promote their learning in their specific area. Some programmes report the implementation of STEM education and problem-based learning to promote thinking skills and STEM problem-solving skills (ONEC, 2018). However, there is no evidence to support students' knowledge regarding SD. Anuruthwong (2017) also point out that student's opportunity for pursue their interest and develop skills such as physical, emotional, communication and life skills, are not the prioritised. This gap highlight the need for support Thai gifted students in skills, values, and attitude, beyond just cognitive ability.

3.1.5 Fostering Gifted Science Students with STEM Education

STEM education is recognised as a promising tool that is beneficial for driving the country and competing with others. Scholars in Gifted education are agree that STEM education is effective to provide education that meet students need (Anderson, 2014; Robinson *et al*., 2014, Schroth and Helfer, 2017). For Thailand, the utilisation of a variety of STEM educational approaches can effectively improve STEM education for all students and contribute to the fulfilment of important requirements for human capital (Promboon *et al*., 2018).

STEM education is also found to be promoted in gifted areas. Due to the fact that gifted students are also the target of STEM learners; they are exceptionally science gifted, even though STEM by itself is not solely designed purposefully for gifted students (Ülger and Çepni, 2020). It is implemented widely among a diversity of students. An example of that is found in the NGSS which allows teachers to incorporate medical, engineering, forensics, and other disciplines into classes that engage students and encourage STEM professions. The and context of learning must be understood including the student demographic which includes gifted and talented students (NRC, 2013). Not only is it an area to promote learning STEM, but it is also considered one of the areas of interest in gifted education research (Lee and Gentry, 2023). It was found that studies conducted on STEM education for students with giftedness outline and fall into categories based on the following topics: job choices; STEM schools and programmes; effect on development; and effect on characteristics (Ülger and Çepni, 2020).

Chapter 2 provides benefits of STEM education. For gifted education, It benefits gifted students through the provision of a rigorous curriculum, specialised training in different areas and a well-defined trajectory towards more demanding academic pursuits (Ozkan and Kettler, 2022). Evidence from Ülger and Çepni (2020) indicates the gifted development on spatial thinking, thinking skills, challenge level as well as understanding science. Positive outcome for gifted learners are reported in the areas such as science process skills, science concepts, and science-content knowledge (Robinson *et al*., 2014) ,reasoning (Ozkan and Kettler, 2022), problem-solving skill (Lakanukan *et al.,* 2021), and creativity (Kim *et al.,* 2016). Due to these facts, various approaches are employed to facilitate the education of academically talented pupils in the field of STEM.

According to Ozkan and Kettler (2022), STEM integrated learning and gifted and talented curricula are components of the theoretical paradigm for STEM in gifted education. NRC (2013) indicates how teachers facilitate the scientific development of gifted and talented students by implementing successful differentiation strategies in the following four areas: (1) fast pace, (2) appropriate level of challenge (including content differentiation), (3) opportunities for independent learning, and (4) strategic grouping (NRC, 2013). One example is the STEM starter programmes which incorporate problem-based learning for promoting giftedness at the primary level (Robinson, 2019) by using inquiry-based learning and problem-based learning. Problem-based teaching helps talented students explore the problem and solution, collect data or resources, undertake experiments and research (Robinson, 2019), and present the results to motivate and interest them (Yu *et al*., 2017). Exciting topics are included in practice; for example, gifted students in grades 5 and 6 can choose topics of interest for independent study, with guidance from the teacher when needed (Yu *et al*., 2017). In the GUIDANCE-STEM inqury based learning strategy, gifted students in Indonesia understand Newton's law of motion and gain social and collaborative skills from making miniature cars (Abdurraman *et al*., 2019).

Group work is also involved in promoting gifted learning. Fostering creativity in gifted students with STEM instruction and integrating discussion and debate in the cooperation process to promote divergent and creative thinking that leads to genuine achievement (Kim *et al.,* 2016).

Many examples of engaging students with STEM are found in many studies. Robinson *et al.* (2014) promote STEM knowledge in gifted students and the outcome is that students' learning is gained. The STEM starter programme helps primary school students from grades 2 – 5 learn science knowledge, process and concepts. STEMulated engineering programmes help promote students' problem solving and design skills (Dailey *et al*., 2018). In Dailey's study, an activity was created by providing students with the opportunity to solve the problem of water conservation by making water transportation. Collaborative discussions were used to encourage students to express ideas regarding solving problems and the tasks promote STEM knowledge and skills (Dailey, 2017). Her study inspired SD integration beyond problem-solving and skill-building.

Gifted programmes in other countries also recognised the value of STEM. In Ireland, the Centre for Talented Youth (CTY) provides STEM courses for students starting from 6 to 17 years old, following national policy on STEM (Ledwith *et al.*, 2017). Activities found in this centre include variations such as natural science, physical science, and technology. The programme runs from 6 to 8 weeks and is divided differently during term time and spring. The specialty of this centre is providing authority for the instructor to decide their teaching and learning for gifted students (Ledwith *et al*., 2017).

In Taiwan, STEM is the key priority for curriculum development to provide a special education curriculum for gifted students from the elementary to the high school level and start the selection process for gifted programmes at the primary school level (Yu *et al*., 2017). Mixed-ability talented students at this level will study science education with creativity in school (Yu *et al*., 2017). Aside from that, the study by Han and Shim (2019) states the importance of the integration of STEM in gifted education and encourages the implementation of the EDP, which the DIGIER model introduces. This illustrates that gifted science students need to learn problem-solving, creativity, and cooperation, and STEM with engineering design methods is successful.

In Thailand, the STEM also adopted this approach in fostering gifted students. The study of Lakanukan *et al.* (2021) integrated STEM and EDP that promote problem-solving skills in special classrooms for gifted primary school students from special science-mathematics classrooms. Based on Thailand and school standards, the students reflected the use of STEM skills such as measurement skills in their learning, making this a blueprint for developing diverse and appropriate activities for learners, especially gifted science students in Thailand Lakanukan *et al.* (2021).

3.2 STEM Activities to Promote Gifted in Science for Learning SD and Skills

Gifted can be defined based on how they employ their intelligence: transformational and transactional giftedness (Sternberg, 2020). Sternberg (2020) describes that transformational giftedness can create change, while transactional giftedness focuses on personal development rather than contributing to the world. This suggests that, in addition to developing themselves to their full potential, individuals who possess transformational giftedness have the capacity to transform the world. Sternberg (2022) distinguishes the short-term state of giftedness as state-giftedness, denoting the ability to surmount real-life challenges under unforeseen circumstances, in contrast to trait-giftedness, the term prevalent in the classical perspective. State gifting is essential in this rapidly changing world, and it is possible to train individuals to become state gifted. Therefore, to achieve sustainability, gifted students need support to become capable of addressing the SD challenges. This research focuses on enhancing their awareness of SD as well as fostering problem-solving skills and collaboration among them.

Based on the literature study, there is a requirement for EDP-based solution to solve future problems and promote giftedness in STEM. For solving problems like environmental sustainability, NRC (2013) claims that the acquisition of a foundation in engineering design equips students with the capacity to effectively tackle forthcoming societal and environmental challenges. Teaching and learning models for those who are gifted in science, and the aim is also to inspire gifted pupils to study science and engineering and develop innovative problem-solving skills (Han and Shim, 2019). According to the integration with EDP, students learn the application of science and create innovative products. However, existing scientific education programmes that are grounded in the EDP have been structured to offer primitive exposure to engineering design activities through the completion of a limited number of engineering design tasks (Han and Shim, 2019).

To promote gifted learning for SD, the success of the behavior change seems to be significantly influenced by the engagement level of the learners (Brundiers *et al*., 2010). As supported by the research of Renzulli *et al.* (2014), gifted learners are keen to know about real-world issues because they are involved in their lives (Schroth and Helfer, 2017). Additionally, Önal (2020) emphasises that gifted students are capable of resolving environmental issues by using their sensitivity, knowledge of science and nature, interest in natural environments, and their development of reasoning and PSS. SD issues, especially environmental sustainability, can serve this need.

Significantly, most of the issue is related to science, which can draw the link between the issue, interests and motivation based on gifted science students' characteristics (Taber, 2007; Shim and Kim, 2005). An example of that is global warming, which happens due to the release of CO_2 into the atmosphere, and the gas absorbs the heat and creates a warm blanket in the atmosphere. Environmental issues in this context serve as problem scenario for students to learn, apply several skills to solve the issues and reflect on their learning. One good example is using water resource issues in STEM learning to teach gifted students about water quality and accessibility, which helps them to comprehend how human affect water resources and water quality (Riskowski *et al*., 2009).

Moreover, for a reason, scientific knowledge is the most important interest of gifted science students, and according to their highest potential, they may become leading scientists, researchers, lecturers, or physicians in the future. They are prone to understand the value of science as the power to develop an innovative future and the adverse effects of science as the tools to destroy the environment from human misuse. This is supportably stated by the 'Declaration on Science and the Use of Scientific Knowledge at the World Conference on Science in 1999, which was co-organised by the United Nations Educational, Scientific, and Cultural Organisation (UNESCO): 'In addition to their demonstrable benefits, the applications of scientific advances and the development and expansion of human activity have also led to environmental degradation and technological disasters and have contributed to social imbalance or exclusion' (UNESCO, 1999). Therefore, ESD helps gifted students understand the value of the science they learned and, at the same time, have an awareness of environmental concerns from the use of science as global citizens for the good of humanity.

Schroth and Helfer (2017) illustrate the ESD implementation in the gifted in elementary and primary school levels from K-2 to K4. They learn to connect to the world and think as a single citizen when realising the effect of human behaviour on the environment (Bland *et al.*, 2010; Fraleigh-Lohrfink *et al.*, 2013 cited in Schroth and Helfer, 2017). It was also suggested how to reach SD by moving from nature context to outside classroom context and global context (Michaels *et al.*, 2008 cited in Schroth and Helfer, 2017; National Research Council, 2000). Clearly, programmes not only aim to promote students cognitive knowledge and skills but also provide opportunities to promote SD learning. Gifted development also enhances agency. As Willcock (2017) identified from gifted curriculum in New Zealand, provided challenge and stimulate learning experience with complex content, personalised learning with choice, content, and process, collaborative opportunity with peers and teachers, and strength, interest, and passion focused are embedded to support gifted students agency.

This research is intended to develop a pedagogical study to support gifted students in Thailand in SD learning and skills. One reason is to provide resources for school teachers to implement in school especially in the gifted classroom. According to Dai (2019) numerous Asian countries encounter the challenge of inadequate resources despite their fervent support for gifted education. While financial resources are a real concern, the absence of essential curricular, pedagogical, and logistical assistance represents a less tangible but nevertheless significant and persistent issue (Dai, 2019). Especially in gifted education in Thailand, which requires the development of programmes to support gifted students (Anuruthwong, 2017).

Not only were resources for gifted development limited, but ESD resources in science classrooms were also limited in Thailand. Although, it places significant emphasis on the SEP, which underscores the importance of a comprehensive approach across the entire school and critical actions such as 3R recycling (Dharmapiya and Saratun, 2016; Lee and Ruwicha, 2020). Their study includes problem-solving skills but not SDGs, SD pillars, or SD competencies. In order to promote learning toward global citizenship, SD concepts, SDGs, and ESD competency, STEM education can be one of the foundations for integrated ESD. Additionally, problem-solving strategies and collaboration have been identified as factors that promote learning for SD and skills to foster gifted students. The integration of the principles of ESD, gifted education, and STEM is embedded in this research through the exploration of several frameworks to promote SD knowledge, quality STEM education, and an approach for developing gifted learning. According to the belief that the strategies can bring positive outcomes, it must demonstrate an alternative education to developing cognitive, analytical, and transformative skills (Wals, 2015).

To support gifted learners in science, higher-order thinking, creativity, independence in learning, groupwork, and inquiry skills are suggested to be considered to create a suitable learning activity for them (Taber, 2007a). Additionally, Taber (2010) adds that students can be engaged by focussing on conceptual content, enquiry and production, offer pace and variety of choices. In this study, STEM activity is consider the approach for gifted learner to address SD issues. Pahnke *et al*. (2019), highlight that STEM education helps students comprehend global issues and advocate for societal activities that effectively tackle these challenges because knowledge, abilities, and comprehension of scientific, technological, engineering, and mathematical phenomena are crucial elements. These outcome is found in the study of Riskowski *et al*. (2011) that demonstrates the increase in societal awareness and their understanding of water quality issue in gifted students in eighth grade.

Enrichment activities are an option and must be designed as a blueprint for further integration in the Thai context as extracurricular activities. To provide SD concepts and scientific knowledge as advanced content that extends from what Thai students learn at the primary school level, this research considers the development of specific practices to be adopted in the gifted classroom in Thailand. Due to the fact that gifted students should be provided with customised STEM education that entails increasingly challenging learning paths (Ozkan and Kettler, 2022). Therefore, a STEM problem-based approach that lets gifted students experience learning by themselves through a hands-on learning opportunity, are promotes autonomy through a collaborative process is the desired outcome of this research. They are allow to make decision and create variety of solutions at the end of learning process.

Apparently, scholars recommend STEM as effective practises for gifted development (Robinson *et al*, 2014; Ozkan and Kettler, 2022), which helps answer the research question. Problem based is recommended by scholar as one of strategies for sustainability education (Tejedor *et al.,* 2019). In the PBL learning, students have opportunity to develop 1) the ability to analyse information and data obtained from a variety of sources and resources critically, and 2) they learn how to derive lessons from the difficulties encountered during the resolution process (Tejedor *et al.,* 2019).

Moreover, For effective STEM units, Guzey *et al.* (2016) indicate collaboration as compulsory of STEM teaching and learning. The STEM PBL encourage teamwork that benefit for collaboration and their learning. Patrick *et al.* (2005) notes that students are able to develop conceptual understanding through team dialogue such as asking their peers, delivering explanation, and identify inconsistencies. This process. The involvement in science and engineering is a communal undertaking, in which students have the opportunity to cultivate essential collaboration skills that can enhance their social-emotional growth and facilitate adaptable learning strategies (National Academies of Sciences, 2022). Students are allow to assume different roles and work toward group goals. This collaborative process are essential for cultivate EHoM (Hanson *et al*., 2021) and promote PSS.

According to Moore *et al.* (2014) that engineering problem must be open-ended. SD issue can be incorporate with EDP, promote EHoM and PSS as well as knowledge regarding ESD in gifted science students. Due to this fact, in the following chapters, the knowledge from the literature study is being used to create the conceptual framework which inform STEM intervention design in this study.

3.3 Conceptual Frameworks for Pedagogical Activities

According to literature study, to promote students' knowledge and awareness for SD, problem-solving and collaborative skills, the conceptual framework was developed. Beginning with broad concepts regarding three main areas: knowledge for SD, STEM education, and environmental sustainability issues. The initial conceptual framework shapes the pedagogical intervention and is implemented in the pilot study, the 'Landslide Prevention Project' (See chapter 4 and Appendix 2). The outcome of pilot provides the idea to design pedagogical interventions. in addition to the literature study that was continuously conducted during the research. As a consequence, the conceptual framework was finally developed with Environmental sustainability issue, specific concepts of SD, competencies of SD, STEM – problem solving approach with the integration of EDP and EHoM, collaboration, engage gifted science students with their characteristics. The conceptual framework informs the design of STEM – ESD programme, the Young Engineer for Sustainability (YES! programme). The frameworks are described respectively.

3.3.1 Initial Conceptual Framework for Pilot Study

In order to explore the STEM activity with an emphasis on sustainability and problem-solving, the implementation of a framework for designing and investigating the potential of STEM activities in SD learning is needed. Begin by selecting certain SDGs to direct the learning theme and process, ensuring a robust correspondence with SD ideas. Integrate Thailand's environmental sustainability issue as a central core, promoting collaborative problem-solving encounters linked to selected SDGs. Incorporate the EDP to promote active learning, foster discussions, and provide opportunities for reflective learning. As shown in Figure 9 below, these aspects have played a significant role in influencing the design of activities, lesson plans, and tasks for student participants throughout the intervention.

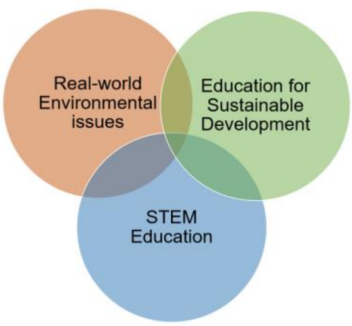


Figure 9 Initial Conceptual Framework for Pilot Study

According to figure 9, details of each element is described below.

1) Real - world environmental Issues

Environmental sustainability issues are served as core content for learning. Following the definition of SD and educational strategies, environmental sustainability issues are ill-structured and definitely wicked issues. Climate change, disaster, biodiversity, poverty, and sustainable consumption are the issues that are complex and cannot be resolved by one solution. According to Renzulli and colleagues (2014), the significance of the environmental issue is attractive to gifted students. The complexity of the issue makes it meaningful to promote the interests of gifted science students. In addition, it provides students with scientific knowledge behind the issue, which can stimulate students' engagement and keenness to complete the challenge. Significantly, integrating the local issues in Thailand brings a sense of relevance to students and makes them see the need to address the issue.

2) ESD: Learning for SD

The lesson plan is incorporated within an ESD framework, contributing to SD, and the goals are to foster students' knowledge and awareness of SD. Human behaviour is involved in creating environmental sustainability issues. So, this study makes a significant contribution towards the attainment of the SDGs and embedding the three pillars of SD, which include social, environmental, and economic. Students can engage in discussions regarding the issue within the context of SD by deliberating on its cause and impacts on society, the economy, and environment. Additionally, critical reflection is an important aspect that students need to practice in the activity.

3) STEM Education

According to the literature study, EDP demonstrates that students can learn to solve problems by starting with a contextual difficulty, identifying the issue, generating ideas to tackle the problem, and finishing the work. The discussion during the problem-solving process can help promote some skills that could be considered to promote knowledge and skills for SD. To design the activity, the problem - solving tasks needed to be planned and organised to avoid making them feel bored or stressed from the task. By providing problem solving challenges, learning activities could serve gifted students' need to engage and enjoy finding solutions. This setting meets the characteristics of gifted science students who continuously express interests in studying scientific phenomena and problem solving (Taber, 2007).

Consequently, the pilot study adopted the landslide issue, and the ‘Landslides prevention project’ was conducted following the initial framework. The details of the activity are described in appendix 1 and 2.

3.3.2 Conceptual Framework: STEM for Solving Environmental Sustainability Issues

Based on the initial version which provides broad scope for designing the intervention. The conceptual framework is developed from the literature study that provided comprehensive knowledge and strategies regarding SD learning to promote knowledge, awareness problem-solving skills and collaborative skills. Additionally, involving students in critical reflection and discussion about the issue must be promising to promote effective learning for SD.

Pilot phase data indicated the potential to promote ESD with a STEM problem-solving approach and provided a clearer picture of how to engage students with problem-solving scenarios for SD learning as an enrichment activity for gifted students. First, environmental sustainability issues from the real world are appropriate and engaging. Landslides in Thailand illustrate how environmental sustainability issues affect local communities and how human behaviour can destroy planet Earth, human quality of life, other living things, and the environment. Students also express their ideas about environmental protection and, more significantly, long-term conservation through the sustainability discussion. This discussion concerns individuals and communities. however, it needs to be emphasised further to make it more explicit and connected with society and the economy. EDP provided an effective problem-solving process, as the literature study illustrated. Students demonstrated strong PSS and enthusiasm for tackling the village problem as they sympathised with the impacts on local people. However, the literature review recommends focusing on ‘society’ or ‘the economy’ and building competencies for sustainability (Chapter 2). Interventions must be carefully designed to be a better version of the intervention that is suitable for gifted students and the learning outcome must be emphasised. To sum up, the conceptual framework needs improvement to be more specific and focused.

To establish an effective SD learning environment, the new framework is a hope to create STEM activities that promote learning for SD and skills. While teaching local scenarios is necessary, the global context must also be integrated to identify significant impacts that could have a greater influence. From individual to community to country to global, students can reflect on themselves and recognise that they are able to make a difference. For sustainability decisions, solving short-term and long-term concerns is vital. When everyone adjusts their lifestyle and quits doing unsustainable things, environmental prevention and sustainable communities arise.

This framework builds on the initial framework, the knowledge from the literature review helps determine each element of the framework. Therefore, a conceptual framework for STEM and SD learning is consists of five elements as shown in Figure 10.

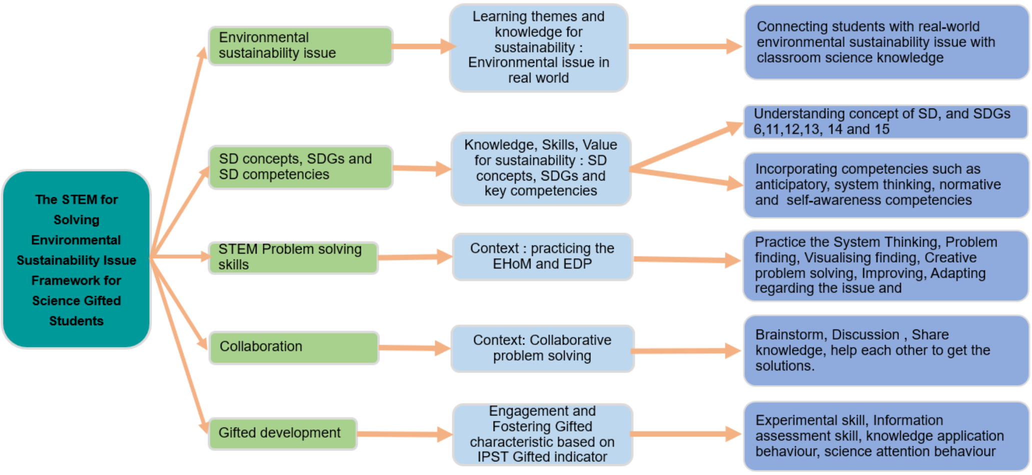


Figure 10 STEM for Solving Environmental Sustainability Issues Framework For Science Gifted Students

As shown in the figure, this conceptual framework provides a focus on SD learning and Problem-solving skills and promotes more collaboration among the students which informs the design of STEM interventions. The elements of the framework are described as follows:

1) Environmental sustainability issues

'Don't forget the content' is suggested by Buchanan and Dailey (2017, p. 122) when considering the EDP to promote problem solving for gifted students. Particularly in this study, where SD is the primary focus, Schroth and Helfer (2017) address the importance of environmental studies that provide opportunities for learners to develop the knowledge and skills needed. Using local issues, the environmental sustainability issues found in Thailand serve as the content which can be delivered through storytelling and the use of visual aids. This study also. This element of framework consider the issues as content that relevance, connecting local issue to global issues to promote global awareness, making it a valuable learning context for skill application and promote reflection. The link to global issue can promote SD by expand students perspective and promote global competence (Asia Society/OECD, 2018; OECD, 2018b).

From the literature, the concept of SD suggests that ensuring environmental sustainability can help achieve a successful sustainable future. Learning knowledge is a type of cognitive ability development that can serve as the foundation for empowering students for behavioural change aside from skills, value and attitude (European commission *et al*., 2021). Environmental sustainability knowledge encompasses scientific facts and concepts that students can grasp. However, as suggested by many scholars, knowledge must also cover the other pillars of SD, which are the economy and society to provide a holistic view of learning SD. As a result, when imparting knowledge to students, the community's perspective and economic ties must be discussed. Passow (1989) stated that by sensitising youngsters to community issues, they would develop their specialised talents to help solve the world's most critical challenges.

The issues in Thailand were chosen as the learning theme in this study. Several studies show that issues such as landslides, floods, droughts, and waste pollution are related to the students' real lives, and students perceived the issues from the media or from personal experience (see table 7). These issues genuinely affect Thai people's life quality, the Thai economy, and the Thai natural environment (Marks, 2011; Gale and Saunders, 2013; Department of Mineral Resources, 2017; Petpongpan *et al*., 2021; Department of Marine and Coastal Resources, 2017; Dechkhamfoo *et al*., 2022; Pollution Control Department, 2022; Ecohubmap, 2023; Inoue, 2023). Real-life evidence, such as the people's stories or pictures of the phenomenon, can be shared with them to illustrate how the situation affects the environment and the local community. Using the local issue ensures that students see learning as challenging and meaningful (Morris *et al*., 2021) and connect knowledge that is related to real life (Pagsangkanae and Yuenyong, 2019).

Issue	**Cause**	**Impact**	**Location in Thailand**	**Supporting literature**
Flood	Rainfall, climate change, water management	Tourism, industry, economic	Bangkok, All regions, Area around river and gulf of Thailand	Marks (2011), Gale and Saunders (2013)
Landslide	Climate change, Rainfall, type of land cover, physiographic classifications, slope angles, and amount of rainfall	traffic and, at times, roadside construction	Chiang Rai, Many part of Thailand	Marks, 2011, Department of Mineral Resources, 2017 Dechkamfoo *et al.* (2022), Petpongpan *et al.* (2021),
Drought	Climate change , deforestation, Dam construction	Lack of water, Economic impact, Agricultural impact	Nakhon Ratchasima, Chiang Rai	Ecohubmap (2023), Marks (2011), Inoue (2023)
Waste in the river and ocean	Factory, Gas station and farm, Climate change, Waste management, Open dumping, Open Burning	The water quality, microplastic	Bangkok, Chiang Rai , Chaing Mai and all region, Area from land to ocean in Thailand	Department of Marine and Coastal Resources (2017), Pollution control department, 2020), Chen and Fei (2023)

Table 7 Summary of Environmental Issues in Thailand

Facts about environmental issues are currently taught in Thailand's science classroom based on Thailand's science standards (IPST, 2017). When learning about surface water, for example, students might learn about floods which occur due to an excessive precipitation rate. To spark their interest in learning about the flood issue for sustainability, interesting facts or evidence can be provided. Another example is waste pollution, which students learn about reduce, reuse recycle of waste in science classroom. Using an illustration of the pathway of river waste accumulated along the river streams, forming a significant cluster in the Gulf of Thailand (Department of Marine and Coastal Resources, 2017), can promote students' critical reflection regarding sustainability. Students can see the picture and data during the problem identification process before going to the problem-solving stage and taking these into account throughout the discussion stage. As a result, this can foster Problem-solving skills.

The review of Thailand's science standard for primary science suggests that students learn environmental science in class which can serve as a basis for learning the content and the scientific facts behind the issue (see Table 8). This research emphasises the environmental issues related to knowledge based on Thailand's primary education core curriculum (A.D. 2008) revision version (A.D. 2018) (IPST, 2017). So, students have fundamental knowledge to assist them in discovering knowledge for SD, articulating and using their knowledge, and solving problems in STEM activities. The students in grades 4 – 6 must learn about living things and living processes, life and the environment, substances and properties of matter, and the changing processes of the earth. These standards explain human life and human habits related to the environment and disasters (IPST, 2017). The link between environmental sustainability issues and classroom knowledge makes learning relevant to students, it engages students and shows the application of science (Littledyke, 2008), and the natural organisms around them (Bourn *et al.,* 2016). Seeing how their classroom knowledge is applied can boost their perception of learning. Table 8 below shows the Thai biological, physical, and earth science contents employed in this study.

Thailand science standard at primary level		
strand	Code	Science content
Biological science	S. 1.1 (year 5)	Food chain
	S. 1.1 (year 5)	Environmental conservation
	S. 1.2 (year 2 – 3)	Water for living and sanitization
Physical science	S.2.1 (year4)	Material and its properties
	S. 2.2 (year 4)	Gravity, Mass, and Force
Earth science	S.3.2 (year 5)	Water sources, water conservation
	S3.2 (year 6)	Global warming, Effect of landslide, flood and prevention.

Table 8 Thailand's Science Standards Linked with Environmental Issues.

In addition, Chapter 2 suggests that although students learn environmental science in class, approach like PBL allow students to learn from discussing with friends through collaborative process. Environmental issues were chosen to be starting topics for them to evaluate and find the solution. Besides, as Thai students may have experienced the issues themselves, they can share their previous experiences or opinions on environmental sustainability issues through classroom discussions, the scenario, and their peers.

2) SD concepts, SDGs and Key Competencies for SD

With the roadmap for ESD, specific learning objectives and guidance are provided to better transform people's behaviors towards ESD, especially for young citizens (UNESCO, 2020). The concept of sustainability must cover the pillars of SD: environment, economy, and society (Hedefalk *et al.,* 2015; Sinakou *et al.,* 2019). Teaching SD concepts is an advantage in helping young students understand complexities and learn to confront ambiguity and problem situations in a productive and courageous manner (Pahnke *et al*. 2019). It is recommended to embed it in the lesson plan as the core of education for SD (UNESCO Bangkok, 2019). Therefore, gifted science students must be taught to understand this concepts.

According to the SDGs learning objective (UNESCO, 2017), and Thailand's science standards, some SDGs show a relationship with science standards and environmental sustainability issues in Thailand. Addressing Thailand's environmental issues is about promoting the SDGs and students can see the link between issue, classroom knowledge and how to achieve SDGs. Based on the environmental issues in Thailand and their link to the Thailand science standard, goals 6, 11, 12, 13, 14, and 15 can be focused such as the link of landslides with SDG 11 and SDG 15. Figure 11 illustrates the link between landslide, floods, droughts and waste in the river and ocean, and SDGs.

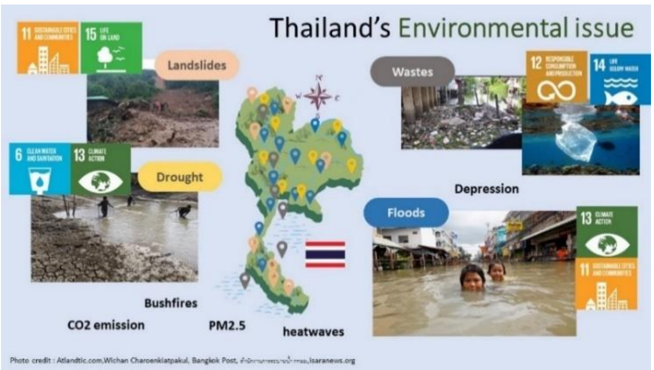


Figure 11 Example of SDGs Linked with Environmental Issues

In addition, the literature review indicates the importance of competencies for sustainability which influence the capability to change. Lozano *et al.* (2017) also highlight the potential of PBL for learning such competencies, while Redman *et al.* (2021) notes that competence is usually teach less than teach-based approach. This research is interested in embedding some competencies based on a competency framework developed by many scholars and UNESCO (Redman and Wiek, 2021; UNESCO, 2017; Wiek *et al*., 2011; Wiek *et al*., 2016) to the STEM problem-solving activities. This research embedded a set of competencies which are system thinking, normative thinking, anticipatory thinking, and self-awareness. According to scholars, prompted questions and tasks are created to encourage and assessed the reflection of SD competencies (Clark *et al*., 2017; Demssie *et al*. 2022; Giangrande *et al.*, 2019; Ojala, 2016; Wiek *et al*., 2016; York *et al*., 2019). Some of these studies value the key competencies, how to embedded and ways to assess them. The Summary of SD competencies are presented in Table 9 below.

Competencies	Descriptions	This thesis implementation
System thinking	• Understand relationship and able to analyse complexity of inherent of social - environmental system (Wiek *et al*, 2015; UNESCO,2017;Senge, 2006 in Grandisoli and Jacobi,2020) • Comprehend how systems are embedded within different domain and scale (UNESCO,2017) • Capable to analyse SD issue across different domains/ sector/ scales (Wiek *et al*, 2015) • Applying systems concepts (cause-effect structures, feedback loops, structuration)(Clark *et al*., 2017; Wiek *et al*, 2015) • Able to describe the need for systemic thinking in sustainability problem solving (Wiek *et al*, 2015) • Able to describe how different professional activities contribute to, or solve/mitigate sustainability problems(Wiek *et al*, 2015)	• Connect pieces of information regarding Environmental Sustainability issue and the given scenario. • Bridging the previous knowledge with knowledge from intervention • Identify the cause and impact relationship
Anticipatory (Future thinking)	• Understand and capable to evaluate multiple futures (UNESCO,2017) • Able to create visions for the future, to apply the precautionary principle, to assess the consequences of actions, and to deal uncertainty (Wiek *et al*, 2015) • Able to anticipate how SD issues might evolve over time (Wiek *et al*, 2015) • Able to create and craft sustainable and desirable future visions with evidence (Wiek et al, 2015)	• Evaluate the future consequences of specific scenario • Evaluate the outcome of the solution drawing form experiment to real life context and in long term
Self-awareness	• Able to reflect on one's own role in local – global society, continually evaluate and further motivate one's actions, and deal with one's feelings (UNESCO,2017)	• Reflect their thought regarding their role in community, their capacity and behaviours • Reflect their own value
Normative / Value thinking	• Able to understand and reflect on the norms, values and concern that underlie one's actions and to negotiate sustainability values, principles, goals and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions' (Komasinski and Ishimura, 2017; UNESCO,2017) • Able to articulate one's moral thinking, • Able to specify, compare, apply, reconcile, and discuss sustainable values, principles, goals, and targets based on justice, equity, accountability (Wiek *et al*, 2015)	• Evaluate behaviours of people in family, community and country • Justify the role of community and government

Table 9 Summary of SD Competencies Adopted in This Study

Based on table 9, competencies must be identified to embed in the tasks to fostering competencies. The implementation of each competencies highlight how this thesis incorporates competencies for sustainability for gifted science students.

3) STEM problem-Solving Approach

According to literature study, many STEM approaches were applied in engineering education and STEM education practices. EHoM was recommended to equip students' PSS, with students expressing engineering thinking when solving problems to promote engineering skills (Karatas-Aydin and Işıksal-Bostan 2023; Lucas and Hanson, 2014; Lucas *et al*., 2014). EDP was also widely used to provide a problem-solving process that students could practice systematically (NASA, 2011; STEMEdThailand, 2014: EIE, 2016). Chapter 2, suggests processes and skills are important to promote PSS. EDP is adopted in STEM teaching and learning to allow students to follow the problem solving and design process, and create solutions in the form of innovative artifacts. However, to enhance engineering thinking skills, EHoM is a useful framework. The open-ended tasks emphasise the ability of students to practice each of the problem-solving steps that each EHoM element embeds.

An example of that is the use of problem-finding to investigate the context given. System thinking can be encouraged when the task is designed for students to investigate the relationship between the data provided and the outcome or link classroom knowledge with the impacts of an issue. Visualising is related to the ability to move from an abstract idea to an innovative artefact to solve the issue. Under team decision and suggestion, students can practice visualising by drawing the invention plan according to different ideas. Each element of EHoM adapted from Lucas *et al.* (2014) is implemented in the context of this research, which leads to instruction design as shown in Table 10.

EHoM	Definitions	Sub habits	Cultivation approaches	Task in the activities
Problem finding	Deciding what the actual question is, solutions, investigating contexts.	• Checking and clarifying: questions reflectively • Investigating: has a questioning, curious and, where appropriate, sceptical attitude.	Providing the problem regarding environmental issue and asking for student to investigate	Identify the issue if there is no help/ or preparation toward the environmental sustainability issue
System thinking	Seeing connections between things, seeking out patterns, seeing whole systems and their parts and how they connect, recognising interdependencies, synthesising.	• looks for links, connections, relationships; working across boundaries. • Pattern-making: uses images etc. to find patterns to illustrate new meaning.	Using the learning tasks for students to grasp the knowledge or concept and integrated that knowledge with existing task or question and ask students to reflect and synthesis knowledge	Seeing the relationship between classroom knowledge and activity, factors regarding issue Connecting the knowledge and create the connection and explicit to mind map
Visualizing	Seeing the end product, being able to move from abstract ideas to concrete, manipulating materials, mentally rehearing practical design solutions.	• Thinking out loud: puts 3D ideas into words as they become pictures or rehearses possible lines of thought or action. • Model-making: moves between abstract and concrete, making models to capture ideas	Drawing, manipulating the materials to create a model , create the mind map	Students are encouraged to think aloud and expressed problem solving idea into the drawing or suggest teammate to create the plan. Create the mind map to visualise idea about micro plastic
Creative problem solving	Generating ideas and solutions by applying techniques from different traditions, critiquing, giving and receiving feedback, seeing engineering as a 'team sport'	• Generating ideas: comes up with suggestions in a range of situations • Working in team: has good people skills to enable idea and activity sharing; good at giving and receiving critique/feedback	Asking students to brainstorm and accumulate ideas to solve problem	Student brainstorm the idea to solve the problem and making the decision toward the solution.
Improving	Making things better by experimenting, guessing, conjecturing, thought-experimenting, prototyping.	• Experimenting: makes small tests or changes; sketching, drafting, guessing, prototyping. • Evaluating: making honest and accurate judgments about 'how it's going'; comfortable with words and numbers as descriptors of progress.	Asking students question to check it they have applied some changes, the idea to improve in the future and check their drawing with the products to see the changes they made during construction.	Student test the model by experimenting it i.e. testing the waste collector machine in the tray that small debris were spread through the water. Then evaluated and suggest how to improve. Investigating the improvement during construction
Adapting	Making something designed for one purpose suitable for another purpose, by adjusting, reflecting, rethinking.	• Critical thinking: analyses ideas, activities and products; able to defends their own thoughts and ideas in discussion and also to change their mind in light of evidence. • Deliberate practising: disciplined; able to work at the hard parts.	Asking students to analysed the idea and observed the outcome of the test.	Students discuss and reflect their idea if the solutions were applied in real life context or using the real material to solve the issue.

Table 10 The Implementation of EHoM Adapted from Lucas *et al.* (2014)

Based on Table 10, this study allow student to have opportunities to practice each EHoM through EDP. Tasks are creates for students to practice and allow them to see how EhoM is employ during problem-solving process, and see their performance of each habits.

Integrated STEM activities allow students to use their interdisciplinary knowledge to solve challenges. Students can also utilise their prior knowledge, such as mathematics and science, to solve the problem. To provide an effective mathematical task, pedagogical teaching must account for primary school arithmetic skills. Students show this by visualising their solution or inventing innovative artefacts with measurement abilities. Students can use their scientific thinking skills to evaluate scientific facts from different data types.

4) Collaboration

To promote collaborative skills, this study focused on group tasks as collaborative learning opportunities that ask members to put in efforts to complete the tasks. The activities' tasks are designed following Cohen and Lotan (2014)'s three stages of group work. Firstly, students autonomously do the task by themselves in group task. Secondly, the tasks need to be completed by all members. Without the help of everyone, it cannot be done. Thirdly, the nature of the task needs to support students collaboration. Thus, the tasks require all group members' contribution (Topping *et al.*, 2011b) to solve specific SD issues using knowledge and EHoM.

Chapter 2 provides principles for practical group work (Cohen and Lotan, 2005; Blatchford *et al.,* 2007; Kutnick *et al.,* 2014), the facilitator plays a vital role in managing this collaborative learning environment. Teachers as facilitators, need to ensure that students have the opportunity to work independently and are encouraged to do their tasks and manage their own time (Baines *et al.,* 2009). When providing support to the students, advice and instructions from the teacher also need to be considered and sometimes limited in order for students to reach their learning goals (Baines, 2016).

To align with other elements of the framework, the problem to be solved in this research is a real-world environmental issues which are complex, requiring the application of knowledge related to the science curriculum (Austin, 2021) and skills to solve the problem. The benefits of collaboration can support learning and problem solving as well as promote SD as key competencies for SD (Wiek *et al.* 2011; UNESCO, 2017).

Based on Chapter2, collaborative skills showcase the behaviour and attitude that encompass the ability to assist verbally, assist with nonverbal, listen and pay attention, participate in discussion and negotiation, participate in the creation of outcomes, and have a good attitude towards working in a team. To investigate students' collaboration, four potential outcomes for team learning are: affective outcome, perceptual outcome, conceptual outcome, and behavioural outcome (Kayes and Kayes, 2006 cited in Kayes and Burnett, 2006). The affective outcome refers to the team member's satisfaction, which can be measured while Perceptual outcome refers to the problem-solving ability and critical thinking ability that can also be measured. The conceptual outcome is illustrated as the development of the task-performing ability resulting in the output level. Lastly, the behavioural outcome expresses the team's ability to complete tasks and improve task achievement (Kayes and Burnett, 2006). These outcomes can help shape the lesson plan and data collection plan to measure the improved collaboration ability in the group during participation in the intervention.

5) Gifted development: Promote Gifted Science Students

Gifted science students at the primary school level is the target group of this research. They are conceptualised as those who express high ability and interest in science. In this context, they were identified by their school. To develop giftedness in science, gifted characteristics are taken into account. Significantly, IPST's indicators of gifted characteristics (see section 3.1.2) are also involved to provide a precise focus when designing a suitable learning task for them. The gifted indicator stretches the skills that meet the students abilities. It is also useful in developing collaborative challenging learning tasks which are complex and have extra contents in an enrichment practice that differentiated from typical classroom. This is to support students for cognitive, affective and social emotional needs. Considering this element is helpful to promote students' engagement and motivation as it meets their learning needs,

Following scholars' model for talent development, this study create STEM - ESD experiences through PBL approach to foster gifted students knowledge, awareness and skills. This is to ensure that the STEM activity clearly demonstrates the potential tools to enhance ability that continuously support gifted learners in science. Apart from engaging them with scientific knowledge, these STEM activities aim to develop their proficient skills and aptitude. However, not all indicators support the intervention. After analysing indicators, fewer indicators can be adopted and embedded in problem-solving activities. As a result, tasks for students in activity are designed to engage students' interest, encourage students to use the skills, show them the value of learning, and offer opportunity for self-reflection.

The example of indicators used in the intervention is embedded in the flood activity where the scenario occurs in Mango city. The students will be given the precipitation rate data so that they can interpret and infer the knowledge hidden behind the graphical data. At the same time, they must predict the future scenario and prepare for future precipitation. This is how the lesson plan is designed, and it asks students to practice one of the data assessment skills. Inevitably, those skills and aptitudes must be applied to the intervention activity.

3.4 Summary

This chapter establishes a connection between theory and practise based on the literature study. It also examines practise and theory in the realm of gifted education, with a particular focus on the scientific gifted attribute. It examines the theoretical dimensions of giftedness and underscores efficacious approaches for their cultivation within the framework of SD. By facilitating the integration of sustainable development (SD) principles into the curriculum of gifted science students via problem-based STEM learning, the conceptual frameworks were established. The discussion of a theoretical structure provides guidance for developing STEM intervention to guarantees a coherent and significant incorporation of scholarly viewpoints into pragmatic teaching methodologies.

CHAPTER FOUR: METHODOLOGY

Education for Sustainable Development (ESD) is crucial for enhancing knowledge and skills and fostering responsibility. In Thailand, where an official ESD curriculum is absent, the Sufficient Economy Philosophy (SEP) serves a similar purpose. This study addresses the gap in research by exploring the integration of ESD in primary school STEM education, focusing on the pedagogical potential of STEM activities. The 'Young Engineers for Sustainability' (YES!) programme is designed to incorporate environmental sustainability, SDGs, STEM problem-solving, collaboration, and gifted development for gifted science students. The study, employing a bricolage approach, reveals that STEM problem-solving activities effectively promote students' SD knowledge, competencies, and engagement in sustainable practices. This chapter discussed all the methods and research approaches in this research.

4.1 Philosophical Underpinning to This Research : Constructivism and Interpretivism

According to research questions that explore how does environmental sustainability issues be integrated in STEM based learning and how it can promote gifted science students in Thailand to learn knowledge regarding SD as well as Problem-solving skills and collaboration. To explore students learning regarding knowledge and awareness for SD and enhance of skills from STEM problem based learning in Thailand, it is critical to construct the research framework with a comprehensive comprehension of philosophical aspects of research encompass ontological and epistemological perspective.

Ontology and epistemology view ‘reality’ differently. To research existence is ontology (Crotty, 1998). Following the ontology, the researcher examines how things seem and work in the real world. The research embraces a constructivist ontological perspective, acknowledging that the collective perceptions and interactions of students influence the reality of learning STEM and ESD. The students and teachers' views, which are the product of the experiences and interpretations of students and teachers involved in STEM interventions, can shape the development of STEM interventions rather than being a solid reality. The philosophical stance underpinning this research directs the research to seek reality by revealing the socially constructed realities of STEM-ESD intervention as perceived by students and teachers. By doing so, it enhances my comprehension of how to develop more effective teaching STEM programmes for gifted students to learn problem-solving skills and collaboration while learning for SD.

Epistemology, according to Burrell and Morgan (1979), is concerned with knowledge's foundations—its nature and forms, how it is used, how it can be received, and how it is communicated. According to Guba and Lincoln (1994), epistemology examines the link between the would-be knower and what can be known. In other words, epistemology requires the researcher to ask what you know and how you know it. This study recognises the multifaceted nature of acquiring knowledge within the realm of STEM education and ESD from an epistemological standpoint and a nuanced comprehension of students' and teachers' perspectives is necessary to comprehend an effective learning. This study embraces an interpretivist epistemological stance and acknowledges the socially constructed and context-dependent nature of students' and teachers' perspectives on STEM learning for SD. This epistemological position is consistent with the qualitative design and emphasises the significance of investigating and interpreting the subjective viewpoints and experiences of gifted science students and teachers in a STEM intervention in Thailand. This is because people are complicated and diverse, and habitual information must be understood. The qualitative data collection and analysis methods for inquiry can be used in an investigation that solicits the perspectives of both students and teachers.

4.2 Positionality in Research

In educational research, it is recommended to consider the positionality of a researcher as it can impact the research (Holmes, 2020; Secules *et al*., 2021). The term positionality refers to an individual's worldview as well as the position scholars take on a study topic and its social and political environment (Foote and Bartell, 2011; Savin-Baden and Major, 2013; Rowe, 2014). In other words, the researchers' experiences in culture, society, and politics can affect their views and beliefs, influencing their research position. Rowe (2014) suggests that the notion of positionality pertains to the researcher's status as of being an insider or outsider in regard to the community involved in the investigation.

Smith (1999) stated that the positionality of individual researchers influences the research process, their outputs, and their interpretation of others' research. Especially in action research, Rowe (2014) confirms that positionality impacts how the study is conducted and dictates the outcomes and voices that will be reflected in the final reports or decisions. Moreover, positionality influences the 6 critical dimensions of research in the study topic: epistemology, ontology, technique, relation to participants, and communication (Secules *et al.,* 2021). Almost every part of the research relates to positionality, and equity issues may arise, thus, positionality is a crucial tool for reflecting on and dislocating privilege while working on equity research (Secules *et al.,* 2021). The importance of being 'reflexive' in research lies in ensuring that researchers are aware of and consider the influence they may have on the research process and outcomes, due to their own perspectives and cultural standards (Smitt, 1999 in Berger, 2015).

As positionality is recognised as the cause of bias and inequality in research, I consider my positionality through reflexivity, which is a critical approach for quality control, and understanding how the researcher's features and experiences may influence it (Berger, 2015). Savin-Baden and Major (2013) recommend that the strong positionality statement to include a description of the researcher's lenses (e.g., their philosophical, personal, theoretical beliefs, and perspectives on the research process) as well as potential influences on the research (e.g., age, political beliefs, social class, race/ethnicity, gender, religious beliefs, previous career). Besides, Creswell and Creswell (2018) suggest that researchers must include statements clarifying how prior experiences with the research problem, participants, or settings may influence their perceptions during the research process. This section will outline the elements that I deemed relevant to my investigation.

As this research includes gifted science students' and teachers' viewpoints since it can provide thorough insights from participants. I am involved in this study in multiple way; doing the literature study, framework and intervention development, examining curricula and creating interventions, implementing the programme, seeking information and gathering data, and interpreting data during analysis.

About the insider and outsider positions, according to Savin-Baden and Major (2013), a category that could affect my view and impact the research work is identified. Academic experiences are considered significant as I was born in Thailand and grew up in a Thai public school from kindergarten to undergraduate. I experienced traditional learning in mainstream education before Thailand's education reform through a more student-centred learning style (Ministry of Education, 2008). My own academic experience impacted my research on the inclination to establish an educational setting whereby students are given the opportunity to collaborate, share common objectives, and engage with classmates, as is instructed in collaborative learning.

My academic background influence my research goals and interest. I experienced various extracurricular activities regarding biology during high school. It enhanced my academic experiences and my aspiration to learn science. A student's life encompasses academic achievements, the formation of friendships, and active participation in the community. My undergraduate education fostered a strong connection with the natural world. In a microbiology course, I enjoyed field trips. The collaborative work with peers is a component of several modules. Moreover, my post-graduate study had a profound influence on me when I relocated to Sweden. I was motivated to actively participate in class, with numerous opportunities for collaborative works including PBL. Furthermore, pursuing a PhD in the UK differs from my prior academic experiences as it shifted from learning science towards education. The educational research I conducted enabled me to delve into social science research and produce scholarly work with a specific focus on education. The topic of my research derives from the questions that have arisen from my previous job experiences and academic background.

Conversely, my professional experiences have enabled me to understand Thailand's educational administration. My work in mathematics and science talented development programmes involved supporting students with national identification and provision scheme, learning resources, school support, as well as developing enrichment programmes for gifted classrooms and supporting teachers with professional development. This bring up my motivation for research. I endeavoured to improve enrichment programmes within my field and interests. Additionally, participating in climate change campaigns and growing up in an environmentally conscious neighbourhood influenced my research topic and methods.

> *Curriculum developers intentionally create curriculum materials and strategies for others to use in the instructional arena. The important ideas here are 'for others to us' and 'instructional.' Curriculum developers can be textbook writers, teachers who work on school curriculum committees, curriculum specialists who work for private educational organizations, or concerned citizens who design instructional materials for homeschooling* (Schiro, 2013, p. 8)

The definition of 'curriculum developer' reflects my thoughts about how I see myself in the future. Collaboration with educators and learners helps me grasp the precise information needed to answer this research issue and improve Thai educational provisions. It can also help the gifted programme adapt to 21st-century educational trends. According to the SDGs, this alignment is part of promoting Thai education for SD and supporting lifelong learning for its students. As an educator, I am starting off by offering programmes to gifted science students, aiming to have a good influence on future generations.

Since I have had no personal relationship with research participants before, I am confident that the information I obtain may not be impacted by personal biases. I have also reduced my personal biases towards the intervention I created by asking teachers to collect the data while observing me. Different tools are combined to reflect each component of knowledge and inform its validity. However, as a Thai student in the United Kingdom, I am able to speak Thai and English. All research is conducted in Thai, as participants are Thai and Thai is the official language in Thailand (Premsrirat and Burarugrot, 2021).

I recognised that my worldview affects several steps. In every step, I followed research integrity to preserve the standard of my research while decreasing biases and considering research ethics to provide fairness by honouring the participants' perspectives.

4.3 Restatement of the Research Questions

Scholars suggests that research questions can guide students' studies the scope of issue, area of literature study which can be more specific to a few questions regarding what will be investigated (Bryman, 2016 ; Creswell and Poth, 2018). In addition, Punch and Oancea (2014) conclude that research questions direct researchers to focus and organise the data, as well as constrain their thoughts during the planning stage. The research questions guiding this study are as follows:

1. How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?
2. How does the implementation of integrated STEM-based activities enhance awareness of sustainable development and improve problem-solving and collaborative skills among gifted students in science?

4.4 The Research Design

Given my interpretivism paradigm and need to engage with qualitative data, the research design is based on this approach and discussed next. The research is designed at the outset to clarify the theory and methods required to conduct my research. According to Harwell (2014) research design in education can have multiple connotations depending on the context and different studies use different framework. Research design includes every stage of the study, from problem formulation to literature evaluation to research questions, data collection, data analysis, and conclusion (Harwell, 2014). Creswell and Creswell (2018) add that research design includes variables, hypotheses, experiments, methods, and statistical analysis. Following these definitions, my research design is framed to plan the promising study at the early stage of the research.

Once again, according to the research questions about how and in what way the STEM problem-solving programme enhance students' knowledge and skills from the integration with environmental sustainability issues, qualitative study is the centre for the inquiry. Based on previous research in ESD, the knowledge construction process through planning-action-observation-reflection in a natural classroom environment is attractive as the researcher can investigate the practice to comprehend and enhance it (Tejedor *et al.,* 2019). Interventions were conducted, and viewpoints of teachers and students were gathered (Amos and Levinson, 2019; Costa *et al.,* 2023; Del Cerro Velázquez and Lozano Rivas, 2020; Hsiao and Su, 2021; McNaughton, 2012; Tejedor *et al.,* 2019). STEM education research regarding students' development also informs the investigation of knowledge and skills development (Cotabish *et al.,* 2013; English *et al.,* 2017; Franco and Patel, 2017; Gao *et al.,* 2020; Guzey *et al.,* 2019; Hiğde and Aktamış, 2022; Karahan and Ünal, 2019; King and English, 2016). To understand the pedagogical approach for investigating student learning, data collection and analysis methodologies must be identified throughout intervention implementation. My research design is constructed as illustrated in Figure 12.

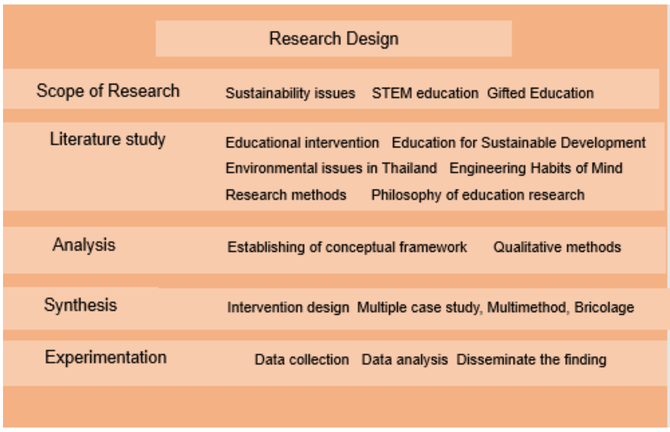


Figure 12 Illustration of Research Framework

Figure 12 shows my research framework which comprises an exploration of STEM Education, ESD, and Gifted Education, with an emphasis on environmental issues in Thailand, EHoM, research methods, and the philosophy of education research, that are the subjects of the literature review. The analysis phase involve the decision to employ qualitative research and the development of a conceptual framework. During the synthesis phase, intervention design and the strategic selection of research methods, such as multiple case studies, multi-methods, and bricolage, are of particular importance. The experimentation phase comprises the gathering and analysis of data, as well as the distribution of the results. Based on the framework, the research procedures are established in Figure 13.

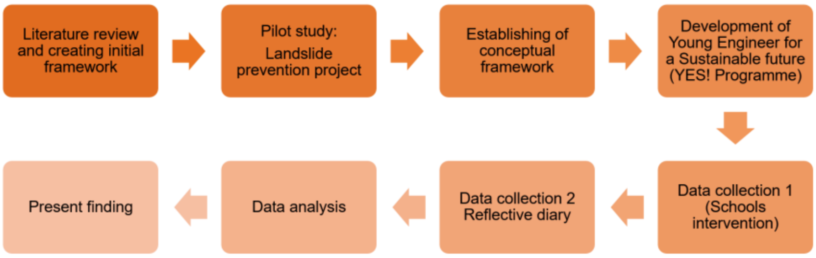


Figure 13 Illustration of Research Procedures

Figure 13 organises the research procedure in stages, starting with the literature study to inform and define the basic conceptual framework. Next, the pilot phase commences, enabling the refinement and adjustment of the research approach, including the intervention design and data collection tools. A STEM problem-solving intervention is implemented in school for data collection, which involves two phases. The summary of research is illustrated in Table 11.

Summary of Research		
Research Approach	Multiple Case Studies	
Methodology	Bricolage	
Participants of research	Students at primary school level and School teachers	
Sampling Method	Purposive sampling	
Research Context	Gifted Science classroom in Thailand Primary school	
Phase of research		
School intervention	1) Students' engineers' logbook 2) Drawing and Photo of innovative products 3) Pre intervention questionnaires 4) Post intervention questionnaires	Students (n < 260)
	5) Teacher interview 6) Teacher observation form	Teachers (n = 16)
	Analysis tool: Thematic analysis	
Student Diary	Data collection tools: Students' reflective diary	Students (n = 32)
	Analysis tool: Thematic analysis	
Data analysis	Thematic analysis	
Reliability and Validity	Bricolage, Critical friends, Research transparency	

Table 11 Summary of Research

According to Table 11, this research employs multiple case studies with multiple methods and a bricolage approach is adopted for adaptability and connecting knowledge together. Two phases of research are designed and different tools are used to collect data from participants. The next section discusses the research methods used in the study.

4.5 Research Methods

In the previous section, the philosophical standpoint was described, and the choice of methodology was justified. Due to the complexity of the research itself regarding teaching and learning pedagogy in SD for gifted students in Thailand, problem-solving skills, and collaboration are paramount. Based on the interpretivism qualitative paradigm, three elements of the research approach are significant and are described as follows:

4.5.1 Case Study Approach

Scholars emphasise the benefit of case studies in research (Noor, 2007; Takahashi and Araujo 2020). Yin (2014) indicate that case study can be used to investigate real – life context. Cases provide in-depth information (Creswell and Poth, 2018), as they 1) contribute to theory through propositions; 2) serve not only to confirm knowledge, but also challenge and overturn preconceived notions; and 3) the complexity of the phenomena studied, not an intrinsic limitation of the method, makes it difficult to summarise their conclusions (Takahashi and Araujo, 2020). So, the research can conduct in-depth, multi-faceted investigations of difficult problems in the context of their actual-life occurrences in business, law, and social science (Crowe *et al*., 2011; Takahashi and Araujo, 2020). Case study can explore a specific issue, problem, or programme, as well as the positives of a case study (Hays, 2004). These benefits made the this approach attractive for this research, as the research question is complex and specific to context of gifted classroom in Thailand.

Case studies use a variety of evidence to provide enough descriptive information for a thorough discussion and powerful interpretation. Yin (2014) indicates that multiple sources of evidence help gain validity in a case study. This approach is currently a prevalent research approach in the health and social sciences as well as applied and natural sciences involving areas such as criminology, medicine, psychology, political, cultural, sociological, and educational studies, especially interpretive work (Creswell, 2009; Rozsahegy, 2019). Qualitative methods were employed, such as questionnaires, audits, and the analysis of routinely collected healthcare data (e.g., interviews, focus groups, and observations), to obtain a full picture of the case and provide the evidence (Crowe *et al.,* 2011). With this approach, the problem of not having enough cross-referenced data for credibility is avoided (Creswell, 2009). Although the qualitative method is more common, it can also be used with quantitative methods (Hays, 2004).

This study focuses on the educational setting related to gifted science students in Thailand within a specific environment, which is gifted classrooms in Thai primary schools. A gifted classroom is undoubtedly an ideal setting for conducting a case study, given its unique characteristics and learning dynamics. The intervention is introduced in school, where students' and teachers' perceptions about the intervention and experiences are investigated. Following Hays's (2004) guidance on initiating case study research, the data source must be considered once the site of study is identified and the issue to study is already established from the research question. In consequence, the data source for this research involves students and teachers. Despite the benefits mentioned above, numerous issues could arise when employing the case study method in this study. Potential pitfalls, such as ethical concerns, rigor, or sample size (Crowe *et al.*,2011), are common challenges in case study research. However, there are strategies that can be employed to mitigate these issues and enhance the quality of the research. Based on Creswell and Poth (2018), case study can be done by selecting purposeful sampling, using different data sources , providing context of case, analysing within or cross case, and providing description pf cases and themes.

Limitations of the case study may be due to the small-scale structure of the design (Peel, 2020), which, on the other hand, allows the researcher to cross multiple fields and examine complicated subjects in depth. This can be mitigated by focusing on the research question and adopting methods to explore the answers (Crowe *et al.,* 2011). In addition, because case study research is context-specific and time-limited, the emphasis on trustworthiness for this sort of research is not on demonstrating that the findings can be replicated (Peel, 2020). Even though, the finding cannot be generalised to place, site or individual but can be generalise findings to theory (Creswell, 2009) and demonstrate the in-depth evidence to informs other research. Takahashi and Araujo (2020) argue that case studies offer valuable insights into the existence of multiple ideographic variations and contribute to the practicality of social science. When talking about generalisations, they should be seen as defining the research parameters. These parameters show the limits of the information that can be made and used in certain places and times (Takahashi and Araujo, 2020).

Lastly, as one single case study may be limited to answer the complex situation occurring in gifted classrooms, multiple case studies are an option. As Stake (2005) mentioned, multiple cases as a collective case study that involve many instrumental cases for study are believed to improve understanding and theorising the broader collection of situations. As recommended by Rozsahegy (2019), multiple-case designs, which overlap with collective case studies, may be needed for more complicated studies. Therefore, in recognising the limitations and drawbacks above, this study considered multi-methods, as discussed below.

4.5.2 Multi-Methods

From the previous section, the case study approach is beneficial for investigating complex phenomena, such as teacher and student perceptions and learning outcomes from educational interventions. Qualitative methods can be employed to investigate the perspectives and opinions of research participants. Thus, different qualitative methods were advantage in reducing the limitation from using single methods, gaining multiple viewpoints of research participants and making sense of human experiences and for triangulation (Cohen *et al.,* 2007; Creswell, 2009; Wyatt and Saidi, 2021; Yin, 2014).

The used of multimethod is found in the research regarding STEM education and EHoM and Gifted education. Even though, Lee and Gentry (2023) reported that the combination of 4 and 5 methods is rare but preferable in research. Example of that is found in the study of Handson *et al.* (2021) in which observation, group discussion, survey and artefacts were used to gain in-dept of single case and gain validity. Similarly, Karatas-Aydin and Işıksal-Bostan (2023) employed tools such as worksheets, sketches, audio and video recording of learning process to observe students' application of knowledge and display of EHoM.

Based on the research questions, the research output must clarify how a STEM-based intervention might include real-world environmental sustainability issues, enhance knowledge and awareness of SD, and expand 21st-century skills for gifted students in Thai primary schools. This process requires multiple methods to find the answer based on qualitative inquiry. However, small number of close end questions were adopted for surveying the issues students interest. The knowledge gathered from the whole process is expected to answer the fundamental research question in a qualitative manner. Therefore, more than one single qualitative method was employed including interviews, open-ended questionnaires, observation, photo, innovative products, engineer logbook and reflective diary to collect data from the research participants.

As illustrated in Table 11, there are two phases of research were conducted to shed light on the different aspects that answered the research question. In phase 1, YES! programme intervention was implemented in the classroom to investigate the effect of the intervention. Students are involved as intervention participants in this phase, while schoolteachers observe the intervention, inform students' learning, and reflect on their perspectives regarding the programme. At the end of the intervention, the teacher informed me of the students' opinions and reflected on the intervention through a semi-structured interview. Thus, in this phase, thematic analysis was used to analyse the qualitative data, however, the statistical method was adopted for the quantitative data analysis in only one additional section in pre intervention questionnaire.

In the second phase, students' perceptions were captured through reflective writing after joining the school intervention. The reflective diary mainly presents the students' ideas and opinions regarding the intervention and explores how students connect the knowledge gained from the intervention with their daily lives. The details of each methods will be discussed in more detail later.

4.5.3 Bricolage: Using Tools at Hands and Creating A Big Picture

From previous sections, this research adopt case study and multiple methods. Many studies report the use of triangulation in multimethod research (Carter *et al.*, 2014; Creswell, 2013; Cohen, 2007) which refers to the use of numerous methods and multiple sources of data to confirm the result (Hays, 2004; Creswell, 2009). As a result, findings from case studies that make use of triangulation of methods and sources are more likely to be reliable and believed to increase validity (Hays, 2004).

According to the research questions, this research seeks to understand the perceptions of teachers and students towards the STEM problem-solving intervention, which involved with cross disciplinary and are broad aspects. The research participants are gifted students in science and their teachers. Based on the research framework, several tools such as interview, observation, a pre- and post-intervention questionnaire, photo and students' sketch analysis, and an open-ended reflective diary are adopted to provide multiple sources of data.

Additionally, the research emphasises Thai contexts, including school intervention and writing at home diary. Schools are located in many regions in Thailand, such as the capital, suburban areas, and secondary provinces. Students are mixed with both boys and girls in some schools; students are unisex at one school; and their ages are range from 9 to 12 years old as they are students from fourth to sixth grade. School types include private and public schools. Those schools are monolingual and bilingual schools. The school interventions involved four environmental issues in the problem-solving scenario, which are landslides, floods, droughts, and plastic pollution in rivers and oceans. Science and mathematics teachers are also involved as observers and interview participants. Artefacts such as photos, narrative discourse, and writing pieces are collected. The bricolage offers the use of all tools that are available (Wyatt and Saidi, 2021), and I get to gain knowledge by making meaning from the data I collected.

According to the concept of triangulation, I consider that it is possible to seek information to answer a research issue, and it contributes to the creation of rigour if I can obtain the same results from many techniques. Consequently, in my research design, various instruments were used to investigate certain characteristics. However, I begin to consider bricolage as there are issues with triangulation, and I have discovered that my study design needs to be flexible according to Covid 19 situation, and that I have uncovered other perspectives as a result of the messiness of my research. I considered that my data informed different perspectives and could contribute to practice in the educational field.

As a result of that, triangulation is viewed as less appealing for me as priority in my research. Many scholars report that the issue of triangulation, such as the broad interpretation that has been criticised by some academics, and the conflict over the context of the tool for triangulation, such as observation or interview, have lost clarity and become too broad to be used as a tool for triangulation. Many researchers believe it has a broad meaning that could refer to meaninglessness (Blaikie, 1991; Fetter and Molina-Azorin, 2017). Fetter and Molina-Azorin (2017) claimed that triangulations are no longer served in the field of research that combines several methods, and they ask for other approaches. More importantly, according to Freeman (2020), who did the bricolage research in geography, when conducting research, triangulation can conceal a significant amount of complexity as well as reality. According to his claims, we must embrace the complexity and not oversimplify the details of the phenomenon under investigation. By adopting bricolage as a methodology, Ben-Arsher (2022) suggests it is significant to understand the fact that no correct accurate depiction of an event exists. Bricolage method, is grounded in a naturalistic interpretive standpoint, which posits that inquiries should be conducted with a little intervention in the natural world (Ben – Arsher, 2022).

Some scholars inspired me how to adopt bricolage to observing the reality of complex phenomena. Odegard (2019) has opted for a combination of data gathering and creative methodologies that assist her to conduct research from multiple angles and see different perspectives regarding early childhood education. Considering students as individuals that can provide different perceptions, she described the stage of doing bricolage by immersing herself in data, taking time to touch upon, sense, and develop bricolage, taking an ongoing process of research, and connecting pieces of ideas when combining thinking and writing (Odegard, 2019). Freeman (2020) envisioned collage as a new framework that goes beyond triangulation and better allows for the complexity of conducting various techniques of research, like in his field of geography. His tools are expanding and have provided him with more than the starting point, and he has connected them all to provide an extra view of the research topics. Ben Asher (2022) encountered methodology difficulties. He used bricolage to make the research flexible and collect data regarding the fisherman's fight in Israel. During Covid – 19, Bueddefeld and Duerden (2022) encounter the difficulties and bricolage provide them with flexibility to conduct the research and gain knowledge. Sharp (2019) adopt bricolage in history education as extending from mixed methods. He reports the gain in confidence in selecting the appropriate tools for the research project.

I discovered evidence in science research, and it appears appealing, and there is a call-in science educational research to use bricolage (Steinberg and Kincheloe, 2011). Kincheloe (2005) proposed that researchers actively design their research methods using existing tools rather than passively accepting existing methodologies that can be applied anywhere (Cilesiz and Greckhamer, 2022). Scholars encourage it as an excellent method for going beyond typical methods or templates (Kincheloe, 2005; Pratt *et al.*, 2022).

To understand bricolage, Denzin and Lincoln (1994) described that bricolage is the incorporation of multiple methodologies, empirical data, points of view, and observers into a single investigation to increase the rigour, breadth, and depth of any investigation. Bricolage is an approach to qualitative research that is flexible, open-ended, multi-perspective, multimethod, and multidisciplinary (Cilesiz and Greckhamer, 2022). One reflection on bricolage research is found. It is a purposeful and thoughtful engagement with and proactive assemblage of analytical methodologies to address the specific goals and challenges of their study (Pratt *et al*., 2022). Additionally, research writing where the bricolage methodology is adopted can be found in five areas including 1) theory, 2) methodology, 3) interpretation, 4) political stances, and 5) narratives (Denzin and Lincoln, 2011). I employ methodological bricolage as an analytical alternative to methodological templates, following the approach proposed by Denzin and Lincoln (2011) and Pratt *et al*. (2022) by using multiple tools to collect multiple perspectives and connect them as the answer.

I believe the findings of my research can be elucidated through bricolage. Denzin and Lincoln (1998, 2011) indicate that researchers who employ this method embrace the idea that the research is subjective due to the researcher's own history, biography, gender, socioeconomic class, colour, ethnicity, and the individuals inside the society under investigation. The context of seven schools may provide a different or similar perspective in terms of how they applied EHoM or expressed their knowledge and attitude towards SD while asking to reflect on competencies regarding SD. The outcome will be determined by the evidence analysis with Bricolage. Individual pre- and post-intervention questionnaires might provide insight into the change in knowledge and attitude among the eight classrooms. The performance of student problem-solving skills can be measured using the team logbook, drawing, and photo of the product, which are all linked and represent the outcome of collaborative problem solving. In addition, teachers' opinions can be collected from two more sources: the feedback section of the observation form and the interview. All those pieces of knowledge are interconnected, and I need to present them as a whole. My role is to assemble facts from the various sources, make sense of the findings of this study, consider the data as a mosaic that paints the stories.

It appears that bricolage may be preferable as not all methods produce the same results because perspectives differ. Bricolage is useful in dealing with the ‘thickness of the research,’ as Lambotte and Meunier (2013) defined what we are unable to observe and what is transparent. Bricolage, allows me to piece together information that reflects the reality found in the context of research related to exploration journeys and constructing interventions and experiments. At this point, the outcome is unpredictable until I reveal it through the lens of Bricoleur, who used tools and materials available to him (Levi Strauss, 1966), as opposed to the practice of following standard procedures, template or checklist protocol (Kinchelo, 2005; Rogers, 2012). Before engaging in bricolage, researchers should analyse and assess concepts from many fields in order to find field-specific presumptions and novel theories, approaches, and techniques (Wyatt and Zaidi, 2022).

Due to its numerous tools and many benefits, bricolage research became realistic and inventive during the COVID-19 pandemic in schools. Bueddefeld and Duerden (2022) also confronting with this issue. Bricolage allowed the investigation to adapt to constrained money, time, and materials in response to the unique demands of this research context, especially the research post COVID-19. The intervention in eight classrooms does not constitute a comparison with the control group and students from those classrooms are from different provinces in Thailand. They face different experiences regarding environmental sustainability issues (See section 4.6.1 and 4.7). I can observe that the reality exists as if the intervention helped them practice and deliver knowledge. Different tools allowed a holistic evaluation of the study topic as illustrated in Figure 14 below.

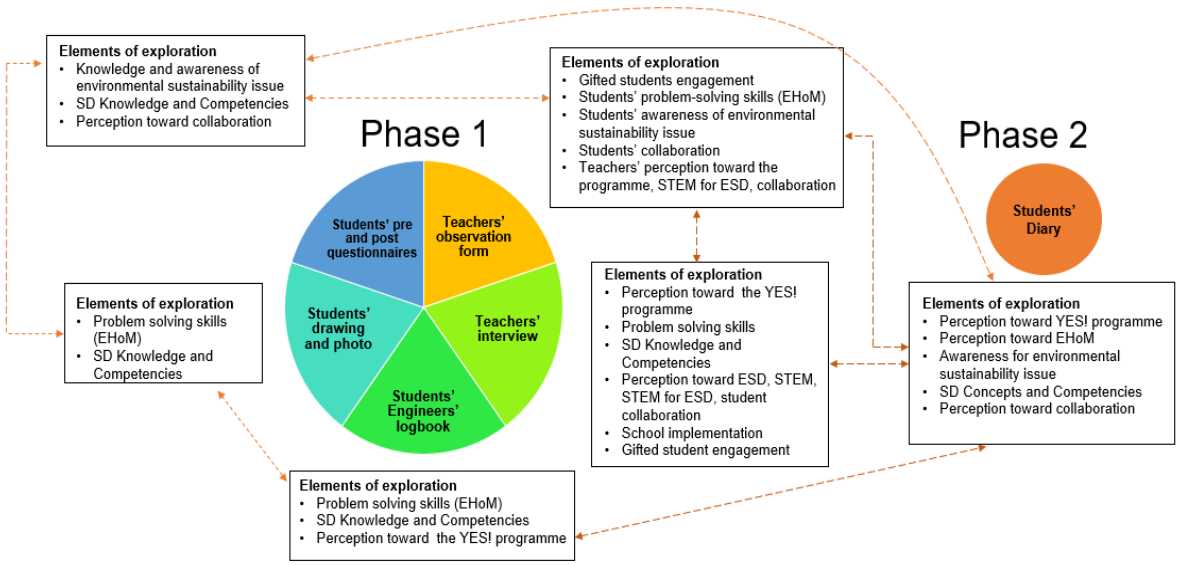


Figure 14 Summary of the Research Methods According to Bricolage Approach

From figure 14, tools and perspectives of research are presented and connect as big picture provide the idea of how the study answer the research questions. For all questions about the validity, and trustworthiness of this research, the methods and procedures are explained thoroughly in the following sections. To increase thickness in terms of how I maintain the validity of the research, the bricolage is still able to provide the rigour of research based on the use of multi-methods and multiple case studies. The use of critical friends and peer support in checking and reviewing themes is also helpful, as is peer translation and language cross-checking to find solutions to the issue of rigour.

4.6 Research Participants and Sampling

Sampling techniques are identified to select the participants in each phase to provide data by using different data collection methods. The participants and sampling methods of phase 1 and 2 are described in the sections below.

4.6.1 Participants and Sampling (Phase 1)

In the school intervention (Phase 1), it is naturally impossible to obtain the data of all students, neither from the national gifted programme nor from the schools' gifted programme. However, this research recruited gifted science students from school programmes, they are the target group of this study. The sampling technique followed the purposeful sampling strategy (Patton, 1990), especially intensive sampling (Suri, 2011). The sampling strategies also adopted random cluster sampling. According to Gaciu (2021), random cluster sampling is appropriate for research contexts in which a complete list of participants is impossible to obtain, particularly in school-based research. So, a group of students is chosen rather than individual students, thus one gifted classroom among many gifted classrooms in school was selected. The criteria are 1) they are selected to study in gifted science and mathematics classrooms by school programme, and 2) they must be students in grades 4–6.

Then, I contacted ten schools from 31 schools that are school partners of the IPST gifted programme via the point of contact teachers of the school gifted programme. I made the request to conduct the research in schools when COVID-19 eased and schools were permitted to conduct face-to-face learning, and all academic activities were allowed following Ministry of Education policy. Once the school principals give permission, teachers who are interested in the research are involved in the recruitment process by asking gifted classrooms that intend to participate in the research. The school administrators and gatekeeper, teachers, helped recruit the classrooms and asked for volunteers because the researcher was unable to reach students individually. The application form was sent to the students and their families, as well as the consent form and participant information sheets. They also asked for their voluntary and parental permission several weeks before the intervention. As a result, seven schools have expressed an interest in participating in the study. The year group and gifted class in each school were assigned at random; for example, students in school A were in year 6, and students in school F were in years 4, 5, and 6. As a result, student participants had a group of mixed characteristics such as age, identity, gender, school, origin, and economic status. The profile and students' stats are identified in Table 12.

No.	Name of school	School location	Code name	Type of school	Gifted programme	Year of study	Number of students	groups	Number of Teachers involved in observation	Number of students
1	Ban Sankong school, Chiang Rai	Chiang Rai, North of Thailand	A1	government schools	Sci Math gifted classroom	Year 6	32	6	1	F: 17 M:15
2	Anuban Chiang Mai, Chiang Mai	Chiang Mai, North of Thailand	B	government schools	Sci Math gifted classroom	Year 5	35	7	1	F: 21 M:14
3	Ban sankong school, Chiang Rai	Chiang Rai, North of Thailand	A2	government schools	Sci Math gifted classroom	Year6	32	6	1	F: 16 M: 16
4	Anuban Ratchaburi, Ratchaburi	Ratchaburi, West of Thailand	C	government schools	Sci Math gifted classroom	Year 6	35	7	2	F: 16 M:19
5	Wat donthong school, Chacheongsao	Chacheongsao, Central of Thailand	D	government schools	Sci Math gifted classroom	Year6	35	6	2	F: 22 M: 13
6	Wattana wittayalai, Bangkok	Bangkok, Capital of Thailand	E	Private school (Single sex, all girls)	ISPT classroom	Year 4	30	6	2	F: 30
7	Saritdidet school, Chantaburi	Chantaburi, North of Thailand	F	government schools	Sci Math gifted classroom	Year 4, 5, 6	30	6	2	F: 18 M:12
8	Phol wittaya,Sonkla	Songkhla, South of Thailand	G	Private school (Bilingual school)	Sci Math gifted classroom	Year 4,5	29	6	1 (2 for interview)	F: 17 M:12

Table 12 Student Participants

From Table 12, student participants are 258 in total in which 101 of them are male while 157 of them are female. Students from four schools are from year 6, while only two school are years 4 and three school are include year 3 students. Age of students range from 9 to 12. Number of students per classroom are range from 29 to 35. The schools located in different provinces; Capital city, Big provinces and small provinces (See section 4.7 Research Context). In addition to the student participants, the schoolteachers were also rich informants in the research who can provide insight into the intervention and different gifted education aspects. They were involved, observed the students using an observation form, and reflected their views in a semi-structured interview at the end of the intervention. They are gifted teachers who are involved in the teaching and learning of gifted science students. They can be science or mathematics teachers, or teachers who organised and facilitated the provisional gifted science classroom in those schools.

Aside from contacting schoolteachers directly for participation, the snowball technique was also used to recruit the teacher participants. Snowball sampling is a widely used sampling approach in qualitative research that relies on networking and referrals as key qualities (Parker *et al.,* 2019). Suri (2011) suggests snowball sampling entails asking key informants for details on other 'information-rich instances' in the field. Due to the limited number of gifted teachers in the school and their availability, teachers were recommended by the head of the IPST gifted programme, the point of contact teachers, the head teachers, and the school principals. 14 teachers are all those who volunteered to join the school's intervention. However, for the interview, the date and time are set as an agreement between the teachers and researcher at their most convenient time. So, the interview conducted after the intervention lasted from one week to two months. The teachers' profiles are listed in Table 13 below.

School	Teacher name	Gender	code	Subject teach and other roles	Year of experiences
A	Busaba	Female	T01	Mathematics, Head of gifted programme	25
B	Anya	Female	T02	mathematics, Head of academic department	20
B	Kirk	Male	T03	Science	4
A	Aran	Male	T04	Mathematics	9
C	Lyla	Female	T05	Mathematics, Head of gifted programme	18
C	Lalita	Female	T06	Science	14
D	Kanda	Female	T07	Science, Head of gifted programme	15
D	Chinda	Female	T08	Science	35
E	Arisa	Female	T09	Science	18
E	Dina	Female	T10	Science	13
F	Anan	Male	T11	Mathematics	18
F	Thana	Male	T12	Science	13
G	Mintra	Female	T13	Science, Head of academic department	20
G	Suda	Female	T14	Science	1 months

Table 13 Teachers' Profiles

Table 13 shows that there are 14 teachers in total. 10 of them are female and 4 are male. The proportion of female teachers in primary schools in Thailand is typically higher than that of male teachers. According to the UNESCO Institute for Statistics (n.d.), 68.52% of primary school teachers in Thailand were female in 2023. Of these 14 teachers, 9 teach science subjects, while 5 teach mathematics. Their roles include classroom teachers, subject teachers, heads of academic departments, and heads of school gifted programme. Teaching experience among these teachers ranges from 1 month to 25 years. All participants have received training from sources such as schools, universities, government educational agencies, private organizations, and the IPST. Only one teacher has never attended IPST gifted programme professional development sessions. Differences in background of the teachers, such as role, experience, and location, may influence their responses and provide varied perspectives for this study.

4.6.2 Participants and Sampling (Phase 2)

Students who are participants in phase 1 were invited to join this phase as they are a valuable source of information to reflect on their learning experiences and their perceptions of the YES! programme. In each school, students were asked if they were interested in writing the diary without any restriction on their age or gender. At the end of YES! programme, at least four students were in each school were asked from each classroom and 40 students volunteered to participate in this phase. While at the other school, students came from different years and would like to join this phase, and 14 diaries were collected. So, from 8 classrooms in 7 schools, there are 40 diaries in total. The student profiles are recorded in table 14 below.

School	Number of students	Year of Study	Age range	Gender
A (1)	4	6	11-12	F:2 M: 2
B	4	5	10-11	F:2 M: 1
A (2)	3	6	11-12	F:2 M: 2
C	3	6	11-12	F:1 M: 2
D	4	6	11-12	F:3 M: 1
E	4	4	9-10	F:4
F	14	5-6	10-12	F:8 M: 6
G	4	5	10- 11	F:4
Total	40			F:27 M: 13

Table 14 Students Participants in Phase 2

Students were informed about the classroom intervention and reflective diary at the beginning of phase 1. They were asked again if they would like to join the reflective diary to share their experience after participating in a one-day programme. They also received the ascend from as well as the leaflet. Their parents were informed in the same way by received the leaflet and the consent form at the end of the day. Students whose parents were allowed to participate in this phase and agreed to join received the diary after returning the consent form. Students are free not to return the dairy without received any disadvantage.

4.7 Research Context: Thai Schools

In phase 1, YES! Programme was facilitated in 8 classrooms within 7 schools. All those schools have gifted classrooms and are school partners of IPST. Six schools are members of the IPST Science and Mathematics Talented Development programme at the primary school level, and one school has an IPST-based gifted programme. The schools have their own gifted curriculum, such as the special science and mathematics programme, or STAMP programme.

Cross-curricular and extracurricular activities are provided in that programme for their students to develop their learning abilities in science and mathematics. Moreover, with the collaboration under the IPST partnership, the schools also provide a 1-day camp for gifted students under the IPST genius project.

In addition to their role in gifted education, the schools serve as educational settings that provide teaching and learning. In this study, all primary schools incorporated the national science standard into their curriculum. Environmental knowledge is found in science subjects, and STEM is taught as an alternative to traditional subjects in schools. The schools are also located in different provinces across the country (see Figure 15).

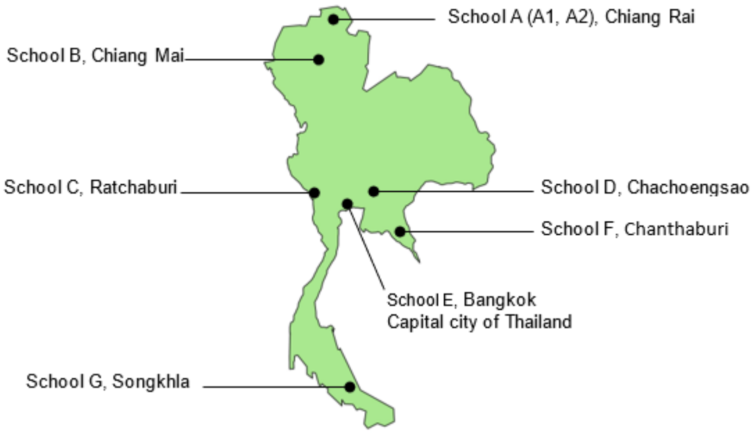


Figure 15 Map of Thailand and School Locations

One reason for this geographical diversity is to encompass the varying provinces where schools are located in diverse regions: North, South, East, North, Central, and West. Second, the geographical information supports the fact that students may encounter various environmental sustainability issues. For example, the northern region is surrounded by mountains. Students in Schools A and B in the north may have the opportunity to learn about and experience landslides. Students in schools F and G are likely to see the impact of the plastic waste in the ocean, as their provinces are located close to the Gulf of Thailand. All students are likely to be familiar with the flood issue as Thailand is located in the tropics, where the monsoon is common and floods frequently happen every year. For example, in 2011, the flood covered 66 provinces out of 77 provinces in total (Siebeneck *et al.*, 2015). While droughts usually occur in the east and central parts of Thailand, students in Bangkok, the capital of Thailand, may have less chance to face other environmental sustainability issues aside from floods, which always occur in rainy seasons. Additionally, Siebeneck *et al.* (2015) indicate that different provinces have their own capacity to deal with natural disasters.

Moreover, schools are located in provinces with socio-economic differences. According to the Statistical Data Warehouse System provided by the National Statistical Office (2021), the average income of each province was reported. In 2021, among the 7 provinces, School E is located in Bangkok, which is the richest province. Chantaburi, where School F is located, also falls into the high-income category. Ratchaburi and Chacheogsao (Schools C and D) are medium-income provinces, while Schools A, B, and G are located in low-income provinces. Significantly, School A was located in the city that has the least income of the five cities. In addition to the income category, there are also cultural differences among the regions where schools are located. Students may also speak a different native language. Premsrirat and Burarugrot (2021) indicate the country's only official language is Thai, however, approximately fifty percent of Thai people speak it fluently as their mother tongue. Thai regional dialects are such as Thai Klang, or middle Thai, which is found in the middle region of Thailand, Khammuang or northern Thai, Lao Isan or northeastern Thai, and Paktai or southern Thai (Premsrirat and Burarugrot, 2021).

Due to these reasons, to gain insights into students' perceptions, I am specifically interested in whether their knowledge and awareness extend to proactive problem-solving, even if students are not located in regions not frequently affected by certain natural disasters or environmental issues.

Schools	Provinces	Regions	Geographical location	Environmental issue by region
A1,A2	Chaing Rai	North	The region covered over 153,000 square km. The mountains run north-south and feed several rivers that merge in the centre. The mountain range averages 1,600 metres above sea level. This region has cold winters, hot summers, and moderate precipitation	• Flooding area covers 15 provinces and cover 2.78 million rai. • Drought is found during March and April each year. The risk area in 2021 was reported that • Landslides are found in this region during June to September. Both province have vulnerable area of landslide.
B	Chaing Mai			
C	Ratchaburi	Central	A lowland area that precedes to the south and reaches the Gulf of Thailand. It covers 73,000 square kilometres. Most are above sea level, less than 30 metres. The west has several major rivers and small mountains. The geography related to flooding in rainy season.	• West and Central parts have Flooding area covered 17 provinces and cover 4.38 million rai. • Drought is found during February to April. • Landslides are found in this region during June to September • Coastal waste was found and the waste release through the ocean from this area
E	Bangkok (Capital)			
D	Chachoengsao	East	The landscape is varied, both hilly and flat areas. □The total area is about 34,000 square kilometres. Located more than 40 metres above sea level. Significant amount of rain falls during the rainy season. In the summer, the weather is moderately hot as it is close to the sea.	• Flooding area cover 7 provinces and cover 0.49 million rai. • Drought is found during March to April each year. • Landslides are found in this region during June to September • Coastal waste was found and the waste release through the ocean from this area
F	Chanthaburi			
G	Songkhla	South	A long peninsula that extends into the sea on both sides. There are several islands and the region covering an area of 83,000 square kilometres. The terrain is covered with forest and largely flat on both sides of the coast with many rivers	• Flooding area cover 15 provinces and cover 0.43 million rai. • Drought is found during March each year. • Landslides are found during October to November • Coastal waste was found and the waste release through the ocean from this area

Table 15 Environmental Issues and School Locations
(Thaiwater.net, 2022; Thai Meteorological Department, n. d.; Southern – East Coast Metrological Centre, 2018; Department of Mineral Resources,2023; Department of Coastal Resources, 2017)

Table 15 indicates that the schools in this study are located in different locations in Thailand, which may be affected by several environmental issues. Due to these facts, STEM interventions were designed with learning content regarding real-world environmental issues occurring in their region.

4.8 Pedagogical Activity: Approach for Learning SD, STEM and Skills

According to Maker *et al.* (2015), the instructional and pedagogical approach that is selected ought to be flexible, practical, and credible. PBL is one of the models recommended by many educators in the field of science education, as a teaching and learning approach. The problem to be adopted must be real; as Maker *et al*. (2015) believe, the real problems provided a real and complex situation that required various methods and factors to find solutions. To engage students in environmental sustainability issues, the problem must be framed in a context that ranges from a local to international scope (Yuenyong, 2012; Morris *et al.,* 2021; Okubo *et al.,* 2022), or it must be what students perceive it to be related to their lives, not only through the news but also through their personal environment.

For students to comprehend why sustainability is crucial and must be attained, the problem must be real-world issues related to the economy, society, and environment, in accordance with the literature. Also, the problem-solving process must be challenging and systematic in order to provide an appropriate opportunity to practice problem-solving and collaborative skills. Following that, a pedagogical activity for the pilot phase was developed, focusing on the landslide issue.

This research used backward design to create the programme that aims to deliver contents in 1) providing knowledge to increase awareness for SD, 2) developing problem-solving skills, and 3) providing student opportunities for collaboration. In contrast to the traditional method, the backward design, was adopted in the pilot phase and begins with the final step, which starts with identifying the outcome of the programme that was already set following the research questions. Specifically, students' output must be innovative artefacts that can help solve the problem, which is clearly demonstrated as the product of the problem-solving process. During the process, students are required to apply STEM skills to solve problems, ensuring that they are the ones actively finding the solutions themselves. They can also investigate the impact of environmental issues on the learning environment and discuss sustainability issues.

4.8.1 Pilot activity: Landslide Prevention Project

Following the initial conceptual framework, pilot study was conducted with STEM activity called 'Landslide prevention project', offering challenging task to find a solution for the landslides in a specific context, The expected learning outcomes is investigate their perception toward the programme, their development knowledge of SD knowledge, problem-solving skills and collaboration skills as well as a positive attitude towards learning for SD and problem-solving.

Landslides issue is selected as content because it represents the problem of the long-term sustainability of the environment. Landslides cause enormous damage to the surrounding environment, society, and the economy; therefore, finding solutions to landslides is essential for achieving SD. It is a disaster found in many parts of Thailand (Department of Mineral Resources, 2017), so it fits well in terms of real-world issues. Landslides were also used to teach gravity and friction in the engineering programme for young children (Teachengineering.org, 2006). The landslide prevention project focused on solving problems in different directions, such as accommodation by moving house within the free area under the lengths that are permitted or mitigation by creating protective barriers. However, sustainable solutions such as planting trees and creating terrace rice fields can be options.

Landslide activity is a 90-minute intervention. The lesson plan is presented in Appendix 1, while data collection, data analysis, and findings are presented in Appendix 4. The significance of the pilot phase is to inform the design of interventions based on the conceptual frameworks to ensure SD learning and promote problem solving and collaboration. The intervention also shapes learning content and the learning process and informs the change in research tools. An example of that is the design of engineers' logbooks to record students' problem-solving skills rather than worksheets from individuals to encourage discussion and reflection in their learning in the team. Additionally, in the pilot phase, students drew solutions to landslides individually, whereas in phase 1 of this study, students drew sketches as a product of collaborative problem-solving. More importantly, as a 90-minute programme is not enough to cover all aspects to observe, the intervention was extended to a one-day programme consisting of four environmental issues. The intervention that is designed and implemented in the research is discussed in the next section.

4.8.2 Young Engineers for Sustainability' (YES!)

'Young Engineers for Sustainability' (YES!) programme is designed as a result of an evaluation of educational interventions that address ESD through STEM problem-solving. Using the conceptual framework established in the preceding section (3.3.2), the YES! programme was designed as the intervention for this study. Each element of framework is critically defined to ensure that the lesson plan consists of the problem-solving task that address SD issue, offers a motivating challenge, and engages gifted science students in finding the solution while focusing on a long-term plan to preserve the environment for future generations. The discussion part encourages group reflections, and focuses on SD concepts involved around environmental impact, social, and economic issues.

The intervention is student centre, hands on and collaborative by nature. Teamwork is required to create a collaborative problem-solving environment and to encourage students to communicate and express their ideas to their peers. Based on the EDP and the intention of developing EHoM to find solutions to issues, while SD competencies are also addressed, the instruction design are described. The scope of the lesson plan of the YES! programme with four environmental sustainability issues is shown in Appendix 3.

To design the intervention, Breslow (2015) suggests starting with the intended learning outcomes when creating the curriculum and generating activities that promote the fulfilment of the objectives specified using backward design approaches. Brundiers and Wiek (2017) state that learning outcomes are correlated with efficient learning environments and suitable evaluations to gauge students' advancement towards the goals. Using the Backward Model (Wiggins and McTighe, 2005), where instruction-design phases progress from the learner outcome to skills and finally to the learning activity, it helps build learning strategies that help students achieve the learning outcomes and meet the research objectives. According to Buttons (2021), the benefits of backward design include promoting intentionality during design, encouraging teachers to define a goal before incorporating it into the curriculum, and assisting in guiding instruction and designing lessons, units, and courses. Therefore, the desired learning outcomes of the YES! programme were determined as shown in Table 16.

Aspects	Desired learning outcome
Sustainable development	- Students can understand knowledge for sustainable development and issues regarding the SDGs. - Students can reflect on and justify human behaviour as well as evaluate solutions - Students express their feelings towards others and express their desire to be a part of the change.
Problem solving skill	- Students can integrate science and environmental science from their classroom knowledge of Thailand science learning standards - Student can create innovative product - Student can express themselves during engineering problem-solving tasks and discussions as the way to use EHoM
Collaboration	- Students express their feelings towards others and express their desire to be a part of the change.
Gifted development	- Students expressed higher-level skills through the present of EHoM and SD competences from the design tasked based on IPST gifted indicator. - Students are engaged and being motivated in the programme according to their interest

Table 16 The Desired Learning Outcomes

From those intended learning outcomes, the lesson plan is designed. The student is presented with intriguing environmental sustainability facts prior to investigating the problem at hand. Students are motivated to formulate their own conclusions concerning human behaviour and future thinking throughout the sustainable discussion that concludes each activity. Consequently, the intervention aims to furnish students with an understanding of the matter, opportunities to develop competencies, and knowledge of SD. The stages of instruction are found following the template of backward design provided by Wiggins and McTighe (2005). The instruction design for YES! programme is illustrated in Appendix 4.

4.8.3 The Intervention: The YES! Programme and Its Teaching and Learning Strategies

The YES! programme is a one-day intervention comprising four activities: 1) Landslides Prevention, and 2) Are We Ready for the Flood? 3) Drought is Coming, and 4) Journey of the Waste from the River to the Ocean. Serving as the continuing system, completion of the mission requires students to participate as members of the young engineer Team. This team assists the Cocoland government in addressing landslides, floods, droughts, and waste issues across various locations in the imaginary country of Cocoland. Students in each classroom are divided into groups and they worked together in the same group for the whole programme. Students participated in the orientation section during the first part of the day, receiving initial training in the engineers’ training session.

The engineers' training session introduced a 'Pop! Popcorn' animation, which visually represents the notion of SD and three pillars for sustainability. The journey of the Pop! popcorn showed the production of a single bag of popcorn, encompassing various stages. This includes an agricultural process under diverse climate conditions, transportation to the factory using a truck and fuel, and the production of bags for packaging. The process persists until the popcorn factory receives the bags and corn seeds, packages them, and distributes them to commercial stores for consumer purchase. Consumers buy these snacks for their children. Unfortunately, due to careless littering, a whale consumes the popcorn bag, leading to the whale's illness.

After watching the animation video, the students were presented with two figures representing nations, labelled respectively as Cocoland A and Cocoland B. The students were encouraged to inquire about the distinctions between the two scenarios unfolding in Cocoland. They were also given the option to choose where they would prefer to reside, and the response indicated that everyone would prefer to live in Cocoland A due to its well-maintained infrastructure and commitment to protecting natural resources. Following the introduction to the concept of sustainability, students were shown a graphic representation of the SDGs on the screen. They were then provided with learning materials to use at their tables, which included details about each of the SDGs. The instructor underlined specific SDGs relevant to the issues addressed in the activity.

In the engineers' training session, students underwent training to develop EHoM by following EDP. Six EHoM are described, each corresponding to the actions and thinking processes of genuine 'adult' engineers when confronted with problems and devising solutions. They are instructed that they will practice each EHoM by following the problem-solving approach represented to them. The process of problem solving was also provided to achieve the goals, which are to save people and the environment by overcoming challenges and effectively resolving issues by creating innovative artifacts. I then gave the students a rehearsal to identify any concepts they might find challenging. Throughout the programme, students are encouraged to observe and assess the application of these habits during problem-solving activities, aiming to find sustainable solutions.

A role-play opportunity was also offered. Students were role played as specific professions in the engineering team, which consisted of five members: project engineer, architect, scientist, mechanical or civil engineer, and operational and maintenance engineer (See figure 16). This mimics the real situation when many professionals in engineering are working together to complete engineering tasks (Jonassen *et al.*, 2006; Trevelyan and Tilli, 2007). Each profession was assigned a unique job and set of responsibilities based on their respective fields. This aim is to provide students with real-world problem-solving experience when the country or community faces an issue regarding a disaster or any circumstance. Many professions will join the special operation and make a great commitment by finding the solutions and helping team to solve the problem. Before leaving the engineers' training session, I assigned roles for students. For the rest of the activities, I showed the graphic of professions at the beginning of each activity and let the teams organise the roles by themselves.

When joining the mission, students must learn how to address the environmental sustainability issue and identify the issues within the presented scenario. I used storytelling to foster immersive experiences, allowing the students to assume the role of an engineering team. Mr. Prime Minister urgently invites them to collaborate in resolving the problems in Cocoland, which is a country in Southeast Asia. Their first challenge is to find a solution to the landslide issue in Apple Village. After achieving success, they advance to Mango City to address the flooding problem, and then proceed to prepare Pomelo Town for the upcoming drought. The final mission involves addressing the most significant nationwide problem—the waste pollutants in the rivers and oceans.

During the mission one by one, tasks are challenging to engage students and make the activity more enjoyable, and it is also relevance when students are invited to share their experiences with issues and allow them to think about the community and local people in different professions. Example of learning materials and summary of activities is illustrate in Figure 16.

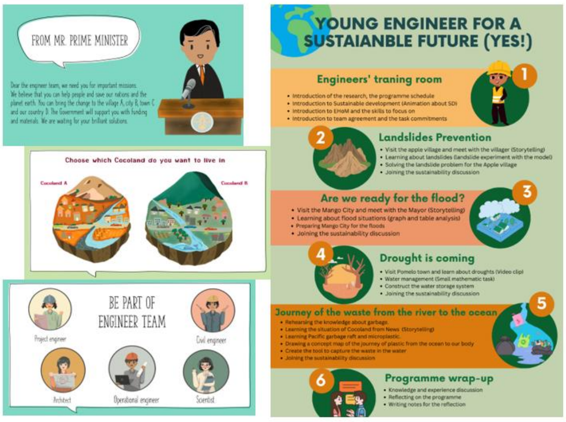


Figure 16 Example of Materials And Summary Of the YES! Programme

From figure 16, students play their roles as engineers and follow the program by solving issues one by one. Students were tasked with generating potential solutions to the problems, engaging in group discussions, and collaborating on constructing models that simulate those solutions under the guidance of a construction leader—either a civil engineer or a mechanical engineer. The testing phase involves encouraging active participation with the operational and maintenance engineer who is responsible for conducting the tests. Emphasising collaboration over competition, the goal of testing is to verify the practicality of the solutions under specific conditions and contribute to finding community-oriented environmental solutions. Students are prompted to address various facets of the issue, considering how to enhance tasks efficiently, implement the model in the real world, and ensure long-term effectiveness. To document their roles and contributions, students are encouraged to maintain an engineer’s logbook. Those assigned the role of a scientist record team discussions and outcomes, while those who are playing the role of architect, draw model designs based on input from team members.

Under the attentive supervision of the project engineer, who acts as the team leader for each mission, every aspect of the group's problem-solving effort is carefully coordinated. Leader plays a crucial role in contacting the government agent to receive materials, encourages members to work together, and monitors group work to ensure the model can be completed within the given timeframe. Members have to take turns in different roles during each activity, allowing them to acquire a diverse set of skills corresponding to their roles. An example of that is the visualising ability, one of EHoM, which students can practice while being an architect. As participants in this study are gifted students in science selected by the school programme, it is assumed that they have similar abilities in completing the task, but they might have different characteristics and specific abilities. As a result, I persuaded participants that individual abilities are critical for achieving the group's goals by arranging the team's roles and switching them in each mission to give them the opportunity to experience a different role and work from a different position. Example of practicing EHoM task are presented in Figure 17.

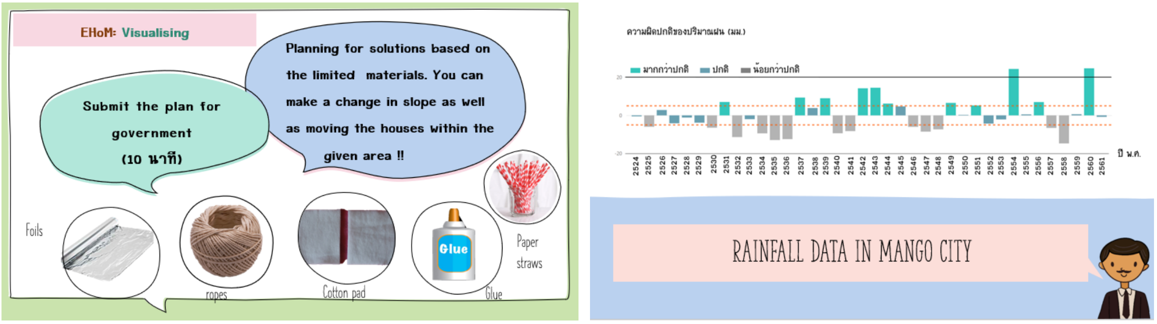


Figure 17 Tasks for Practicing Visualising and System Thinking

Students are able to apply interdisciplinary knowledge and skills through mini-tasks that vary in each activity. The discussion and reflection enable students to practice different EHOM and competencies for SD based on IPST indicators. For example, students are encouraged to observe the landslide experiment, making the connection to reality, and analysing villagers' voices. During the flood activity, they were presented with a graph depicting atypical precipitation data and a table containing flood-related data, including the water level and the associated emergency fund expenses. They practiced future thinking by forecasting the situation in the absence of a resolution strategy and analysing the correlation between climate change and flooding. Students were tasked with determining the water provision to each sector of the town of Pomelo as part of the drought activity. In drought is coming activity, they identified the impact of drought to each sectors in the town. They practiced EHOM by going through prompt questions in the engineers' logbook, for example, to identify the characteristics of a good water storage system for the droughts. Finally, as part of the waste in the river and ocean activity, they were encouraged to create a visual diagram that elucidated the journey of microplastics, starting from a snack bag until reaching the human body.

The intervention is created to build up students' motivation, as the environmental issues are complex but meaningful and a challenge to achieving the mission, requiring engineers to work together. The solutions generated during sustainability discussions are designed to address issues in a specific scenario, simulating solutions for problems at the local level with a focus on long-term prevention. The presentation of solutions, including ideas students purposed, drawings of the plan, and innovative artefacts they created or ideas during discussion, contributes to the good of this society by serving the characteristics of gifted students and engaging students in the activities in both cognitive and emotion. The intervention has adopted student-centred learning as students are also in charge of their own learning as they brainstorm and draw conclusions from the group's decision to solve the problem. They also found ways to improve and adapt to the real world by themselves. They can make choices from designing their own solution from given resources and doing their own strategies. Example of that in flood activity that allow them to raise the house level, construct the wall or use the sand bag or even apply all solutions.

Students presented their work before testing and shared their opinions during sustainability discussions. Additionally, the real-world applications of small ideas leading to innovative solutions, examples are provided for discussion. For example, in Hong Kong, soil nails are used to prevent landslides, offering a more economically feasible and environmentally friendly alternative to cementing slopes, a practice adopted by many countries, including Thailand. Moreover, different types of water storage solutions are explored, provide idea of using variety of shapes and materials, size and their placement depending on the specific purposes of water usage for different premises. Example of real-world waste collection technologies are also shared with students, such as the Interceptor used in Thailand, and the Waste Shark used in the United Kingdom, simultaneously highlighting the potential consequences of inadequate solutions that worsen environmental issues. The goal is to encourage a shift in human behaviour, preventing investments in technologies that may not provide long-term solutions.

At the end of programme, the wrap-up session is conducted to reinforce what students have learned for SD, EHoM, and collaboration through the programme. Students were encouraged to reflected their preference using sticky notes enclosed with the engineers' logbooks before concluding the activity. This is to promote both hands-on and mind-on participation. Figure 18 illustrates the example of implementing YES! programme in schools.

Figure 17 Implementation of the YES! Programme in Schools

The figure above shows the students working in team and invent the innovative artefacts to solve different environmental issues. The YES! programme intervention was implements in school and data collection methods are discussed in the following sections.

4.9 Phase 1 School Intervention

In Phase 1 the YES! programme was implement in a gifted classroom as one day intervention. Throughout the intervention, students' interactions, expressions, and perceptions are monitored. An intervention conducted in a gifted classroom in Thailand involves at least one teacher from each school and students of authentic classroom size. Many gifted education and STEM research implement STEM interventions in their research and explore the outcome of the intervention by adopting a series of tools such as observation, pre- and post-open-ended questionaries, workbooks, concept maps, self-reflection forms, and interviews (Robinson *et al.,* 2014a; Robinson *et al*., 2014b; English *et al.,* 2017; Robert *et al*., 2018; Lakanukan *et al*., 2021). Following this idea, the impact of STEM activities can be investigated observation by teachers to observe students behaviours together with other tools.

During the YES! programme, 30–35 student participants were divided into six or seven groups with 1 to 2 observer teachers. Each teacher observed only one group for the entire intervention. Methods are used differently for collecting students and teachers' reflections. Table 16 depicts a brief overview of the methods used in this phase.

Research participants	Tools	Materials
Student participants	Pre and Post intervention questionnaires	Set of open – ended questions
	Engineers' logbook	Set of open – ended questions, and sticky notes
	Drawing and Photo	Drawing of construction plan, and Photo of innovative artifacts
Teacher participants	Observation form (Observing students by teachers)	Open – ended questions
	Semi-structure interview	Open – ended questions, and Zoom application

Table 17 Data Collection Methods in Phase 1 School Intervention

From table 17, tools for collecting data are identified. For students, pre-intervention questionnaires were given before the intervention, while post-intervention questionnaires were given after intervention. Students' reflections through engineers' logbooks, students' drawings and photos were also collected. To collects teachers' viewpoint and what they have observed, observation forms as observational field notes, and the teachers' interview transcriptions were collected. The details of each method are discussed in the following sections.

4.9.1 Open-Ended Questions: Explore Students' and Teachers' Reflections

This study integrates environmental sustainability themes into STEM activities for gifted science students in primary school in Thailand. The activities aim to foster knowledge and awareness of SD and enhance problem-solving and collaborative skills. Based on research questions, students learning outcome are investigated including knowledge regarding SD, SDGs, competencies for SD, and the use of EHoM and collaborative skills.

The research uses bricolage approach, in which many tools are employed and designed to explore students' and teachers' perceptions. In addition to observation, which is discussed later, reflections are discussed in this section, as they helped to explore research participants experiences, perceptions, and thoughts regarding knowledge and awareness of SD, problem solving, and collaboration. Scholars highlight reflection as foundation for learning as it involving how individual and group making meaning through engagement (Gosh, 2014), through the reflection of ourself, relationship and knowledge (Dyball *et al.*, 2009). Reflection, according to Tarricone (2011), is beneficial for developing higher-order thinking skills, such as PSS. The students' reflections involved their experiences of learning as well as the development of understanding and skills (Tarricone, 2011; William and Otrel-Cass, 2016). Reflection can yield behavioural adjustments, willingness to apply, and commitment to action (Boud *et al.,* 1985, cited in Phielix, 2012).

Many educational studies focus on the reflections of students and teachers regarding educational practices. Examples are the use of students' writing to reflect middle school students' problem-solving using game-based learning (Carpenter *et al.*, 2021) and using teacher interviews and student focus group interviews together with the analysis of students working materials to observe ICT learning and collaboration in secondary education (William and Otrel-Cass, 2016). A semi-structured interview was used to investigate students understanding of sustainability (Walshe, 2008). Another example is the student journal, which is used to obtain reflections on a group investigation of learning science among secondary students in South Korea (Oh and Shin, 2005) and to obtain emotional reflection and inquiry reflection through the journal of primary school students (Simms and Shanahan, 2019). Furthermore, students' handbooks can contain student reflections according to their successful work (Helyer, 2015).

Questions can be used to observe students' reflections in many studies. To investigate problem solving, the strategies of questioning, such as asking students about what, why, and how regarding practice and feedback, are integrated with monitoring and reflection (Woods *et al.*, 2000). Carpenter *et al.* (2021) use questions as the reflection prompt for students to write answers and reflect on problem solving in game-based intervention. Questions asked them to describe themselves in their own words (Carpenter *et al*., 2021). Those prompts are based on open-ended questions.

According to Charif (2022) reflection should help students comprehend the concerns of SD and make critical decisions to formulate and implement decisions. Following that, this study investigated student reflections regarding six aspects, including: 1) learning about SD, 2) awareness of SD, 3) perceptions regarding norms, the future, and themselves, 4) problem-solving experiences, 5) collaborations, and 6) experience of the Yes! programme. The summary of question development for asking students' reflections is illustrated in Table 18.

Element	Type of inquiry	Tools	Aspects	Supporting literature
Knowledge and Awareness of SD	Open – ended question	Pre and post questionnaires, diary	Concept of SD involving three dimensions, SDGs, attitude toward environmental sustainability issue	Libarkin *et al.* (2005), Simms and Shanahan (2019), Zeeger and Clark (2014), Geden *et al* (2019),
EHoM	Open – ended question	Engineer logbook , Photo , Drawing	Problem finding, System thinking, Improving, Adapting, Creative problem solving, Visualising,	Lucas and Hanson (2014), Carpenter *et al.* (2021), Snieder and Allen (2019), English *et al.* (2016)
SD competencies	Open – ended question	Engineers' logbook, Diary	Anticipatory , Normative Self-awareness, System thinking	Giangrande *et al.* (2019), Simms and Shanahan (2019), York *et al.* (2019), Clark *et al.* (2017), Rodríguez- Aboytes and Nieto-Caraveo, (2018)
Collaboration	Open – ended question	Pre and post - intervention questionnaires, diary	Perception, Engagement	Phielix (2012) , Hyler (2015)
Experiences of YES! Programme	Open – ended question	post questionnaires, diary	Perception, Engagement	Helyer (2015) , Karaca *et al.* (2016)

Table 18 The Summary of Questions Development

In brief, the table above informs how reflections are obtained from each tool in this study by using open-ended questions to prompt students' reflection toward aspects of the conceptual framework. The prompts for reflection were embedded in the data collection tools in this research using open-ended questions adapted from the questions asked in many studies regarding STEM education and gifted education.

4.9.2 Pre- and Post-Intervention Questionnaires

The questionnaires are designed to capture the students' background knowledge and perceptions regarding sustainability issues before participating in the intervention and the change of those aspects after the intervention, which is the answer to the question ‘How STEM problem-solving activities enhance students’ knowledge regarding SD, problem-solving, and collaboration'.

Questionnaires provide benefits for educational research, Artino *et al*. (2014) indicated that they are an effective method for collecting data that is challenging to measure, such as opinions, attitudes, and beliefs. The study by Ssossé *et al.* (2021) reported that in qualitative research used in ESD, questionnaires are often used aside from other tools such as interviews, observation, and case studies. Research regarding educational interventions also used questionnaires to explore specific perspectives such as participants’ attitudes, knowledge, and perceptions. For example, in Lim’s (2018) study, where a game was used to teach global citizenship, students were asked to complete a questionnaire. The results from the questionnaire can be compared among students who join the intervention from different school locations and reveal the intervention's outcome by reflecting on the change in their thinking after participating in the programme.

The questionnaires for pre- and post- intervention were constructed to obtain students’ reflections toward knowledge and opinion regarding SD issues, collaboration and the STEM activity. Pre- and post-questionnaires offer crucial insight of student perspectives (Zeegers and Clark, 2014). As students’ attitude is also observed, many studies report positive relationships between attitude and behaviour in environmental psychology education (Bamberg and Möser, 2007; Escario *et al.,* 2020). Moreover, perceptions toward STEM informal learning initiative are also observed to investigate student enjoyment and engagement (Robert *et al*., 2018). Based on Ssossé *et al*. (2021), the space to respond to open-ended questions enables students to provide a concrete example of the fact. Following that, attitudes regarding environmental sustainability issues, collaboration and STEM activity were explored in both pre – and post intervention questionnaires.

The open-ended questionnaires are also adapted from research regarding ESD (Kagawa, 2007; McGibbon and Van Belle, 2015; McKeown-Ice and Dendinger, 2008 ; Zeegers and Clark, 2014), competencies (Geden *et al*., 2019; Simms and Shanahan, 2019) and collaboration (Topping *et al.,* 2011). Then, the questionnaires were developed to fit the purpose of the research and focus on self-reflection. The questionnaires were reviewed by two experts in the STEM education field. The English version was translated into the Thai version by a researcher and critical friends before cross-checking to get the revised version.

Overall, the pre-intervention and post-intervention questionnaires contain a set of open-ended questions to obtain students' reflection regarding understanding and perceptions before and after joining the activities. The pre-intervention questionnaire consists of four sections. First, general information is provided with data about students' demographics, such as their school location, gender, age, and year of study. Section 2 seeks background knowledge concerning the students' awareness of the issue addressed by the school intervention and explores their understanding of the impact of such issues and how they perceive them. This section contains, Yes-No question as probing question with 4 open-ended questions items, and 4 closed-ended regarding sources of source of learning. Additionally, in section 3, the questionnaire includes one open-ended question inviting students to identify the environmental issue that they are most concerned about and do not want to confront. Five open-ended items were used to solicit feedback on how to resolve those four issues and the different aspects they have explored in previous STEM problem-solving experiences. The last two open-ended items asked participants to express their perceptions about collaboration. The pre-intervention questionnaire in English is shown in Appendix 11.

Unlike the pre-intervention questionnaire, the post-intervention questionnaire consisted of three sections. The first section asks about what they have learned from solving landslides, floods, droughts, and waste in river and ocean activity with 4 open-ended items. The second section contains 6 items regarding perceptions toward SD. The last section of the post intervention questionnaire is about working collaboratively and collaborative problem-solving, with 5 open-ended items. This section aims to show attitudes towards working in a team and problem-solving. The post-intervention questionnaire in the English version is presented in Appendix 12.

4.9.3 The Engineers' Logbook, Students' Drawings and Photo

As per Table 11, as part of Phase 1, Logbook is employed to find student perceptions during the intervention regarding knowledge SD, the practice of SD competencies, problem-solving skills regarding EHoM. Logbook is one of qualitative approach in research regarding ESD (Ssossé *et al.*, 2021). Students can share and visualize their idea through drawing and writing in logbook (Bianchi and Chippindall, 2018)

Students, in groups of five, perform the roles of different engineering professions, such as mechanical engineers, architects, and scientists. They applied their knowledge and skills, and completed tasks according to their roles while assisting the team in accomplishing the activities. The students were provided with their team engineers' logbooks. The engineering logbook is intended to document progress when participating in interventions and is divided into four sections, beginning with landslide prevention (Activity 1) and ending with the waste journey from rivers to oceans (Activity 4). In each section, open-ended questions with space for drawing, taking notes, and writing the answers were provided. Students recorded the team's problem-solving process, from finding the problem to improving the design and experiment after completion, in the engineer's logbook. The team's reflections as the outcome of sustainable discussion and the use of SD competencies were also recorded. The team's scientist must be the one who answers the question and takes notes in the logbook, while the architect is the person who creates the sketch. So, in each activity, students alternated roles, switching the responsibility of the logbook, between an architect who draw the design and a scientist who record the group answers toward the questions.

Logbook is the workbook for students to follow during the problem-solving process. Workbook is employed in many research about STEM activities and it is used to analyse student responses. For example, in a study about anti-earthquake designed buildings activity for year six students (English *et al*., 2017), the researcher examined students' responses to questions about how they learned from the building tests, how they answered those questions, the redesign modifications they would implement, and reason behind. Tracking the students learning about design in shoes design activity (English, 2019). In the improving catapult activity (Watson *et al*., 2022), the workbook was used to record students' catapult's experiment results and show the graph created and the answer to a specific question. As the aim of the activity is to promote collaboration in all processes, tools was changed from the individual worksheet in the pilot study to the engineers' logbook for a team, where a set of questions is being asked. The logbook contains an open-ended question section ranging from 7 to 9 questions for each activity, and a drawing section with a space is provided for drawing the plan and creating concept maps.

In addition to section 4.9.1, the prompt questions were also framed to with Bloom's taxonomy (1956), to assessing competencies by categorising a student's knowledge. In a nutshell, Bloom's taxonomy is a hierarchical description of cognitive talents and learning objectives commonly represented visually as a pyramid containing six levels. Starting from the bottom of the pyramid, each step reflects an increasing ability from low to high order thinking skills: from basic concrete cognition such as knowledge, understanding, and application to a more abstract, conceptual understanding, which is analysis, synthesis, and evaluation (Bloom, 1956). Steps of Bloom's taxonomy are considered in the questioning process to promote students' critical thinking during the sustainability discussion and to check the completion of problem-solving tasks following EHoM (Lucas *et al*., 2014) as well as assess students' reflection regarding competence for SD. The questions were created using phases following Pappas *et al.* (2012), in which many terms are used to identify the characteristics of each step of Bloom's Taxonomy (see Figure 18).

level of thinking descirbed by words					
Knowledge: describe, identify, recognize, record	Comprehension: discuss, explain, summarize	Application: change, choose, apply, assess	Analysis: analyze, classify, research, compare	Synthesis: create, design, integrate, construct	Evaluation: assess, choose, evaluate, prioritize, predict, justify

Figure 18 Bloom's Taxonomy (Pappas *et al*., 2012)

Aside from open-ended questions that are shaped by terms in figure 18, the student drawing is a piece of learning evidence that reflects the students' ideas from their thought in to concrete. Visualising is an essential EHoM, and planning is a step-by-step problem-solving process. The meaning of the items and what students represented in their drawings can be analysed, demonstrating their learning process and conceptualization and critique in label and image composition (Hopperstad, 2008; Göçmençelebi and Tapan, 2010). Many researchers in science and STEM education have used drawing as a research tool to assess students' learning, especially as part of engineering design (Zainuddin and Iksan, 2019). STEM research includes several examples of sketches used as a tool: the study of primary students' design and construction of earthquake-resistant buildings and shoes design (English *et al.,* 2017, English, 2019), grade 4-6 students' design of optical instruments (King and English, 2016), and the tool for learning methods to investigate primary students' misconceptions in photosynthesis in a preservice teacher's research (Köse, 2008).

Drawing is used as a tool in many STEM research projects. Zainuddin and Iksan (2019) found that nine studies used drawing as a process in engineering design in integrated STEM learning environments. All studies used qualitative and mixed methods to record students' cognitive and emotional responses to the learning design. They also suggest that instead of focusing on the final product, drawings must be evaluated according to the concepts that they include (Zainuddin and Iksan, 2019). Moreover, English *et al.* (2017) reveals that students' drawings reflect their planning while designing as part of the problem-solving process. To promote EHOM, students are encouraged to visualise their solution to the problem through drawing.

In the process of designing the engineers' logbook, two experts in the field of STEM education reviewed the questions in the Engineers' Logbook English version. After the translation by myself and checking with critical friends, the Thai version was sent to an expert in the environmental field and another in the field of gifted education. The questions in the engineers' logbook are illustrated in Appendix 13.

When students satisfied with their design, they can submit it to the instructor before getting the materials. This is also an instructional approach for developing student design skills and increasing students' engagement. At this point, the instructor also acted as a government official who could approve the construction, demonstrating to students a real-life situation in which the engineer must submit the plan and request government permission before constructing a building or any other structure. This study also asks students to draw visual diagrams to encourage students system thinking representing relationship between consequence of plastic snack bag and food chain.

Unlike drawing, photos of the innovative product were gathered to reveal the construction change from planning. Study regarding STEM activity investigate students products such as building against earthquake (English *et al.,* 2017). Product can be used to investigate science knowledge and scientific creativity (Karademir, 2016). Product creation involves the process that students demonstrate their ability to adapt after recognising the need for change, receiving a clue during construction, or performing some tests and continuing construction. The photo of products can represent the experiment's outcome during the testing process and confirm that the solution works in solving problems such as preventing the village from landslides or protecting the houses from flash floods.

Similar to student drawings, the innovative product represents the students' visualisation and realisation of their ideas to solve the problem in terms of the creative problem-solving product. The product will be captured as a photograph before and after an experiment that will be further evaluated by photo analysis with different dimensions, such as how it invents and how it changes according to plan.

4.9.4 Classroom Observations by Schoolteachers

As described in Table 11, observation by school teachers is expected to informs students' expression and behaviour during the YES! intervention in gifted classroom, including their engagement, displaying problem-solving skills, and collaboration. through the lens of observers, providing insight into the teaching quality and effectiveness of the programme. In the observational form, the reflections of teachers were also included to explore the quality of the intervention as well as instructions and instruction management regarding YES! programme in their lens.

Observation is used in many education studies related to the implementation of the intervention. Observation is employed for investigating live information and collect authentic data from natural setting (Cohen *et al*., 2007). Observation is essential for understanding students learning and knowing their competence, emotion, and ability in different situations. In a perspective of classroom intervention, scholars agree that observation is a direct and sensitive measures of teacher instructional practices aside from teacher self-report (Dignath and Veenman, 2021), regarding curriculum or framework (Palaiologou, 2019), as teacher instructional practises are the factors that most influence student learning (Palardy and Rumberger, 2008). Observation can used to assessment learning, as students experiences, which are complex, can be evaluated through observation (Formosinho and Formosinho, 2016). Observation also offers feedback for professional development, called peer observation, when another teacher observes the teacher instructor teaching in the classroom (Gosling, 2002). However, Dewey (1938) suggests that observation alone is invaluable until we understand what we have observed. So, the observation can revolve around the assessment method that makes the observation's outcome meaningful.

Observation yields more than assessment, as Palaiologou (2019) highlights observation uncover students' relationships with their environments, such as parents and caregivers, as an evidence-based assessment of practice and child development expressed throughout their activity or from their works. It can be assumed that, from what we observed before the practice, they expressed what they perceived from their environment. Observation can reveal the evidence of students collaboration in many studies. For example, in the SPRinG Project, systematic on-the-spot observation with videotape recording was used to observe the behaviours and interactions of students in the programme (Blatchford *et al.,* 2007). The project observed students under four criteria, including the level of student participation and engagement, socio-emotional (group maintenance or blocking), topic focus (sustain or change topic), and interaction between students when conducting a collaborative discussion (Blatchford *et al.,* 2007). Similarly, in the MAST project, students with SEN were observed for their interaction with their peers (Baines *et al.,* 2015).

In the study of Topping and colleagues (2011), observation was done to collect the data needed to determine the effectiveness of cooperative learning and students' interactions. Topping used the collaboration and tutoring code to observe collaboration among students. In addition to collaboration, observation can be used to observe the teaching process and students' problem-solving abilities through STEM-EDP activities (Lakanukan *et al.,* 2021). Additionally, Wang *et al*. (2011) observed educators incorporating STEM integration modules into their classrooms. The study examined the language used by teachers during their practices and their interactions with students. Additionally, observation is employed together with other tools such as field notes and reflective journal to investigate teaching and learning regarding EHoM in primary classroom (Hanson *et al.,* 2022).

Although some scholars argue that observation can only observe the student's behaviour, it cannot observe the student's mental capacity (Dignath and Veenman, 2021). As behaviour and expression are the dimensions that contribute to answering the research question, observation was applied in this research as it captures students' emotions expressed in their faces and behaviours. This is to conduct the qualitative observation according to Creswell (2009) that filed notes are recorded regarding participants behaviours and activity at the research sites. In this manner, O' leary (2020) takes subjective perspectives that researchers play a role of explorer to collect data, offer multiple reality of knowledge.

Scholars provide numerous methods for carrying out the observation. Milos (1992) distinguished two types of observation protocols: open-ended observation protocols and structured observation protocols (Milos, 1992). For open-ended observation, Smith *et al.* (2013) emphasised the benefits of using open-ended questions to provide meaningful feedback to observers and instructors. The data, however, is observer-dependent and cannot easily be standardised or compared across many classrooms and environments (Smith *et al.,* 2013). Structure type of observation is also considerable. Semi-structure allows observation with less clear guidance and less systematic than the structure one, but an observer is capable to write independently even if the pre-established category is provided (Cohen *et al*., 2007; O'Leary, 2020).

Additionally, Valasco *et al.* (2016) identified three main observation protocols in classroom observation, which are segmented, continuous, and holistic procedures; following that, there are many protocols to be followed. Among those protocols, degree, frequency, or quantitative-based evaluation protocols are not what this research expects according to my epistemological perspective. Instead, the holistic approach is adopted with series of questions.

Following Gosling's (2002) recommendation, to avoid the subjective or anecdotal nature of a lot of observation, more systematic ways to collect data can be used, like making observation schedules and checklists, looking at timelines, and so on (Gosling, 2002). According to the open-ended question, it is framed into four sections to divide the time frame of observation, including the knowledge given section, the problem solving section, the discussion section, and collaboration. Starting when the intervention begins, the schoolteacher uses the teacher observation form to observe the activities. The teacher observation form is constructed with 22 items. Following that, the protocol with five aspects was created as illustrated in Appendix 14. The observation aspects of problem-solving are adapted from the EHoM definition and observation protocol (Lucas and Hanson, 2014; Hanson *et al.*, 2022; Wheeler *et al*., 2019), while the collaborative skills are adapted from the Spring project's collaborative codes (Topping *et al*., 2011).

As observation provides many benefits, observation was conducted during the YES! programme intervention to capture students' physical behaviours and emotions, both on-task and off-task, during the intervention as a team. The observation technique was used at this stage to identify individual students' expressions in their learning environment with methods regarding children (Neaum, 2010). I play a role of an instructor who facilitates the activities and has more interactions with students by delivering the story, content knowledge, challenging tasks. Their schoolteachers, who are not involved in designing the YES! programme, played the role of the observers, and observe students in a group throughout the day. Based on Cohen *et al*. (2007) teachers are active participants in the research process as they are 'observer as participant'. Their main tasks were to observe students by focusing on problem-solving ability during the on-task period, how students behave or express themselves during knowledge delivering, and how they collaborate and express collaborative skills.

The observer teachers are the teachers from their school. Since Gosling (2002) recommended that even when a class is small, the presence of an observer or the use of a video camera might impact what is being seen. Instead of having a researcher as an observer, observer teacher may bring a sense of relevance to the student participants and reduce the impact of the researcher on the participant during the observation. This is how to reduce bias which may cause by researcher who design the activity and conduct observation by themselves. Observation by observer teachers is also conducted in STEM – engineering based activity while researcher is conducting the intervention (Karatas-Aydin and Işıksal-Bostan, 2023). Although, Cohen *et al.* (2007) note that observation can be limited by decision, the selection, judgement and preference of observer. This study embrace the reality and try to minimize it. Observer teachers in this study are informed to stay away from the students for 1 metre and not involved or intervene the intervention. This research also ask observer teachers to involve in reflection process and interview.

To ensure that the teachers understand objectives, their role and what to observed, the observation protocol must be trained and provided with observation guidelines (Cresswell, 2009; Morton *et al.*, 2016; O'learly, 2020). Morton *et al.* (2016) highlight that guidelines are helpful to prevent disagreement among all parties regarding standards and protocol which can affect reliability of research and quality of evidence. Therefore, the participant teacher received the observation form and observation guidelines as well as discussion with researcher before the intervention began. This approach help to ensure that teacher understand criteria and observation protocol, the research context, their role and the participant's role, the procedure of the observation, and ethical considerations.

Scholars suggest observation must adheres to a high standard practice. Observation guideline was constructed following the significant elements of observation studies addressed by Morton *et al*. (2016). Ethical aspect is adapted from the ethical guidelines for observing children (Peterson and Elam, 2021) as well as follow observational protocol suggest by scholars (Creswell, 2009; Cohen *et al*., 2007). Accordingly, an observation form includes 1) introduction, 2) observation protocol, 3) observation criteria, and 4) recommendation. The guideline is illustrated in Appendix 14. The observation guideline serves to remind the observer of the significant points of observation, along with any linked themes of interest, and it motivates a reflexive exercise in which the observer can reflect on their relationship to the observed at any given point in time.

Overall, to record observation information and focus on specific aspects of each activity, teacher observers must complete an open-ended observation form that serves as field notes. Teachers were also requested to share their perspectives on the Yes! programme's implementation in the reflection section of the form.

4.9.5 Teacher Interviews

The schoolteacher is another significant primary stakeholder in the educational sector that can contribute to SD. To achieve a sustainable future within 2030, building educator capacities is one of five priorities targeted by the 2030 toolbox (UNESCO, 2021b) because teachers' responsibilities encompass inspiring, motivating, encouraging, and educating students to become powerful change agents (UNESCO, 2017). To bring about societal change through SD in teaching and learning, it is crucial to strengthen teachers' ESD knowledge, and equip them with the necessary information, skills, values, and behaviours to guide and empower students.

This research acknowledged the importance of teachers' perceptions in shaping the STEM-ESD intervention and evaluating its implementation in schools, particularly in the Thai context. The teacher interview aims to explore the teachers' perspectives on integrating ESD with STEM-based pedagogical activities, thereby deepening students' knowledge and skills. Previously, involving the teachers in the observation process enabled them to experience YES! intervention. Using their teaching experiences, they are able to evaluate the STEM-ESD integrated intervention. After the school intervention ends, asking the teacher to share their thoughts can reveal aspects related to student engagement and intervention, especially ESD and STEM integration. They can offer valuable insights into the YES! programme implementation, highlighting obstacles, opportunities, and strategies to improve the intervention for future implementation. Therefore, interviews were conducted with the teachers who witnessed the programme to gather more comprehensive insights.

The interview is a standard tool to observe teacher opinions. This approach is found in many ESD and STEM education studies to collect student and teacher perceptions towards the intervention; for example, in the green school project, stakeholders were interviewed for their opinions on the green school concepts (Iwan and Rao, 2017). Also, teachers were interviewed for their opinion on the study of using the Atlantis Quest game to enhance global student citizenship (Lim, 2008). Charif (2022) also uses interviews to explore teachers' initiatives in schools, especially primary schools in France, with 15 interviewers providing in-depth information regarding ESD initiatives in schools. Similarly, Ssossé *et al.* (2021) interview experts to gain practical and expertise perspectives regarding ESD. Additionally, Wang *et al.* (2011) conducted 45-minute interviews with teachers who had implemented STEM practices in their classrooms following their participation in a STEM integration-focused professional development programme in order to examine their perceptions towards STEM integration.

Interviewing was found to be the method used in research in gifted education, for example, seeking perceptions towards the programme for gifted people in minority groups (Granada, 1997) in Hays (2004) or asking teachers regarding gifted policy, programme identification, and management in school (Anuruthwong, 2017). Aside from that, the interview can be used to gather the teacher's thoughts on interventions involving group work practices. For example, semi-structured interviews were done with questions related to teacher experiences and their reflections regarding the SPRinG project (Blatchford *et al*., 2007).

Research indicates that interviews yield evident advantages. The interview may uncover the instructor's perspective regarding collaborative learning. As well as informing policymakers about STEM education for SD and gifted education, it is vital to provide teachers with insight and recommendations for programme enhancement, particularly concerning future implementation and limitations. For these reasons, I considered using interviews in my study. The semi-structured interview was chosen even though there are possible drawbacks, such as that it requires a lot of time and work and requires the interviewer to be smart, sensitive, calm, and quick on their feet, and they also need to know about the important issues (Adams, 2015). This type of interviews are useful for when follow-up inquiries or formative programme evaluation are needed and it can be employed in mixed-methods research to add in-depth information along with other approaches (Adams, 2015).

To prepare the interview questions, the question draft and interview structure are important elements to ensure the broad scope of the topic to be asked. Based on Cohen *et al.* (2007), Questions can be translated from research questions. This research employed guidelines for drafting questions and interview guides regarding Adam (2015). It also planned a sequence that flowed from introduction to end and contained a wrap-up session with some suggestions that were less intense (Galletta, 2012). As a consequence, the interview guide included questions that covered five topics: general information about teaching experiences, ESD, STEM problem-solving activities, student collaboration, and programme feedback which are illustrated in Table 19. The questions are based on previous research on teacher perception in ESD and STEM (Charif, 2022; Hill *et al.*, 2014; Margot and Kettler, 2019; Robinson *et al.*, 2014; Siew *et al.*, 2015; Srikoom *et al.*, 2017; Wang *et al.,* 2011; Wright and Waxman, 2021). Aside from that, it is also based on the intention to seek the personal experiences of teachers who teach gifted science students in order to inform further recommendations for future implementation.

Aspects	Details
General information	Teaching experiences, School gifted programs, Professional development.
ESD	Perceptions towards ESD , SD definition, experience regarding ESD, ESD with young children, ESD in Thailand, school, and initiative regarding ESD, etc.
STEM problem solving activities	STEM implementation in schools, attitude toward STEM , STEM implementation barriers, and STEM professional development
Collaboration	perceptions towards student collaboration, classroom obstacles for collaboration, techniques, etc.
Perception toward Intervention	STEM with ESD includes ideas to conduct, feedback, suggestions, school implementation, etc

Table 19 The Aspect Regarding the Teacher Interview

Based on aspects of questions in Table 19, both closed-ended and open-ended questions were adopted because the closed-ended questions helped to probe the information before the open-ended questions were asked (Adams, 2015). The open-ended question not only reflect teachers viewpoint, it can makes conversation clearer and offers unexpected information (Cohen *et al.*, 2007). The interview guide also included some extended questions to prepare in case the interview went in the predicted direction. The list of questions and the complete version of the interview guide are shown in Appendix 15.

The initial draft of questions was developed based on the aspect to investigate in relation to the research question, which focused on teacher perceptions of STEM problem-solving practice, gifted education, and ESD. The questions were then listed and sent to colleagues in the science education group for review and feedback. Then it was a trial with another colleague to see if they understood the questions. The revised version is then reviewed by the supervisory team before being translated into Thai by myself and a critical friend to cross-check the language errors.

The interview was conducted with a Zoom application that can record audio and video. Zoom, like Skype and other online video conference platforms, allows users to chat in real time with others in different locations using devices such as computers, tablets, and mobile phones (Archibald *et al*., 2019). It made data collection through Zoom economically feasible and easy for both researchers and participants.

Zoom interviews is less invasive and safer to collect interview data under the COVID situation in Thailand. Even though the school intervention was conducted face-to-face in school, I selected this approach because it can be conducted remotely, reduce close contact and minimise the risk regarding COVID-19. Scholars recommend the Zoom interview under unexpected circumstances, as researchers had to make decision on whether to abandon their current qualitative study or adopt a virtual platform for data gathering (Oliffe *et al*., 2021). Accordingly, Zoom is a viable instrument for collecting qualitative data due to its low price, user-friendliness, data management tools, and safety precautions (Archibald *et al*., 2019). Despite the fact that Zoom is difficult to use and may encounter technical difficulties, it is flexible, secure and provide extra tools such as recording.

Overall, Zoom interviews were conducted with 14 teacher participants after the Yes! intervention ended by conducting one-on-one interviews from 4 days to 2 months after the intervention ended at the most convenient time for teachers. The interviews lasted approximately 43 minutes, and all transcripts were analysed using thematic analysis. However, there were some technical issues when using Zoom, such as registration and installation of the application, the electricity incident, and the internet connection issue. An alternative system, which is the Line application, was adopted at that critical time to assist in data collection and resolve the technical problem in some cases. Line is the mobile application for chat and meetings that is commonly used by Thai people on a daily basis. This benefit helps aid the data collection process quickly and effectively.

4.10 Phase 2: Students' Reflective Diary

As per Table 11, the research endeavours to examine the enduring consequences of the intervention by investigating the attitudes and long-term thoughts of students regarding the Yes! programme subsequent to its conclusion. In pursuit of this objective, students' reflective diaries were utilised to collect student feedbacks. These methodologies afford students the chance to articulate their ideas and perspectives concerning SD concepts, SD competencies, and attitudes regarding the YES! programme.

In the same way that an interview or focus group might gather information via a series of questions, writing can do so. Even though the interviews appeared to be a terrific technique because they do not require respondents to be able to read or write to participate (Parker, 1984), this research used the diary for data collection as alternative. Because information is gathered through nonverbal behaviour and follow-up questions, it is not necessary for a person's self-awareness and writing ability to be crystallised before an interview. Nonetheless, the attitude and characteristics of the interviewer, as well as the interview atmosphere, can cause bias and interfere with student opinion (Parker, 1984). Additionally, with the COVID -19 situation, the researchers chose to gather students' diaries.

Since Thai students in grades 4 to 6 and their age range from 9 – 12 years old. They have developed their writing abilities through various writing tasks in school. As a result, writing can be an excellent tool to collect data because it allows the student time to think critically and reflect on what they have learned and expressed through their writing (Karaca *et al.,* 2016). It can reduce the impact of the interviewer and the interview conditions. Many researchers have reported the use of diaries to assess students learning and perception in several educational practices. For example, reflective diaries are collected from eighth-grade students to evaluate their views on science lessons (Karaca *et al*., 2016). It was used to inform fourth-grade students' academic achievement and writing skills (Can and Kutluca Canbulat, 2019). The findings of Lamsa (2012)'s study indicate that using diary in research with children is benefit for provide individual differences and daily dynamics and some of the conventions in child-related everyday interactions at home. Moreover, the longer-term attitude of students can be collected from their narrative writing over a period of time such as through reflective journal regarding learning for sustainability (Zeegers and Clark, 2014). Another example is when students wrote a reflective report on their problem-solving towards carbon footprints (McGibbon and Van Belle, 2015). The writing can record students' ideas initiated by participating in the intervention.

The reflective diaries are designed with small notebooks with blank spaces for students to take notes and write. Students response provide rich information and impacts of educational programme based on their perspective (Zeegers and Clark, 2014). Following sections 4.9.1, questions may help students think and reflect on their thinking during three months after joining the intervention, and reflection the perceptions about YES! programme. The questions in diaries are based on a self-reflection of aspects including, their perception toward the programme, reflection toward their own action, family and community, the SDGs learning, awareness on environment and their reflection regarding problem solving and EHoM. Example of questions and space for writing is shown in Figure 19. The questions and aspects of the diary are illustrated in Appendix 16.

Figure 19 Example of Reflective Diary.

After classroom intervention, diary are provided to the student. They are able to write to provide evidence of their thinking, learning, and perception about environmental issues and how they deal with them. At home, students can reflect on their thoughts and opinions. They are free to reflect, and at the same time, they are free to skip any prompt they have no intention to fill.

4.11 Ethical Consideration

As the research involved children and teachers and the data collection process was done during the COVID-19 epidemic, it is crucial to take into account multiple elements to safeguard the participants' well-being and address ethical considerations. The ethical protocol followed Brunel University’s code of research ethics, and research ethics approval was obtained (Brunel University London Research Ethics Committee, 2018). The documents used in this research, including the consent form, leaflet, and data collection documents, were reviewed, and the

Brunel research committee approved the research. The ethics approval for this thesis is shown in Appendices A and B. The ethical considerations are explained below.

For the pilot phase, which is done with 160 students, the research information was provided at the opening ceremony and registration. The research information was provided to parents and students by the IPST academic staff, and the research leaflets and informed consent were distributed for the parents to consider. Parents and students are also informed that they are allowed to participate in the activity even if they do not intend to be involved in the research. To emphasise, they have the freedom to submit the documents or decline submission of the worksheet, and there is no negative outcome from not being involved in the research. The research outcome is not related to their academic achievement or indicates their learning ability. After the Q&A session, the consent forms were collected, and the IPST staff marked students whose parents allowed them to participate in the research. Before the activity begins and during the activity, students are informed that they can withdraw from the research or from the activity at any time. After the landslide activity programme ended, 138 worksheets were collected from 145 students with informed consent. The document was packed in a secure envelope and stored with a lock and critical system by the Olympiad and Genius promotion unit head. A reliable system in the UK delivered the package to the researcher.

In the data collection phase, students and teachers from seven schools in Thailand are involved. The data gathering procedure was under the COVID-19 situation, and the research followed the rules in the United Kingdom and Thailand. Permission for data collection was requested from the gatekeepers, who are the school principals and they agree for the research to be conducted in school. School teachers also agree to help in the recruitment process. Risk assessment was done in advance to reduce the risk to students and teachers, and it shaped the research design to conduct the one-time intervention in one day at each school. Due to the fact that research was conducted as fieldwork in Thai schools, school interventions were done in the classroom when the COVID-19 pandemic eased and face-to-face teaching and learning were permitted. All documents and processes were reviewed under the consideration of Brunel University's Research Ethics Committee, and ethical approval was issued before the data collection took place (Brunel University London Research Ethics Committee, 2018).

After getting approval, the application form was sent to each family along with the consent form for parents, the assent form for students, and the research leaflet before the data collection began to inform them about the research and ethical issues. Researcher information was also given to parents to contact for their inquiries. The consent and assent forms were collected before the intervention began. Aside from the information mentioned in the leaflet regarding confidential issues, during the introduction of the Yes! programme in each school, research information was also announced. This research protects the privacy and confidentiality of students and teachers by adopting secure data storage and using pseudonyms to ensure anonymity, guaranteeing that their information is maintained in strict confidentiality, and minimising the risk of participant identification.

To ensure the safety of participants during the COVID-19 situation, the researcher and research assistant were required to provide their COVID – 19 test results two days before and on the day of the intervention to the school. Prior to participating in the programme, both students and teachers underwent COVID testing in accordance with their school regulations. During the classroom intervention, it was mandatory for the researcher, research assistant, students, and teachers to consistently wear protective masks. Students are strongly encouraged to remain in the same group for the whole duration of the programme. In addition, sanitization was conducted consistently during the intervention, including alcohol gel, alcohol sprays, and hand washing. Both before and following the intervention, the materials were thoroughly sanitised. While the schoolteacher was observing the pupils, they were instructed to observe the students from a distance.

This study also takes into account the sensitivity of emotional well-being. The research instruments were designed with the intention of avoiding inducing stress in students, and the methodology was adapted to ensure adherence to cultural norms and values and awareness of culturally sensitive and respectful practices. As the research topic focused on students' environmental concerns, the intention to obtain the students perspective was provided to ensure students understood that their view was beneficial to improving the teaching and learning regarding STEM education and ESD. Although students have the right to reflect and express their opinion about this issue, they will be observed closely during the intervention and will be asked if they need assistance. Their teachers also accompany them during the intervention for additional emotional support. However, the instruction design was carefully planned. The materials used, such as video clips and pictures, were chosen with caution to avoid exerting pressure on the students and without emphasising human death.

During the school intervention, the researcher provided students with information about their discomfort and offered them the opportunity to seek assistance or choose not to participate in the research. Unwilling students can withdraw without any negative consequences. Participants have the option to either observe or actively participate in the research activity or decline to provide information. Their decision will not have any effect on their academic accomplishments. The research does not assess the learning aptitude of pupils or substantiate their talents in the learning process. In the next section, limitation of this study is discussed.

4.12 Limitation of Study: Impact of COVID – 19

The research aims to understand how students' perspectives inform the promotion of their knowledge, awareness, and skills through the intervention. This research was impacted by COVID-19 in the process of data sampling as well as the selection of the research tools as well as the implementation in Thai schools. Thailand is one of the countries where COVID-19 has had an impact on the educational system. The COVID-19 pandemic was a significant concern for students, academic personnel, schools, and educational institutions, while also exposing many societal disparities (Pal *et al.*, 2021). According to Satoshi (2022), the emergence of COVID-19 in Thailand occurred with three waves of situations, resulting in school closures. There are school closures in some provinces during data collection periods. Following research ethics and Thai national guidelines, the data collection schedule was postponed to ensure safety. The research process was modified to ensure the safeguarding of participants regarding the COVID-19 situation. All of the data collection and school intervention were done at the school that opened under the permission and reach safety criteria of Ministry of Education policy. The research was conducted under risk assessment and following the protocol regarding the Thai government. In response to the pandemic of COVID-19, students' perspectives were gathered through safe and accessible methods.

For participant sampling, at first, research participants are expected to recruit the volunteer primary students from the IPST Science and Mathematics Talent Development Programme (SMTD programme) who passed the identification process. Notably, the COVID-19 pandemic had a huge impact on Thailand's educational system, the nationwide programme and summer camp for gifted children has stopped operating. At the same time, government regulations and safety concerns, school gifted programme is an alternative, where on-site learning is permitted under Thai government policy.

The data collection was also impacted by COVID – 19. The ethical application was delayed according to the concerns of health risk. After getting approval, school intervention was conducted with a set of four STEM activities for a period of one day in the school classroom. The number of participants and researchers is less than the limitation of the school classroom according to the on-site teaching policy regarding the Ministry of Public Health. Additionally, on-site learning is one form of education in the COVID situation, and regular teaching can be resumed if the COVID is resolved with social distancing and a plan for emergencies (OEC, 2022). The Thai Ministry of Education has released a set of guidelines for schools, their staff, and students to follow in order to resume onsite classes. The school can open for face-to-face learning or onsite learning under the determination of Thai Stop COVID Plus (TSC+) (Satoshi, 2022). Following the guidelines, the researcher is permitted to conduct the intervention and gather data in one day.

Under the consideration of restriction and risk assessment, I minimised face-to-face contact with research participants and chose alternative methods to obtain rich data. This research opted to conduct classroom observations by schoolteachers and interviews with these teachers using an online platform instead of interviewing individual students. The reasons not to interview students include avoiding in-person interviews for safety, overcoming school time constraints, and reducing technological limitations of online interview. Scholars indicate that many families had economic issues that affected educational support for their children during the COVID situation (Pal *et al*. 2022; Dipendra, 2023). Over 700,000 disadvantaged children in Thailand may lack the financial means to purchase essential equipment for online education including, computers, laptops, Wi-Fi routers, internet access, mobile signals, and TVs (Pal *et. al.* 2022). Mobile phones were limited in some households, especially in the north-eastern and southern regions of Thailand, in 2019, and students in some regions of Thailand were unable to access the internet and devices (Dipendra, 2023). This digital gap was also reported as a major issue in schools since it limits access to broadband internet, computing equipment, and high-quality instructional resources in schools nationwide (Dipendra, 2023). For these reasons, alternative methods were adopted.

4.13 Summary

This chapter explores the philosophical foundations of the research, focusing on the selected methodology—using multimethod with multiple case studies—and the way in which bricolage was incorporated as a methodological framework. The chapter provides a comprehensive account of the pedagogical intervention's progression in developing and the implementation of the YES! programme intervention. Then, this study delves into the intricacies of gathering data during school intervention by employing qualitative methods that are consistent with the epistemological and interpretive aspects of the research design. Diary is used in phase 2 to acquire students reflections toward the programme and SD relevant questions. To sum up this chapter provided an illustrations of tools, participants, and contextual information that establishes the foundation for the ensuing analytical methodologies discussed in the subsequent chapter.

CHAPTER FIVE: METHOD FOR DATA ANALYSIS

In the previous chapter, the data collection was described, including all methods adopted in this research to collect the data based on bricolage approaches. In what follows, this chapter focuses on the analysis methods that were adopted to analyse all the data obtained from several data collection methods. To emphasise, the data analysed in this chapter is inclusive of phase 1 (School intervention which is described thoroughly, as well as phase 2 (reflective diary). The analysis procedure was also described following the obtention of data from both phases. Example of aspects obtained from analysis are also illustrated in this chapter.

5.1 Methods for Data Analysis

The data analysis methods are conducted in this chapter following the data collection methods discussed in chapter 4. This data analysis chapter is divided into four sections, in which different data analysis methods are explicitly discussed and applied according to the three main sections according to the phase of research analysis is divided into four sections, in which different data analysis methods are explicitly adopted according to the three main sections according to the phase of research. In phase 1, evidence collected from student participants was analysed, including pre- and post-intervention questionnaires, the engineers' logbook, photos of innovative products, and students' drawing. Teacher observation forms and interview transcripts were also analysed as was the diary, which is the evidence collected from Phase 2 of this research. The details of each method and the implications are described in the discussion below.

5.1.1 Thematic Analysis

In educational research, thematic analysis is a well-documented method for data analysis, as evidenced in case study research or mixed-method research that involve interview data or student writing data (Chittum *et al.,* 2017; Karlsson, 2020; Peel, 2020). So, when I look into my research design and my data set, there is evidence of research, including the students' answers to the open-ended questions, the observation notes from the teachers that were taken during observing the school intervention, the teachers interview transcripts, and the student's writing in their diaries. These qualitative data sets provide an account of how students and teachers interpret and engage with the intervention and how it affects teaching and learning. Overall, I am looking for the knowledge of the participants, as I believe they are a valuable source of data, and I would like to discover if any pattern or themes emerge from the data collated.

According to Braun and Clark (2022), ‘Thematic analysis is defined as a strategy for producing, analysing, and understanding patterns across qualitative data sets that involves a systematic process of data coding to produce themes for ultimate analytic purposes’ (p. 4). With six steps , thematic analysis can be done by starting with 1) familiarisation or getting acquainted with the data, 2) coding or creating the initial codes, 3) searching for themes, 4) reviewing themes or going over the themes again, 5) establishing themes by defining and naming themes, and 6) writing up or creating a report (Braun and Clark, 2006). Based on Maguire and Delahunt, 2017), these steps are not linear and it allows to step back and forth between them.

Themes in analysis capture important aspects of the data in light of the study questions; they show the existence of underlying patterns of response or interpretation within the data; determining what is to be considered a theme requires judgement (Braun and Clarke (2020). However, the step to consider before creating the theme is coding (Braun and Clarke (2020), state that when doing a reflective thematic analysis, codes are building blocks of analysis which capture meaning that is pertinent to the research issue, and these elements can range from being summative to descriptive to being more interpretative or conceptual. So, what to look at in the coding is not only the information or the product as an analytic fragment, but it can also be somewhat interpreted from the information. Maquire and Delanhunt (2017) suggest that coding minimise data into small chunk that contain meaning. After coding is done, a theme must be initiated before being reviewed and established.

In this research, the analysis was done several round. The first round came up with the initial themes with an early set of codes and potential topics that need further research before being settled. The initial theme emerges from coding through an example number of data from all tools used in this research. These initial themes were reviewed before asking critical colleagues in the educational field to assist and determine that codes are suitable to establish the theme in the thematic analysis process of those pieces of evidence. This is to ensure that I covered all aspects and that the analytic process was done to generate the theme.

The full set of themes was then reviewed again to establish the final theme, and as the data collated in the research is in Thai, Thai themes must be translated into English to be reported. The use of critical friends as well as the issue of translations between Thai and English are discussed in sections 5.2 and 5.3, respectively.

5.1.2 Drawing and Photo Analysis

Previously, the data collection was described in Chapter 4. For analysing student drawings, Hopperstad (2008) suggested that drawings can be analysed in terms of the meaning of the objects and what the students expressed. The students can display their learning process and conceptualisation and can be evaluated with the label and image composition (Göçmençelebi and Tapan, 2010). This type of evaluation of the labels in the drawing was often used to analyse students' drawings in science education (Hoese and Casem, 2007; Göçmençelebi and Tapan, 2010). In those studies, three categories of labelling were defined: comprehensive labelling, partial labelling, and incorrect labelling (Hoese and Casem, 2007; Göçmençelebi and Tapan, 2010). The composition of the concept was also examined and characterised into three categories: visual-iconic drawing (exactly representing what had been taught), conceptual drawing (correct but different from what had been taught), and redundant drawing (not related to the concept) (Hoese and Casem, 2007).

Example of student sketch analysis is found when coding is done related to students design. Students' sketches were analysed to investigate the ability to visualise which fall under two themes: 1) ability to visualise, and 2) meaning of what they visualised. The first one refers to the ability to plan and express ideas and 'visualise' their ideas to a team that represents it through perspectives and material placement. The meaning of what they visualised is the idea of solutions, which was the result of their decision-making to solve the problem. Following the pilot phase, where the students' drawings were analysed, the analysis in this phase was also conducted with the same protocol.

Aside from the sketches, this research also collects the photos of inventive products created by students and the photos of the products after testing. The photo was used in research especially in the social science area for qualitative inquiry (Szto *et al.*, 2005). Hanna's (2020) study of 32 articles supports the idea that over 19-year periods, many scholars adopted photos in research in education, and primary education is one of the areas where photos are considered research tools. Her work also reviewed that photos were taken in the form of both researcher and participant generation, and they support the inquiry around visual, participatory, and art-based research methods (Hanna, 2020). This is because students are research participants and participate in hands-on problem-solving activities, photos were used to capture the product they created as a result of EHoM application.

Visual methodology is known as a method that requires understanding and interpretation of the photo (Glaw *et al*., 2017). A photo can be analysed, and a theme can emerge from the analysis of the photo like text or a sketched offer. Glaw and colleagues (2017) also support the idea that evaluating photos can provide perspective about life's sources of meaning and attitudes about life's purpose in people. Example is found in the study of Karademir (2016) when third and fifth grade students drawing were analysed regarding their design and imagination for investigation of creativity based on criteria. Thomas (2009) provided the analytical methods for the photo by looking for themes that indicated numerous themes arose and interpreting how the themes were grouped.

As a result of the thematic analysis, which provided a clear demonstration of the qualitative process, it was adopted to find the theme in the photos and students' drawings obtained in this research. The studies by scholars guide the analysis during the process when initial codes were created arising from the photo and drawings, leading to the emerging of themes such as ability to visualise or solutions that students constructed.

5.2 Role of Critical Friends in Research

Qualitative research often faces the issue of rigour and validity, and critical friends are considered to increase rigour in research (Coghlan and Brydon-Miller, 2014; Noor and Shafee, 2021). In this research, experts, PhD students, IPST colleagues, Thai postgraduate students in the UK are considered critical friends, and reflections are provided following the critical friend process (Costa and Kallick, 1993; Storey and Richard, 2013). Critical friends are the people suggested to give both negative and positive feedback to develop the teaching and learning practices in various education researches and provide benefit in improving educational settings (Costa and Kallick, 1993; Baskerville *et al*., 2009; Storey and Richard, 2013), such as in action research in ESD at the higher education level (Cebrián, 2016), and improve the school and leadership in school (Gurr and Huerta, 2013). They can be individuals from both within and without the research fields (Noor and Shafee, 2021). Insiders refer to those who are connected to the inquiry, whereas outsiders have no affiliation to the research being conducted (Coghlan and Brydon-Miller, 2014).

Critical friends play an important role in this research in three ways. First, they provided critical reflections on the practical intervention and data collection tools as Cebrian (2016) highlights the advantages of critical friend in facilitate learning. For example, the Engineers' logbook was reflected by an IPST colleague who experienced gifted educational programmes with young children, together with a Thai expert in the field of ESD. The visual aids and instructional approach were reflected by IPST colleagues to ensure the engagement of the programme and school intervention organisation. These insights increased the strength of the programme before the 'YES! programme' was implemented at schools.

Second, in the analysis process, critical friends reflect on theme and code at the initial state of coding and the final stage before presenting the result. English *et al*. (2017) also adopted this step with their research team for review initial themes and codes. As Miles and Huberman (1994) believe, incorporating two outside/independent reviewers at two separate phases would 'probably' build a strong analytical credibility process 'equivalent to reliability from a positivistic perspective' (Miles and Huberman (1994), cited in Hosmer, 2008, p. 52). Alhojailan (2012) advised researchers to look through the outside reviewer's theme list and find participant excerpts that support each theme. According to the critical friend discussion, I was able to continue analysing the rest of the evidence after reviewing the theme at the early stage of coding. After a critical friend reviewed the findings, I was also able to come up with and report finalised themes to address the research questions. Additional round of reviewing is also conducted by English *et al.* (2017) to check and find agreement among the team members.

In addition to theme reviewing, critical friends took part in the translation process to ensure the rigour of language in documents, lesson plans, and findings. The issues regarding the translation of data and its meaning are described in the following section.

5.3 Issue of Language for Interpret Qualitative Data and Rigour Enhancement

This research is conducted in a Thai setting and employs the Thai language for research inquiries. Smith and colleagues (2008) highlight that data collected in regions where English is not the primary language, such as Asia, are often gathered in the national language, which poses challenges for analysis. Translating transcripts into a shared language throughout the research team is a time-consuming and expensive process (Smith *et al.,* 2008).

To bolster the rigour and validity of qualitative data in this research, many strategies were employed. This ensures that the findings accurately capture the experiences and perspectives of participants within their cultural context. First, the research collected the data in Thai, and the initial thematic analysis was done in the same language. Smith *et al.* (2008) proposed strategies to tackle the difficulties associated with collecting, evaluating, and interpreting qualitative data in a particular language in order to maintain transparency in qualitative studies. Additionally, scholars also advise adhering to the original language, as it can help mitigate potential constraints in the analysis and increase validity (Abfalter *et al.*, 2020; van Nes *et al.,* 2010). The advantages are found to overcome unambiguous communication, streamlined data gathering, and precise transcription (van Nes *et al*., 2010). These benefits enhance the efficiency and validity of the qualitative research process.

Secondly, translation plays a crucial role in cross-language research, influencing research methodology (Temple and Young, 2004) and ensuring rigour and validity (Abfalter *et al*., 2020; Cormeir, 2018). Following this, decision-making in translation becomes a critical consideration during the data analysis process. It is advisable to perform translation after data collection as it preserves the original meaning of qualitative data and is more cost-effective (Abfalter *et al*., 2020; Cormier, 2018; Temple and Young, 2004). We conducted translation after data analysis in this study in accordance with the framework as Abfalter *et al.* (2020) suggested. At this stage, critical friends—Thai Ph.D. students in the United Kingdom and Thai colleagues who work in international environments—were volunteered and involved in translating only themes and codes without accessing the original data. Both the researchers and colleagues translated themes from Thai to English after the Thai analysis. Due to the challenge of translating Thai concepts without losing their meaning and context, thinking and reflection processes and collaborative discussion were employed when significant differences emerged between the two versions to deliberate and determine the most suitable wordings. (van Nes *et al*., 2010). Discussions between the researcher and critical friends ensured the accurate representation of meaning in Thai. Importantly, these discussions aimed to address issues of bias and inaccuracy, common problems when interpretation is involved (Brämberg and Dahlberg, 2013; Cormier, 2018).

5.4 Role of Technology in research : NVivo

Using technology in qualitative research is encouraged due to its benefits, such as increasing research rigour, saving time, and assisting with data management (Hilal and Alabri, 2013). NVivo, one of the computer software programmes for analysing qualitative data, provides numerous benefits and enhances effective research (Hilal and Alabri, 2013). Wong (2008) claims that NVivo assists qualitative research analysis beyond data coding, sorting, and retrieval by combining coding with qualitative linking, shaping, and modelling. Although issues are presented that the tool can create separation between data and researcher and generate oversized qualitative research (Mortelmans, 2019), this research used NVivo for data management. This study use NVivo to assist with the manual coding in Thai which is beneficial for managing different types of data in this research. Begins by uploading the Thai transcript to the software. The documents are organised by category and order before coding. With the use of the highlight option and node creation, I can produce distinct colours of text and groups of codes that are safely stored by the software. Unlike traditional coding, which was done by hand and used coloured pens to identify data before sorting it, software speeds up the sorting process and aids in data organisation and storage (Wong, 2008). At the final stage, the codebook can be generated and used for language translation. After interpretation, this research adopted NVivo to translate all qualitative data.

5.5 Analysis Methods Applied in Phase 1 School Intervention

In the previous Chapter, Data collection in phase 1 (school intervention) was explained in detail about the materials used differently and its rationale. Data analysis will be made to analyse the different types of data including Pre and Post intervention questionnaires, student logbook, Sketch, Photo, observation form and interview transcripts. The entire analytical procedure of the evidence is delineated as follows:

5.5.1 Pre-and Post-Intervention Questionnaires

This research employed thematic analysis to examine the responses to the open-ended items in the pre- and post-intervention questionnaires. Since the students are Thai, they communicated in Thai, resulting in responses solely in Thai language. The data was transcribed from the paper document onto an MS excel form. The answers of opened questions were imported to NVivo. According to the type of question asked in the pre-test and post-test, open-end questions which provided qualitative answers were analysed with thematic analysis. Themes encompass students' background knowledge, knowledge of SD, attitude toward solving environmental issues, awareness of SD, perception toward collaboration. Key themes from this phase are presented in Table 20 and Table 21.

Elements of framework	Themes and Subthemes
Environmental issue	Students' Understanding about environmental issue • Causes • Impacts • Solutions • Sources of understanding landslide, flood, drought and waste in the river and ocean, Students' perception about environmental issue • Future perspective • Significance of solving the issues • Issues that students most concern about
SD concepts, SDGs and Competencies	Students' understanding of SD • Concepts of SD • Link between SD and environment
STEM problem solving	Students' perception regarding problem solving with environmental issue • Solving environmental issue
Collaboration	Students' perception toward collaboration • Characteristics for working in team • Factors for Successful teamwork

Table 20 Keys Themes From Pre-Intervention Questionnaires

Table 20 shows key themes that emerged from the pre- intervention questionnaires. Additionally, key themes from post-intervention questionnaires are presented in table below.

Elements of framework	Key Themes
Environmental issue	Students' Understanding about environmental issue • Causes • Impacts • Solutions Students' perception of environmental issue • Significance of solving environmental issue
SD concepts, SDGs and Competencies	Students' learning SD concepts, SDGs and Competencies • Students' concept of SD after joining the YES! programme • Awareness of SDGs • Students' practicing competencies for sustainability
Collaboration	Students' Perception toward collaboration • Awareness of collaborative skills, • Awareness of significant of collaboration, • Awareness of their team members

Table 21 Keys Themes From Post-Intervention Questionnaires

On the other hand, students were asked yes-no questions, which were only used as probing questions and classification questions. Numerical data was analysed with basic descriptive statistics. There are four nominal items regarding the source of knowledge about four environmental issues so that I can see how they learn the knowledge regarding ESD. They also reported that they knew or did not know about the issues. This dichotomous data was analysed statistically. From figure 20, the number of students who know or do not know about landslides, floods, droughts, and waste in the river and ocean is displayed.

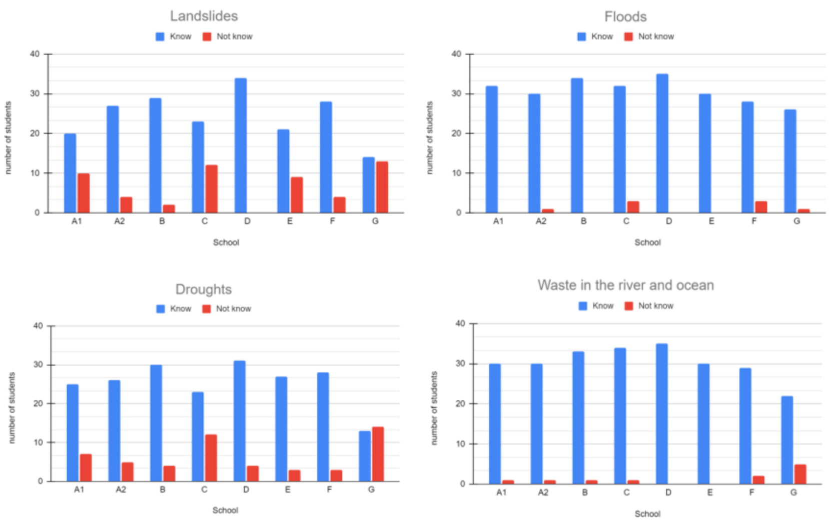


Figure 20 Students' Background Regarding the Environmental Issues

Finally, students also indicated how they perceived about the issues through different sources such as school, TV or news, personal experiences, and others. Figure 21 depicts how students from various schools learned about landslides, flood, drought and waste in the river and ocean.

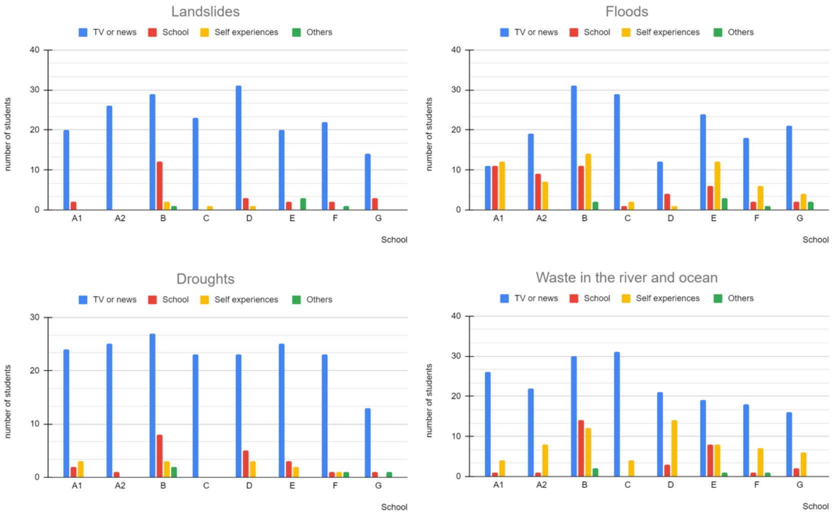


Figure 21 Students' Sources of Learning About Landslides, Flood, Drought and Waste issues

5.5.2 Engineers' Logbook, Drawing and Photo of Innovative Artifacts

The engineers' logbook, as mentioned in the previous chapter, is written material that is expected to collect in-depth qualitative data reflecting problem-solving ability and environmental awareness in each activity during the sustainability discussion. In educational research, different coding schemes can be used to analyse students' workbook. An example of that is the research on students making buildings against earthquakes; the student workbook was analyzed by ethnographic analysis, which looks at students' focus group talks in detail, while the workbook on building earthquake-resistant buildings adopted open coding with iterative refinement cycles (Lesh and Lehrer, 2000, cited in English *et al.,* 2017). As already mentioned, thematic analysis is considered a crucial part of the analytical process because it breaks down the data and creates something new. Given its benefits and clear analytical steps, the engineers' logbook also undergoes thematic analysis.

Chapter 4 outlines the design of the engineers' logbook, which includes elements that monitor students' problem-solving abilities as they practice EHOM and reflect on their SD competencies during sustainability discussions. The open-ended questions are framed to assess students' knowledge about environmental issues, the application of EHoM, understanding of the problem-solving tasks, how students solve problems, and their reflection during the sustainability discussion. Following the six steps of thematic analysis the Engineers' logbook was analysed. Theme and subthemes that emerges are what to explored regarding to that.

Reading carefully through the students' reflections from the logbook to familiarise myself with the data reveals that the writing embodies the group expression of EHOM, which is based on six elements including problem finding, system thinking, visualising, creative problem solving, improving, and adapting. Furthermore, their reflections on SD and SD competencies, as outlined in Chapter 3's framework, encompass self-awareness, anticipatory, normative, and system thinking competency. Despite the fact that the scientist is only a member who participated in the writing and recording of all ideas in each activity, it is assumed that all reflections are the result of the decision-making process used in the collaborative problem-solving and sustainability discussions. Figure 22 is an illustration of what students wrote in the engineer's logbook to answer the open-ended questions.

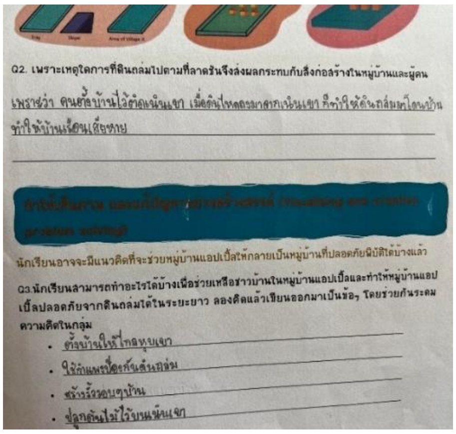


Figure 22 Example of team 1’s Engineers’ Logbook of School D.

Moreover, the protocol for analyse the engineers’ logbook is displayed in figure 23.

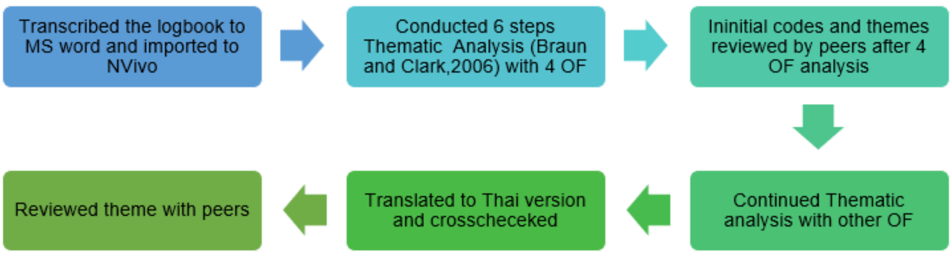


Figure 23 Procedure for the Analysis of Open – Ended Answers in the Engineers’ Logbook

At the initial coding step, the initial codes and themes emerged from the analysis of four engineers’ logbooks were reviewed by peers in order to ensure analytical credibility as recommended by scholars. Subsequently, the thematic analysis was conducted with all engineers’ logbooks manually through NVivo following the 6 steps of thematic analysis before the themes were translated into Thai under the process of critical friend translation. Then, English themes and codes were reviewed with critical friends who are PhDs in education for feedback and consideration before presenting the findings. Theme of logbooks encompass practicing EHoM and reflection of competencies for SD. The example of themes, codes is presented in Table 22 below.

Elements of framework	Themes	Subthemes	Code
SD concepts, SDGs and SD competencies	Students' SD competencies	System thinking Anticipatory thinking Normative thinking Self-awareness	How landslide create impacts, link between flood and climate change, Effect of drought in different sectors Future consequences of no plan, Long term solutions People adaptation to flood Awareness of drought
STEM problem solving	Students' practicing of EHoM	Problem finding Visualising System thinking Creative problem solving Improving Adapting	Problem of the village , Flood issue of Mango city, Problem without govern support, Problem of the whole country, Solutions in Drawing, Drawing perspectives, Annotations Water management system for drought Solutions for landslide , Solutions for drought, Solutions for floods, Soltuioons for waste in the river and ocean, Solutions of aretefacts Students' making change, How to improve the aretefacts Solution in real life context
Gifted development	Students' attitude of YES! programme	Preference Emotional Engagement Negative attitude	Problem solving, Acquisition of knowledge, active participant, increase imagination, collaboration, career aspiration Positive emotional engagement, Negagtive emotional engagement Activity,

Table 22 Key Themes From Engineers' Logbook

Table 22 shows the themes from the answers toward the open-ended questions. In addition to the open-ended sections, spaces also provided for students' drawings. Students who create the drawing have the role of architects. Four architects took part in drawing their own sketches. There are four sketches in total for each engineering team according to four activities: landslides, floods, droughts, and waste in the river and ocean. The examples of drawing in each activity are shown in Figure 24.

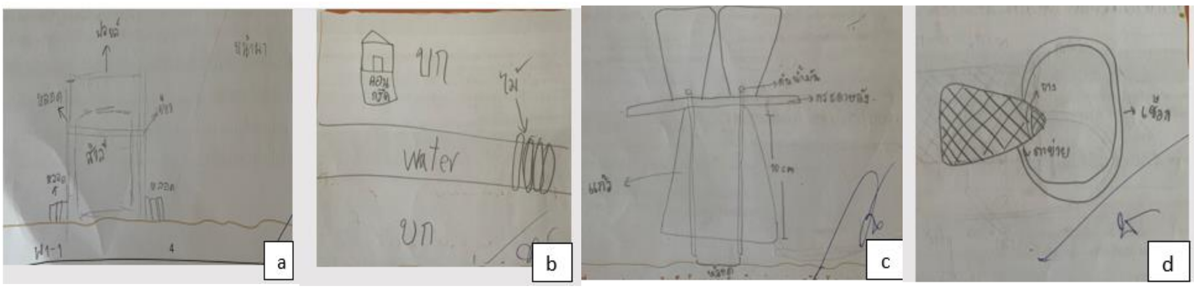


Figure 24 Example of Students' Drawings

a) Landslides prevention b) Are we ready for the flood
c) Drought is coming d) Journey of the waste form the river to ocean

Based on several studies regarding students design and drawings (English *et al.*, 2017; King and English, 2016; Kose, 2008), this study investigates ability of students to visualise and the meaning of their plan in drawings as the themes and codes. Also, the annotation of the drawing with the label investigates the design process and informs the materials used for further construction, which better helps solve the problem.

Additionally, in activity 4, students also created visual diagram to demonstrate how microplastic was found in the body of a man who lives in Phuket, Thailand, the source of the microplastic was a Yoi-Yoi snack packaging which was thrown in the river in Chiang Mai, Thailand. Figure 25 illustrates the students' concept map, which refers to the application of food chains to describe the situation. The concept map was analysed with Thematic analysis to reflect their application of knowledge in science (food chain) and plastic degradation (microplastic generation) that was taught during the introduction of activity 4.

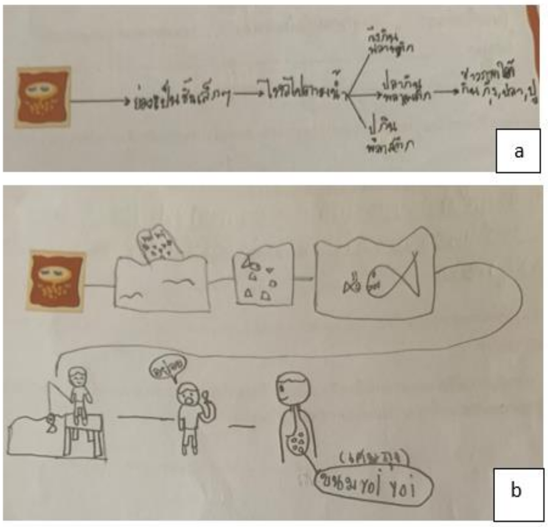


Figure 25 Two Example of Students' Visual Diagrams from School B
a) Group a b) Group b

The figure above represents how microplastic from plastic waste was found in the body of a man in a different location from where plastic was irresponsibly littered. The analysis of this drawing diagram is focused on the meaning of 'conceptual' as the outcome of the integration of knowledge from the classroom and the intervention. The conceptually provided connection of how microplastic was transferred from its original source to the human body via the food chain was the focus of the content analysis. Furthermore, components of a concept map were also used to describe the visualising ability that is related to representing processes and bioplastic transfers through the related concept of the food chain. The components are arrows, figures, and labels. Students' visualising in 2D and 3 D also observed.

In addition to the students' drawings, photos can be analysed to see the results of practicing EHoM through EDP in the activity. As mentioned in the previous chapter, two shots of a photograph were taken. The example of photos and drawings taken form activity are presented in Figure 26 and Figure 27 respectively. Each shot was evaluated using thematic analysis by looking through the drawings carefully and create initial codes. Themes in Table 22 are emerged from clustering the codes, and then reviewed before defined and naming themes.

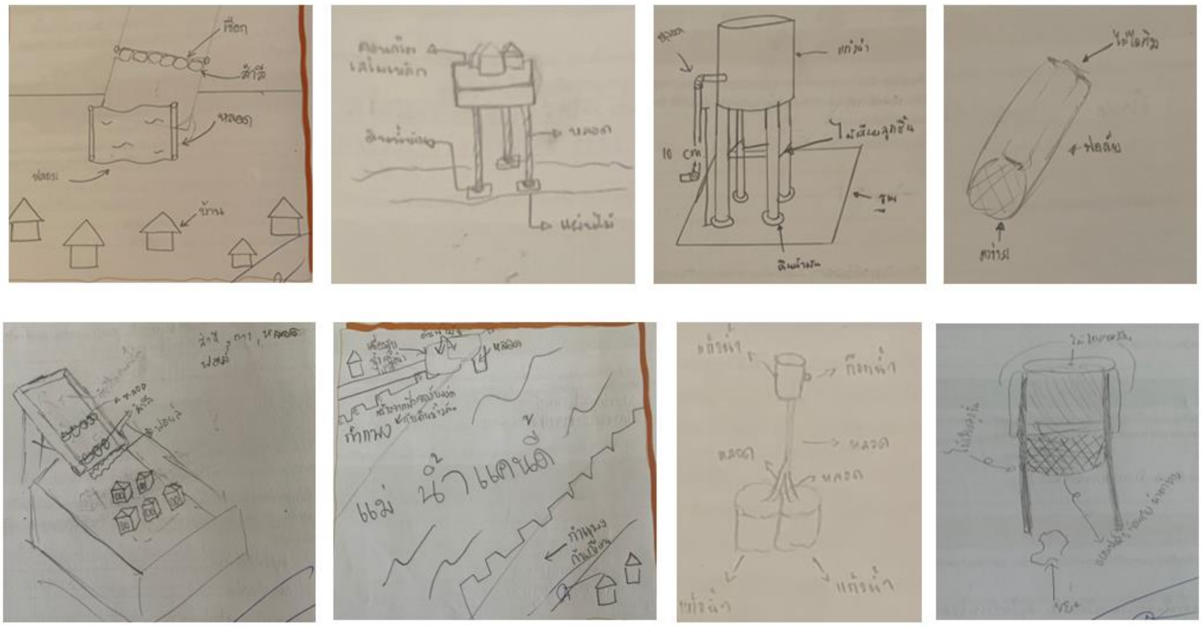


Figure 26 The Students' Drawing

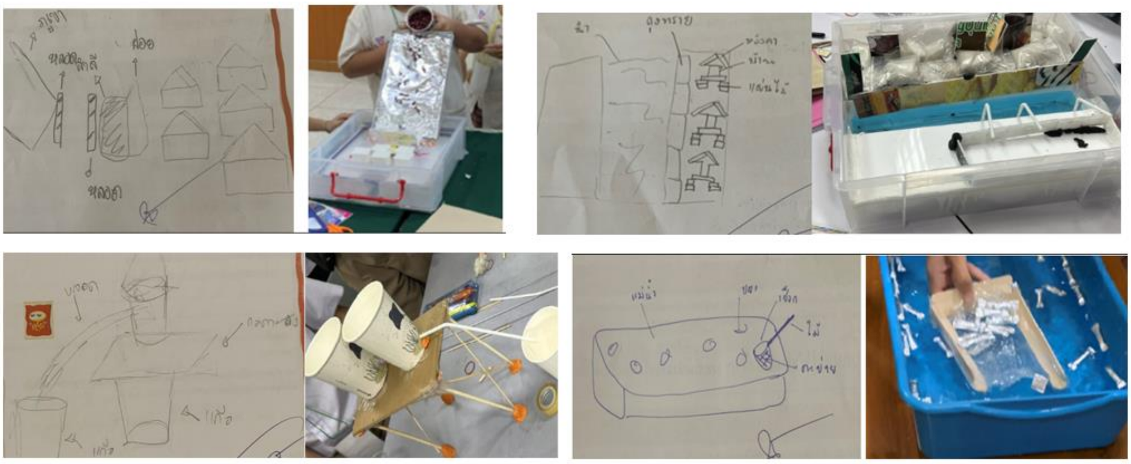


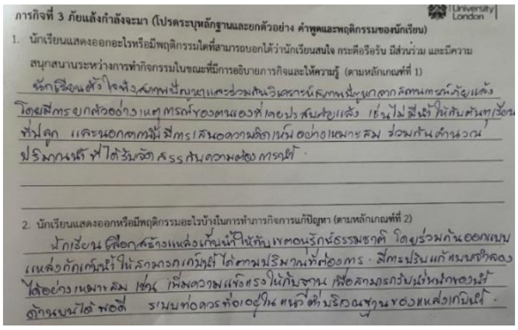
Figure 27 The Students' Drawings and Photos of Artifacts

The Figure 26 and 27 above illustrate the students' visualising and improving habit of mind as codes and themes regarding EHoM are emerges from the meanings and compostitions of the drawings and photos of their products.

5.5.3 Analysis of Teachers Observation Form (OF) in Phase 1

According to Chapter 4, the observation form is used to collect the qualitative information that indicates the expression and behaviour of students while participating in each activity through the eyes of the teacher observers. The information answers several items of the open-ended question and covers aspects such as student engagement during knowledge delivery, student engagement during problem solving, and student expression and engagement during the sustainability discussion in all four activities in the YES! programme. Moreover, the reflection of the teacher regarding intervention, student problem solving opportunities, collaboration opportunities, the appropriation of the intervention, and the appropriation of knowledge given are also included.

The observation form was recorded with teachers' handwriting on the form. The data were then transcribed into MS Word before being imported into NVivo, where I conducted the analysis manually. As in the previous section, the thematic analysis is used to analyse the data in six steps (Braun and Clarke, 2006). The themes regarding all those aspects are created. An example of the observation form obtained from the data collection is presented in figure 28 before it was transcribed in MS Word.


ภารกิจที่ 3 ภัยแล้งกำลังจะมา (โปรดระบุหลักฐานและยกตัวอย่าง คำพูดและพฤติกรรมของนักเรียน)

1. นักเรียนแสดงออกอะไรหรือมีพฤติกรรมใดที่สามารถบอกได้ว่านักเรียนสนใจ กระตือรือร้น มีส่วนร่วม และมีความสนุกสนานระหว่างการทำกิจกรรมในขณะที่มีการอธิบายภารกิจและให้ความรู้ (ตามหลักเกณฑ์ที่ 1)

นักเรียนตั้งใจฟังสภาพปัญหาและร่วมกันวิเคราะห์สภาพปัญหาจากสถานการณ์ภัยแล้ง โดยมีการยกตัวอย่างเหตุการณ์ของตนเองที่เคยประสบภัยแล้ง เช่นไม่มีน้ำให้กับต้นทุเรียนที่ปลูก และนอกจากนั้นมีการเสนอความคิดเห็นอย่างเหมาะสม ร่วมกันคำนวณปริมาณน้ำที่ได้รับจัดสรรกับความต้องการน้ำ.

2. นักเรียนแสดงออกหรือมีพฤติกรรมอะไรบ้างในการทำภารกิจการแก้ปัญหา (ตามหลักเกณฑ์ที่ 2)

นักเรียนเลือกสร้างแหล่งเก็บน้ำให้กับเขตอนุรักษ์ธรรมชาติ โดยร่วมกันออกแบบแหล่งกักเก็บน้ำให้สามารถเก็บน้ำได้ตามปริมาณที่ต้องการ มีการปรับแก้แบบจำลองได้อย่างเหมาะสม เช่น เพิ่มความแข็งแรงให้กับฐาน เพื่อสามารถรับน้ำหนักของน้ำด้านบนได้พอดี ระบบท่อควรต่ออยู่ในแนวที่ต่ำบริเวณฐานของแหล่งเก็บน้ำ.

Figure 28 Example of Observation Form Recorded by Teacher Thana

Figure 28 above demonstrates the language teachers used in their writing which is Thai. Therefore, the coding process was conducted manually because the observation forms were written and transcribed in Thai. With the benefits of NVivo, the inductive thematic analysis was conducted in six steps, as described at the beginning of this chapter. The programme is useful for getting acquainted with the data. The annotation is helpful for making comments that reflects my thoughts on the code or note that I created. It was particularly beneficial when I wanted to review the nodes and themes generated.

Having two critical friends with strong critical thinking skills who are also PhD students in the field of education. They assisted by reviewing the transcript and checking the codes, themes, and subthemes in the codebook I obtained from my analysis using an example of the observation forms. The feedback helped me ensure that I covered all aspects and that the codes were under the right themes and subthemes. This process gave me confidence, and before diving into further observation and analysis, we settle on what, if anything, should be added to or removed from the codebook. At the end of the six steps of thematic analysis, I and another peer translated the themes into English, and then we compared the two versions to make sure they were consistent linguistically. After making sure that the themes were well represented, the answer to the research question was addressed, and the code and subthemes represented the response, The English version was reviewed again by critical friends to make sure that they were all correct. The process of data analysis is illustrated in Figure 29.

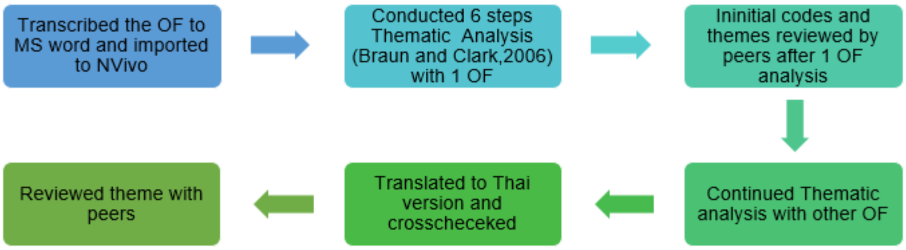


Figure 29 Analysis Process of Observation Form (OF)

From the process above and the 6 steps of thematic analysis employed with observational data, thematic categories of codes emerged, such as student engagement, problem-solving skills, and collaboration opportunities. Examples of excerpts are found in Tables 23 to illustrate the initial coding process before reviewing by peers.

Theme: Practicing Engineering Habits of Mind		
Sub Theme	CODE (NODES)	EXERPTS FROM OBSERVATION FORMS
System thinking	Connect background knowledge with the cause of issue	มีการเชื่อมโยงความรู้ของตนเองจากปัญหา "หน้าผามีความลาดชัน ทำให้เมื่อฝนตกดินจะเปียกจะทำให้ดินสไลด์และถล่มได้ There is linked to their own knowledge of the problem "The cliff has a steep slope. So when it rains, the soil will get wet, causing the soil to slide and landslide' (T9)
Creative problem solving	Analysing material	เพื่อนในกลุ่มบางคนพูดแย้งว่าวิธีที่เพื่อนเสนอมานั้นไม่น่าจะได้ผล เพราะวัสดุที่ใช้น่าจะไม่สามารถป้องกันได้นาน ดังนั้นจึงต้องเปลี่ยนวัสดุเพื่อให้ยืดอายุการใช้งานของวัสดุ เพื่อให้เกิดความคงทนและคุ้มค่า Some friends in the group argued that the method proposed by the friends was unlikely to work because the materials used should not be able to protect for a long time. Therefore, materials must be replaced to extend the service life of materials to achieve durability and cost-effectiveness. (T1)
	Apply STEM knowledge to solve problem	สร้างถังที่มีท่อ และปิดสนิท ใช้แรงดันอากาศ คือถ้าเปิดฝาถังน้ำถึงไหลได้ เป็นการควบคุมระบบการจ่ายน้ำ Building a water tank with pipes and seals, using air pressure, that is, if the cover of the water tank is opened to reach a flowing state, it is the control of the water supply system. (T10)

Table 23 Example of Themes, Codes and Excerpts from Observation Form Analysis

From Table 23, after reviewing themes for several rounds and were checked with critical friends. Thematic analysis was conducted with all observational data. Themes are reviewed before being finalised, which then translate into English as present in Table 24.

Elements of framework	Themes	Subthemes
SD concepts, SDGs and Competencies	Students' engagement in sustainable development discussion	Behavioural engagement Emotional engagement
STEM problem solving	Students' engagement during problem solving Teachers' Perception of problem-solving skill and EHoM	Behavioural engagement Emotional engagement
Collaboration	Students' engagement in collaboration Teachers' perceptions regarding students' opportunity for collaboration	Behavioural engagement Emotional engagement Collaboration opportunities Attitude toward the programme regarding collaboration
Gifted development	Students' engagement in the YES! programme Teachers' attitude toward the YES! programme	Behavioural engagement Emotional engagement Advantage of the programme Limitation of programme

Table 24 Key Themes from Teachers' Observation Form

From Table 24, example of key themes and subthemes represents some findings. Next section, analysis of teachers interview is discussed.

5.5.4 Analysis of Teachers Interview in Phase 1

The interview transcript is the product of the interview, which is qualitative data, just like the observation note by the teacher and the Engineers' logbook written by students. Again, as mentioned in the qualitative data analysis, information obtained by semi-structured interviews was analysed using thematic analysis (Braun and Clarke, 2006), which was done manually with NVivo.

Teachers and I spoke in Thai throughout the interviews, following the guidelines of semi-structured interviews conducted in a natural setting, and I transcribed the audios word for word. The 14 interview transcripts were imported into NVivo using the same protocol as the observation form (Figure 29). I conducted the analysis manually using the tool provided by NVivo. The observation form analysis proved that NVivo is considered a valuable tool for handling the large amount of data I collected. I was able to make notes about how teachers responded to certain codes and then use different colours to highlight related themes and subthemes. I became acquainted with the teachers' responses by reading through fourteen interviews before analysing the teachers' questions, using inductive line of reasoning based on the recurring themes that emerged in our discussions. Then, data was analysed using the 6 steps of thematic analysis.

From the analysis of the interview, themes and codes existed and reflected the answer to the question, while others emerged during the conversation. An example of excerpts and codes presenting some themes that reflect the answer to the research questions are presented in Table 25.

Theme	Code	quote
Theme: Teacher perception toward the programme		
Sustainability knowledge and awareness	Linked to real world problem	เขายังย้อนกลับมาถามคุณครูว่า คุณครู ถ้าไม่แก้ที่บ้าน เราแก้ปัญหาน้ำท่วมที่โรงเรียนได้มั้ย อย่างงี้นะคะ เพราะว่าเวลาฝนตกเยอะๆ บางพื้นที่ของโรงเรียนเรามันเป็นเหมือนกับว่า มันต่ำกว่าจุดอื่นน้ำก็จะไหลไปรัง มันต้องรอสักพักนึงน้ำถึงจะระบายไปทัน แล้วทีนี้เขาจะเดินผ่านไม่ได้ เขาก็จะเปียกอย่างนี้นะคะ เขาก็เลยมองภาพออกเลยนะคะ ครู ถ้าเราแก้โรงเรียนเราก่อนได้ไหม อย่างนี้นะคะ The students also came back and asked the teacher ...Teacher, if you don't fix it at home Can we solve the flood problem at school? When it rains heavily, some areas of our school seem lower than others, and water will overflow. It had to wait a while for the water to drain. Then he is unable to walk through and He can get wet. So that, he can see the picture clearly... He said.. Teacher, if we solve it in our school first, like this
	Aware the impact of human activity	อันที่สองค่ะเรื่องของการพัฒนาที่ยั่งยืน คือทำให้นักเรียนตระหนักถึงสิ่งแวดล้อม น่ะค่ะ ตระหนักถึงว่า ว่าเมื่อเค้าทำตัวนี้ หย่อยหย่อยน่ะค่ะ ถุงหย่อยหย่อย มันทำให้เค้ามองว่า เอ้อ ที่ตรงนี้ บางทีมันอยู่ภูเก็ต แต่ได้รับผล ไม่เฉพาะที่ของเรา แต่เป็นที่อื่น The theme of sustainable development is to make students aware of the environment and realize that when they do so, they will become worse. The case of the small bag 'Yoi Yoi snack bag' made her think oh, maybe it from here, the impact can affect at Phuket ... So, not only ours, but somewhere else

Table 25 Example of Themes, Codes and Excerpts from the Teachers Interview

Table 25 shows the emergence of initial themes and codes prior to peer review. Table 26 illustrates initial themes and codes.

Aspect	Theme	Codes	
Teacher perception toward Intervention	Positive feedback of Activity content	• linked to future scenario • related to Children background knowledge and experienced • Provide student knowledge and skills • Activities are new • Global issue • Related to classroom knowledge	• Students are part of the situation • Daily life issue • Story telling • Continuation of situation • Simulate of the situation
	Suggestion for future improvement	Extension of activity • Develop more activity • Use cheap and available material • Apply with more SD topic • More environmental situation in Thailand • More activity linkage with curriculum • More easy to use for teacher • Add more different way to solve problem Time Management • More time for reflect opinion • More time for idea generation • Speed up the activity • Reduce number of activity per day • More time for doing activity	Management • More assistants • Need suitable place Activity improvement • Content related with Waste • Technology implementation • Encourage career appreciation • Increase information seeking • increase interest stimulation • More presentation • Add entertainment • Use easier language (EHoM) for understand
Teacher perception toward ESD	Definition of SD	• Long-term solution • Living, good quality of life, coexisting with nature, and maintain the future • Sustainable agriculture, building construction and housing development • Continuous development from the present to the future • Developments that improve living standard, preserve resources,	• enable the replacement for the part that was used and continues to develop, • allow further promoting of resources until sustainability is achieved. • development or preservation having resource for long-term usage, not only in our generation but also for next generations. • Simultaneously develop economy, society and environment
Teacher Perceptions toward STEM	STEM for Gifted Education	benefits for student development • understanding of knowledge • practice the thinking process • working together • practice problem solving • practice presentation • design practice • practice skills • practice inventing and constructing • involve technology.	Encourage learning engagement • Enjoyable • Challenging • Hands-on • meets various interest in gifted student
Teacher perception of collaboration	Collaborative skill perceived by teacher	• suggest pinions • Help each other • Time management in the team • Accepting each other's opinions	• Accepting each other's roles • Understand responsibilities • Problem-solving skills • Experimental skills
	Obstacle in classroom	• Disagreement and misunderstanding • Cannot work with friends • Students do not listen to their friend' opinions	• Some students do not participate in activities • Students desire to work only with their own group

Table 26 Example of Initial Themes, Subthemes and Codes

Table 26 displays themes and codes that I cross-checked with peers to determine if they contribute to answering the research question. Then I conducted a thematic analysis, following six steps, before reporting the findings and engaging in a discussion. After translated by a critical friend, key themes are finalised and presented in Table 27 below.

Elements of framework	Themes and Subthemes
Environmental issue	Teachers' reflections of teaching environmental issues • Contents Knowledge • Strategies • Schools' initiatives
SD concepts, SDGs and Competencies	Teachers' Perception of SD and ESD • Concept of SD • Perception about ESD, • Perception regarding teaching children for SD • Attitude toward YES programme learning content.
STEM problem solving	Teachers' Perception of problem-solving skill and EHoM • STEM implementation • Perception toward Problem solving Opportunities
Collaboration	Teachers' perception toward collaboration in YES! programme • Collaboration opportunities, Attitude toward the programme regarding collaboration
Gifted development	Teachers' attitude toward the YES! programme Teachers' recommendation for implementing the YES! programme

Table 27 Key Themes from Teachers Interview

Table 27 shows key themes emerged from teachers interview. Next section, data analysis of students' reflective diary is discussed.

5.6 Analysis methods applied in Phase 2 Students' Reflective Diary

Due to the objectives of the previously described research question, the student diary contained many questions for students to write their ideas after participating in the intervention towards a question or set of questions per week. Students' long-term thinking and attitudes were expressed over time through writing, note-taking, or drawing. Students were encouraged to fill out the diary in their own unique way, with no pressure. The diaries were sent back to researcher for analysis three months after the intervention. The texts students wrote have been analysed in the same way as other qualitative data in phase 1, which were analysed according to the six steps of thematic analysis (Braun and Clarke, 2006) with the aid of NVivo.

5.6.1 Analysis of Reflective Diary

The handwriting in the students' diary was in Thai. According to the format of the diary, which is a paper book, I transcribed all 40 diaries verbatim into MS Word. Then I began uploading the files into NVivo and began reading students' reflective diaries and familiarising myself with the data. Across the students' diary, I explored common threads in students' reflections from the open-ended questions that explicitly elicited their experiences with the YES! intervention, how they connected knowledge about environmental sustainability issues to their daily lives, and their perceptions about the issues and how to solve it at the individual and community level. An example of a student diary is shown in Figure 30:

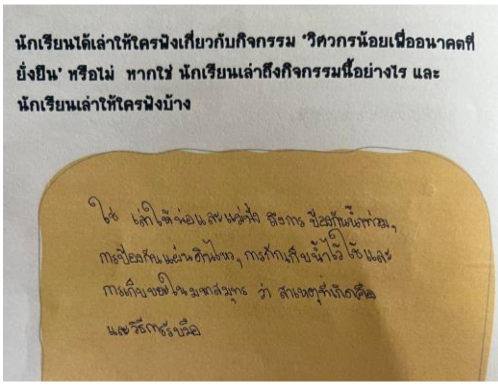


Figure 30 Diary Written by Sarah (Week 2)

Questions : Have you told anyone about the intervention? If yes, please tell me what you have shared and whom you shared it with?

Sarah' answer: 'Yes, I told dad and mom about flood prevention, Earthquake prevention, Water retention and Ocean waste collection. Talk about the causes and How to cope with it'

After reading carefully and considering the type of data gathered, I used an inductive approach to thematic analysis (Braun and Clarke, 2006) to identify themes within the responses to questions in diaries. I analysed the students' writings as a reflection on what they learned from the activities in the intervention, focusing on their perceptions of environmental sustainability issues. This included examining whether they recognised issues in their own lives, and consider whether they can help solve the problems or whether they can modify their daily routines to mitigate these issues. Additionally, their thoughts on how individuals and communities can help solve the problems raised during the discussions they had with friends during the 1-day programme. As a result, themes encompass attitude towards the programme, perception towards STEM learning science and skills, perception towards SD and environmental issues and competencies for SD, and reflection towards their own action and community.

The validity of this analysis was also determined using critical friends to check the initial themes and codes. Four of the forty transcribed diaries were sent to colleagues with a codebook so that they could look over the themes and codes, and the results were cross-checked against each other. Before starting to look at the other diaries, everyone agreed on any addition or revisions to the codebook. Once the six steps of thematic analysis (Braun and Clarke, 2006) were completed, then the languages of the two translations were checked against each other. The English version was reviewed by critical friends to see if the codes and subthemes answer the research questions and aligned with the related themes. The finalise themes from students' reflective diaries are presented in Table 28 below.

Element of Framework	Themes and Subthemes
Environmental issues	Awareness of environmental issues • Awareness of local issues • Awareness of global issues
SD concept, SDGs and Competencies for Sustainability	Awareness of SDGs • SDGs that students are interested in • SDGs that students want to solve • SDGs that students think it can be solved Practicing Competencies • Self-awareness • Normative
STEM problem solving	Perception regarding STEM for problem solving • Positive attitude toward EHoM • Implementation of EHoM
Gifted Development	Perception regarding YES! programme • Positive attitude toward the programme

Table 28 Key Themes From Students' Reflective Diaries

The table above demonstrates key themes which are discussed under the bricolage approach according to the framework in the next chapter.

5.7 Summary

In order to answer the research question and conduct the analysis of the data, this chapter makes use of a collection of different methods of analysis. Both textual and visual information, such as the pre- and post-intervention surveys, engineers' logbooks, photographs of creative artefacts, and drawings by students, were subjected to thematic analysis. This analysis was carried out in order to collect phase 1 data. Moreover, the theme analysis was utilised in order to analyse the data from phase 2, which included the student reflective journal. As well as that, key themes are presented. In the following chapter, we will talk about the analysis of data and the discussion of it.

CHAPTER SIX: FINDING AND DISCUSSION

This chapter presents the findings of the analysis of data sets from school intervention (Phase 1) and students' reflective diaries (Phase 2). The purpose of this chapter is to discuss the findings and themes that have emerged from this research to answer the research questions and highlight the actions that need to be taken as a result of the implementation of the 'Young Engineer for Sustainability' (YES!) programme in schools. The YES! programme intervention was implemented across a total of eight classes in seven schools located in different areas of Thailand. As the bricolage approach is employed to analyse the data collected from numerous tools, findings are combined from the diverse qualitative data sets related to the students' and teachers' reflections, attitudes, and perceptions of the YES! programme within the Thai gifted classroom setting and STEM problem-solving context.

Research question

1. How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?
2. How does the implementation of an integrated STEM-based activities enhance the awareness of sustainable development and improve the problem-solving and collaborative skills among gifted students in science?

6.1 Big Picture : Connecting Knowledge Together With Bricolage

To answer the research questions, bricolage is adopted as the methodological approach for collecting data for phases 1 and 2 to capture both the unique perspectives of students and teachers participating in the YES! programme. The aim is to explore the programme's impact on student knowledge of SD, instructional strategies, problem-solving, collaborative learning outcomes, and students' engagement. Bricolage utilises multiple tools to observe real-world and complex phenomena, aiming to acquire broad and in-depth knowledge (Denzin and Lincoln, 1994; Rogers, 2012; Cilesiz and Greckhamer, 2022), which is advantageous for the investigation of knowledge in gifted classrooms in Thailand.

According to Chapter 4, the research context involved obtaining knowledge from multiple case studies occurring in 8 classrooms located in 7 provinces in Thailand. The students ranged from grades 4 to 6 and attended both public and private schools, each offering distinct gifted programmes. Notably, the local culture, including dialects and geographical locations, varied, contributing to differences in the environmental issues they faced. As suggested by the study of García-Jiménez *et al*. (2022), various factors determine the effectiveness of education centred around the explanation of educational performance, including economic, social, and cultural status, native language, gender, and the size of the school. Although these factors may influence the research participants' background knowledge, personal experiences, and educational performance, their perceptions regarding programme participation remain crucial. An example of that is for the benefit of environmental sustainability; positive environmental results are possibly attributable to an individual's perspective (Abdullah *et al.* 2018). Understanding their attitudes, knowledge, and engagement in the YES! programme can contribute to the development of a better ESD integrated with STEM (Science, Technology, Engineering, and Mathematics) programmes to promote student learning for SD.

Bricolage approach is employed to achieve a comprehensive understanding of the factors influencing students' engagement and perception in the YES! programme. It also aims to identify effective strategies for fostering engagement, as argued by Denzin and Lincoln (2011), thereby adding rigor, breadth, complexity, richness, and in-depth knowledge. Thus, the key finding of this thesis is demonstrated by the development of the bricolage map, which illustrates the interrelated and combining results from diverse data sources such as student pre- and post- intervention questionnaires, Students' drawing and photo, engineers logbook, teachers' observation form, teachers' interview and students' diary (see Figure 31).

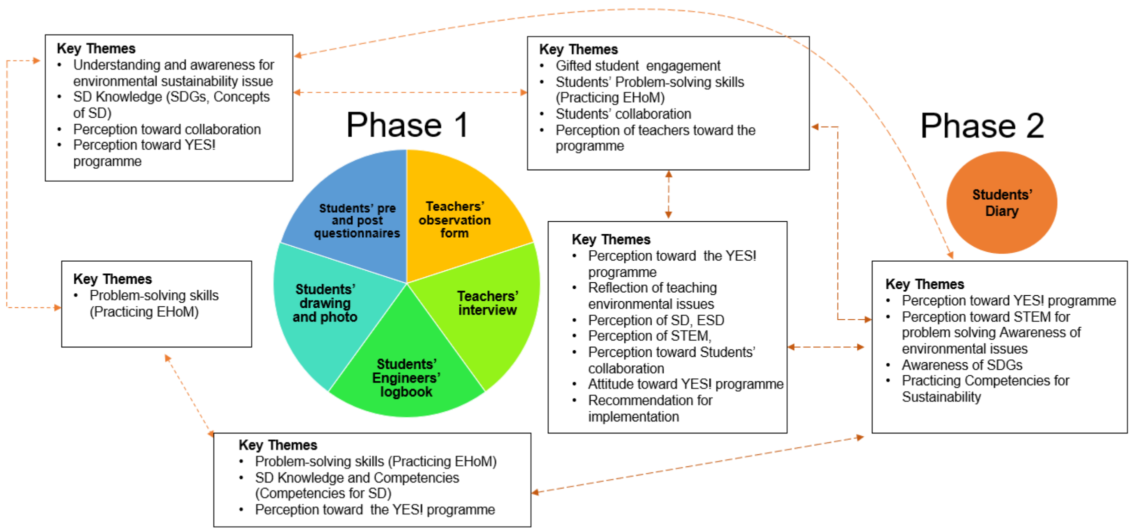


Figure 31 The Bricolage Map Represents the Big Picture of the Research

The Bricolage map above illustrates how diverse methodologies and data derived from various sources can be combined in a creative process. This approach involves assimilating and synthesising different pieces of knowledge and ideas to generate new insights (Ben-Asher, 2022; Wyatt and Zaidi, 2022).

Furthermore, as discussed in the preceding chapter, the framework for addressing environmental sustainability through STEM influences the theory and practise of developing pedagogical activities within the YES! programme. This framework, illustrated in Chapter 3, can be seen in Figure 32. It serves as a valuable tool in identifying the central concept for data analysis and facilitating the bricolage approach to inform the answers to the research question, providing a holistic perspective of the research, particularly regarding the programme's impact. The dataset encompasses five major elements that pertain to the current themes—specifically, the elements inside the framework. These include: 1) the environmental sustainability issue, 2) SD concepts, SDGs, and SD competencies; 3) STEM problem-solving for practicing EHoM, 4) collaboration; and 5) gifted development. The utilisation of multiple data sources allows for the triangulation of data, enhances the validity and reliability of the results, and helps in mitigating limitations and uncovering intricacies that may be overlooked by a single approach.

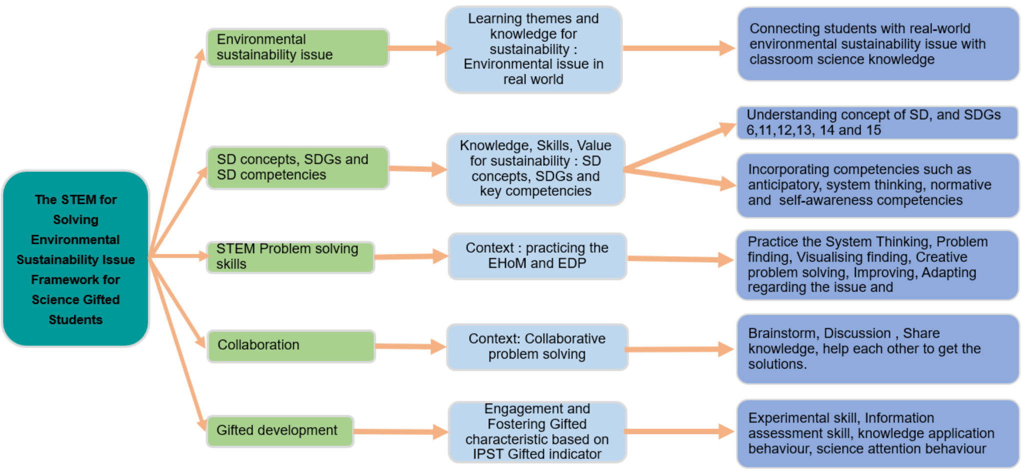


Figure 32 The STEM for Solving Environmental Sustainability Issues Framework for Science Gifted Students

From Figure 32, the conceptual framework provided the element of inquiry that themes are presented and answered the research questions. The following section discusses the themes based on the research questions of this study.

6.2 Potential for Gifted Students Development and the Outcome of the YES! Programme

From the research questions, themes emerged from the dataset obtained from different tools used in Phase 1 (School interventions) and Phase 2 (Students' reflective diaries) and are presented in Table 29 below.

Elements of framework	Themes	Subthemes
Environmental issue	Students' understanding about environmental issue	Understanding about landslide, flood, drought and waste in the river and ocean, Source of understanding landslide, flood, drought and waste in the river and ocean, Causes and impacts, Solutions, future perspective
	Teachers' Reflections regarding environmental issue	Content, Teachers' strategies, Schools' initiatives
SD concepts, SDGs and Competencies	Students' understanding of SD	Concepts of SD, link between SD and environment,
	Teachers' understanding of SD and ESD	Concept of SD, Perception about ESD, Perception regarding teaching children for SD, Teacher's attitude toward YES programme learning content.
STEM problem solving	Students' perception regarding EHoM	Attitude toward EHoM
	Teachers' Perception of problem-solving skill and EHoM	Students' engagement of problem-solving task, teachers' perception toward problem solving opportunity.
Collaboration	Students' perception toward collaboration	Students' solving problem, Students' collaboration , Students' learning SD
Gifted development	Teachers' perception regarding the programme	Advantage of the programme, limitation of programme
	Teachers' recommendation	Suggestion for improvement, Suggestion for implementation

(a) Key Themes for RQ1

Elements of framework	Key Themes	Subthemes
Environmental issue	Students' awareness regarding environmental issue	Significance of solving the issue, Issues that students most concern about, Awareness of local issue, Awareness of global issue
SD concepts, SDGs and Competencies	Students' learning SD concepts, SDGs and SD competencies	Students' concept of SD after joining he YES! programme, Awareness of SDGs, students' practicing competencies for SD
STEM problem solving	Students' practicing of EHoM	Problem finding, Visualising, System thinking, Creative problem solving, Improving, Adapting
	Students' engagement regarding problem solving	Behavioural engagement, Emotional engagement
Collaboration	Students' attitude toward collaboration Students' engagement in Collaboration	Attitude of collaborative skills, Attitude toward collaboration, Attitude toward team members Students behavioural engagement in collaboration
	Teachers' perceptions regarding students' opportunity for collaboration	Opportunity for collaboration, Practicing collaborative skill, Opportunity for collaboration, Promote positive attitude toward collaboration
Gifted development	Students' perception regarding the YES programme	Students attitude of the YES programme Interdisciplinary knowledge, Higher order thinking skills
	Teacher's attitude toward the YES! programme	Learning objective, Teaching and learning strategies, career aspiration, Promote gifted students, Learning content, Level of difficulty, Engagement in knowledge instruction, Engagement in problem solving task,

(b) Key Themes for RQ2

Table 29 Themes and Subthemes for Answering Research Questions
(a) Key Themes for RQ1 and (b) Key Themes for RQ2

Themes in Table 29 are discussed under the elements of the framework elaborated in later sections.

6.3 Environmental Sustainability Issues

To design the education settings for SD, a new teaching approach is needed to help students deal with wicked issues (Wals *et al.*, 2015). Thus, environmental sustainability issues serve as the learning theme in the YES! programme.

The analysis of several tools in Chapter 5 provided information about students' perceptions toward environmental sustainability which they expressed as themes. Based on Section 6.2, themes regarding this environmental sustainability issue emerge and answer the research questions discussed below.

RQ1 How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?

6.3.1 Students' Understanding About the Environmental Issues

Students' data sets from phases 1 (Pre-intervention questionnaires, post intervention questionnaires) and Phase 2 (Students' reflective diaries) indicate that students have different understandings about environmental issues, which encompass several subthemes. particularly, basic understanding about landslides, floods, droughts, and waste in the river and ocean, source of understanding about the four issues. These knowledge indicate how can environmental issue be integrated as contents for students learning to align with their background knowledge.

6.3.1.1 Causes and Impacts of the Environmental issues - Landslides, Flood, Drought and Waste in the River and Ocean

An open-ended item of pre-intervention questionnaires shows that students expressed their understanding of the causes and impacts of landslides, floods, droughts, and waste in the river and ocean differently. There were 122 students from all schools who perceived landslides as a natural occurrence from an earthquake, gravity, underground hole or burrow, water erosion, heavy rain downpour, force, soil condition, and no tree. Meanwhile, 18 students from classes A1 and A2 from schools A, D, E, and F attributed landslides to human behaviours that are related to deforestation. 189 students agreed that floods are caused by both natural factors and human behaviour, while 134 of them highlighted human behaviour as the cause of the flood. Furthermore, they found that human behaviours contributing to floods include issues with drainage systems and deforestation. Notably, only students from schools B and F did not mention deforestation in their responses. For the cause of drought, the majority of students also agree that human behaviour and nature are the factors. While, most students from all schools agree that human activities encompass industrial factories, lack of waste management, improper garbage disposal, and disposing of garbage into water sources lead to waste in the river and oceans.

When asked about the impacts of issues, 198 students indicated the impact of landslides as having social impacts, while 138 students specifically mentioned the impact of landslides on human life. Across all schools, students agreed that landslides significantly affected human well-being, particularly regarding housing and human life. Notably, students from School G did not highlight impacts on personal assets. Furthermore, 40 students reported an impact on transportation, a detail not mentioned by School C students. Additionally, 34 students reported an impact on city and town destruction, which was not mentioned by School G students. Surprisingly, in terms of environmental impact, a minority of responses were found from the five schools, indicating impacts on natural resources, ecosystems, animals, and soil, respectively. It can be seen that, in students' view, landslides affect society more than the environment.

Regarding the flood issue, 237 total students reported the social impact of floods. Among these, 159 students across all schools were aware that floods significantly affect life and well-being, impacting housing, personal assets, health, and overall quality of life, respectively. Additionally, 82 students mentioned that floods have adverse effects on transportation, while 19 students noted impacts on city and town infrastructure. Both views were obtained from all schools. Surprisingly, a few students from six classrooms reported the impact on the environment, and less than ten students from schools D and F mentioned impacts on the economy. Of all schools, 248 students addressed the impact of drought, while 147 respondents reported the causes of drought. Students from all schools agreed that drought creates environmental impacts, affecting living organisms and natural resources. Additionally, they recognised the impact on social issues related to professions, human life and well-being, and food and water shortages. Interestingly, in comparison to other issues, 16 responses from six classrooms highlighted the economic impacts of the drought on household expenses, incomes, trading and imports, goods prices, and inflation rates. The perspective on waste in the river and ocean differs from the other issues. Most of the students agreed that it has an impact on the environment. Students from all schools expressed concern for living things and natural resources rather than impacts on society. This concern was specifically reported by students from schools A (A1, A2), C, D, E, and F, but not mentioned in School G, one of two schools located in the city near the sea.

Additionally, the post-intervention questionnaires from phase 1 also demonstrated the students' understanding of the impacts of the issue. For instance, a student from School D remarked, 'The fact that we are not prepared to deal with a landslide disaster causing damage to houses; however, if we are ready to cope with the catastrophes, landslides will pose less of a threat to residential buildings'

The fact of issues students understand is align with many literature regarding environmental impact of the issues (Mark, 2011, Department of Mineral Resources, 2017 Dechkamfoo *et al.,* 2022; Petpongpan *et al.,* 2021, Mark, 2011; Gale and Saunders, 2013; Department of Marine and Coastal Resource, 2017; Pollution control department, 2020; Chen and Fei, 2023). Their understanding of environmental issues reveals that human is part of the cause of the issues as they address human behaviours together with the natural factor. They see the issues also occur naturally, while in the study by Abdullah *et al*. (2018), 12-year-old students in Malaysia see humans as the cause of issues such as throwing trash, and students in another study by Simsekli (2015) view humans as the cause of lake issues, global warming, waste problems, and soil pollution. Similarly, students in this study believe that, as part of the causes, human behaviour is related, especially to the issue of water in rivers and oceans.

Overall, for the impact of environmental issues, students in this study perceived that it encompasses the environment and society perspectives, which is in contrast to the study of Abdullah *et al*. (2018) and Simlekli (2015), as the students are aware of impacts on the environment. Evidently, students in this study indicate the impacts on nature and society; this awareness could serve as the foundation of SD learning. This understanding, with the aim of ESD, as Pavlova (2013) indicates that students must be taught to see the relationship between environmental and social. It can be seen that gifted science students in this study see the relationship between human and environmental issues. This understanding is the foundation for learning and behaving for sustainability.

6.3.1.2 Solutions to the Environmental Issues

The data set from phase 1 of the post intervention questionnaire also demonstrated students' understanding of solutions to the issues. Meanwhile, a student from School B suggested, "*To prevent drought, we have to work together with people in the community to dig wells in order to collect rainwater that has fallen for usage*." A student from school A2 articulated:

> *I have learned that dumping waste into rivers has a significant negative impact on aquatic life. Therefore, we should not litter carelessly and should properly remove waste from the rivers.* (A student from school A2)

Students are aware of the solution to the environmental issue. Students deliberated on various ways to contribute to solving environmental issues, and one impactful approach they identified is to conserve resources and engage in environmental protection. A total of 235 students highlighted the importance of changing behaviours. Across all schools, 122 students agreed that they emphasised forest preservation. Furthermore, 171 students focused on waste disposal and waste management. Nearly 30 students from seven schools expressed their commitment to conserving resources and energy, such as electricity and water, by using them effectively and promoting campaigns and positive behaviours through different activities. Notably, this view was not articulated by students in School G. When asked about how to overcome the issue, students suggest significant ways to address environmental issues to reduce the impact of issues on society and the environment. They suggest that they can contribute to solving environmental issues in various ways, including changing their behaviours and engaging in environmental protection. For example, a student from school A2 explains how behaviour change can take place as follows:

> *Global warming can be minimised by not burning things and saving electricity. Planting trees helps prevent landslides. Garbage in the ocean and water can be reduced by not littering in the water and instead throwing rubbish in a bin.* (A student from school A2)

26 respondents believed they could help solve the situation, while 21 students could help raise awareness. Students' understanding of environmental issues and their rationales shows that primary school students cherish nature, recognising it as the foundation of SD.

It is evident that students in this study have perceived several solutions to the issue by identifying human behaviour as part of it. According to Simsekli (2015), students perceived that human behaviour can help reduce water pollution. More importantly, they believe that they can be part of the change by providing some idea that they can take in general for positive outcome that align with Trott (2020).

6.3.1.3 Source of Students' Understanding about the Environmental Issues - Landslide, Flood, Drought and Waste in the River and Ocean

The data was obtained from the pre-intervention questionnaires. These questionnaires asked students prior understanding of environmental issues such as landslides, floods, droughts, and waste in the river and ocean. Students reported how they learned about the four topics from various sources—school, TV/news, parents, or by themselves. The majority mentioned learning about almost every issue from watching TV and the news. This highlights that students are engaged in real-world concerns beyond the classroom. From the data, it's evident that only a few students mentioned learning about these issues from their schools. Interestingly, all students from every school have experienced flooding and river and ocean waste. Only one-third students from schools B, E, F, and G indicated other learning sources, including their parents. One reason for this might be that students learn about waste management in the community during Year 5 at the beginning of the first semester, as per the ISPT science book manual for teachers of Year 5, Part 1. Notably, in School D, the number of students who reported learning about waste issues in the river and ocean from school is nearly equal to those who reported learning from TV and news. A small number of Year 6 students from Schools A (Class A1 and A2), C, and D, and one-third of School F students, indicated learning about these issues from school.

The students in this research study stated that their perception of these four environmental issues originated from several sources, especially those outside of school. It corresponds to To-Im and Klungklueng (2014), who argue that environmental education in Thailand is undergoing a paradigm shift from conventional classroom-based instruction to experiential learning beyond the classroom. According to this fact, it is possible for students to grapple with the challenges of environmental sustainability in their everyday lives, directly experiencing the effects of these challenges, and C is located in provinces where some towns are affected by droughts twice a year (Department of Disaster Prevention and Mitigation, n.d.). This source of knowledge confirms that students are interact with issue around them as Scholars note that learning about environmental issue serve gifted students interest (Renzulli and Reis, 2021; Schroth and Helfer, 2017).

6.3.1.4 Future Perspectives of Environmental Sustainability

The Phase 1 data set (pre-intervention questionnaires) reveals students' future environmental expectations. When asked about their expectations regarding the environment in the future, the data shows 221 students voice their hope that in the future, environmental issues will be decreased or entirely eliminated. 52 students expressed expectations for a better society, and 26 students stressed behavioural changes in people. One clear example is given by a student from School B who stated, '*It must be better than before. There is more nature and technology that are environmentally friendly*.' Another student from School D wrote, '*I want to live a better life, and I hope that it is what everyone thought it would be.*'

This reflection of students regarding future perspectives demonstrated that they have a positive attitude toward environmental sustainability. They also indicate the importance of environmental sustainability and value social dimensions. It can be seen that students have hope regarding environmental issue which is needed for learning SD according to Ojala (2016). This view is similar to students in France as they view their future with positive perspective, even though the environmental issue make them feel hopeless (Kalali, 2017). Students in this study see that solutions can be made to address the issue.

6.3.2 Teachers' Reflections of Teaching Environmental Issues in Schools

Based on teachers interview from Phase 1, some evidence indicates that primary science classrooms included teaching on environmental issues. Teachers use different approaches to teaching students about environmental issues by either focusing on knowledge, action, or both. The teachers' reflections revealed that the instruction aimed to promote positive habits without prompting students to evaluate norms or reflect on their day-to-day actions.

6.3.2.1 Content Knowledge for Teaching Environmental Issues

When I ask teachers about the environmental issues they teach in the classroom. The teachers highlighted the topics of global warming and climate change, solving environmental problems, waste processing, self-preparation for disasters, environmental resources, conserving and securing the environment and natural resources, and the impact. In addition to this, teaching topics also include the impacts of issues on communities, society, and the country, such as electrical power, disasters, living organisms, and the environment. Seven teachers from schools A, B, C, D, E, and G reported that they raised the waste issue. For example, Mintra from school G said, "The waste issue is more obvious than others." While another six teachers mentioned teaching about conserving the environment, natural resources, and natural disasters. Some teachers also covered various issues such as solving environmental problems, waste processing, self-preparation for disasters, the impact of environmental issues, electrical power, disasters, living things, water pollution, and general knowledge regarding the environment. An example of that is what Suda said: "The direction is regarding preservation and is related to the life cycle." Another teacher, Arisa said, "Save the earth is to care for the environment.. its depends on what it means, and they will share opinions together and at the end of the day of practical work, they will present their work." Ten teachers from all schools confirmed that the environmental knowledge delivered in the classroom is related to the science curriculum. Another teacher participant, Chinda said, 'Just the topic of waste is relevant. but in the unit, it really pertains to water. water is related to water pollution.' Kanda, another teacher noted, 'I used to teach grade 6, and yes, I taught about disasters, their causes, and how to prevent them. Students will learn according to those facts, but they will not be continuously related to how we live with them in the future. They learn about the present, about the current knowledge.' From this, teachers teach environmental issues in the classroom, however, the SD approach is less integrated and does not include critical discussions on norms and the future.

Findings demonstrate that several environmental issues were taught to students in the classroom. However, as students in this study reported, their sources of learning of issue, the teaching contents may not cover landslides, floods, and droughts, as students' perceptions of these four issues largely originate outside the school environment. Teachers in this study mentioned waste and recycling as a major focus, together with other issues, which is similar to the study of Torkar (2014) which found that teachers focus on recycling, sustainable energy use, bird feeding, and school cleanliness. It is demonstrated that in classroom-based learning, students learn about various issues, which is in line with education standards that promote facts about ecosystems, natural phenomena, and disasters in primary school (Ministry of Education, 2008; IPST, 2017).

6.3.2.2 Teachers' Strategies for Teaching the Environmental Issues

Aside from the contents, the data set from phase 1 (Teachers' interviews) also demonstrates teaching approaches, seven teachers from schools B, C, D, F, and G reported that they primarily use lectures. Only five teachers mentioned applying active learning to teaching, allowing students to engage in group work, present ideas, search for information, participate in discussions, conduct experiments, and work on the EDP and model invention. Thana shared:

> *The contents at year 3 that I taught is about electricity generation […] I let them explore their community about what can generate electricity […] Now, our school is working on solar cells, so that we can describe solar cells, how they generate electricity, and when it come to the future, we can use this source of electricity for use.*(Thana)

Active learning was not emphasised by Thana and Anan from School F, and outdoor learning was only reported by Chinda from School D, who focused on raising awareness. Teachers from school B, Anya and Kirk, encouraged students to share knowledge with others. Especially, Kirk provided examples of situations in the classroom, and Anya invited experts for classroom instruction. while Anan (School F) and Mintra (School G) used visual aids for instruction. Lalita, Kanda and Chinda indicated that learning is not involved with STEM education. Surprisingly, only Arisa and Anan from schools E and F reported lessons related to EDP. Only school C provides environmental STEM camp activities.

It is evident that the incorporation of STEM into environmental education is still limited in these schools. It is in line with the literature regarding Thailand environmental education that engaging learning is still limited (To-Im and Klungklueng, 2014; Laiphrakpam *et al*, 2019) as well as the integration with STEM education (Srikoom *et al*., 2013). Teachers focus on knowledge, and only one mentioned awareness and no mention of empowerment, suggesting that awareness and empowerment are lacking, which aligns with the study of Torkar (2014). This suggests that the environmental issue integrated with STEM can serve as alternative approach for teachers in school to promote knowledge and awareness of environment.

6.3.2.3 Schools Initiatives for Teaching the Environmental Issues

The same data set also indicates school initiatives as teachers disclosed their approach to addressing environmental issues in their schools. It was observed that only two schools integrated environmental issues across different disciplines such as social studies, Thai language, mathematics, and health education. Despite the perception that eight classrooms dedicated to gifted students in seven schools may not sufficiently engage students in active learning opportunities, nine teachers reported that their schools still provide opportunities for students to learn certain aspects of environmental sustainability issues, or SD.

Six teachers from four schools mentioned school activities related to waste, including initiatives such as zero waste campaigns, waste management, fertiliser production, rubbish-crusher activities, and rubbish banks. Only one teacher from school A claimed that her school provides opportunities to learn about disasters, especially earthquake issues. This stems from the school's location in an earthquake-prone area and its collaboration with local authorities. Teachers from Schools B and D indicated that green classrooms were provided for students to learn about energy-saving practices at home and in the community. Additionally, Schools A, E and G actively involve students in environmental conservation projects within the schools. Another two schools reported integrating environmental issues into their camps. Lastly, individual teachers from various schools reported different extracurricular activities such as environmental week activities, invention contests, after school activities, scout activities, and democratic activities. It becomes apparent that a whole-school approach, as suggested by many scholars (Wals, 2015; Leicht *et al*., 2018; UNESCO, 2020;) as an effective method, is not consistently based on national educational policies but rather depends on school administration. This variability limits the students' exposure to different environmental issues and SD within the school environment.

Overall, teachers reported that the school provides education to support students with environmental knowledge in different ways. Some teachers gave examples of educational activities or lessons they taught regarding the environment. This is to confirm that Thai students are aware of the environment as they perceive it from classroom and from life experiences. However, teacher interviews reported that students from some schools may experience school activities or campaigns that promote learning and practice for the environment, which can be a basis for promoting SD. As Thai teachers mentioned about SEP, this may have contributed to Thai schools embedding SD more at the school level that align with Nuamcharoen and Dhirathiti (2018). This is unlike the study by Charif (2022), in which teachers in French primary reported that SD was integrated into the classroom more than the school projects.

Clearly, the findings provide room for integrating environmental issues as content for learning concept of SD and STEM. These interventions focus only on issues, such as waste management and the recycling of rubbish, similar to many studies regarding whole school approaches for SD (Asia Pacific for Cultural Centre for UNESCO, 2012; Iwan and Rao, 2017; Leight *et. al*., 2018). Other SD issues must be taken into inconsideration to be embedded in schools and classrooms as found in many studies such as community resources, mining, noise pollution and climate change (Clark *et al*., 2017; Costa *et al*., 2023; Morris *et al*., 2021; Trott, 2020) Moreover, to promote the implementation of environmental programmes, it is necessary to provide teachers with training and resources to address the low implementation of programmes related to the environment (Spiropoulu *et al.*, 2007).

In the next section, the data set indicates the findings to answer research question two.

RQ2 How does the implementation of an integrated STEM-based activities enhance the awareness of sustainable development and improve the problem-solving and collaboration skills among gifted students in science?

6.3.3 Students’ Awareness of Environmental Issues

From the Phase 1 and Phase 2 data sets, the students’ awareness of environmental issues was examined. Themes report what students are aware of including the importance of solving environmental issues, the issues most concerning them, local issues, and global issues.

6.3.3.1 The Significance of Solving Environmental Issues

Phase 1 questionnaires conducted prior to the intervention reveal the emergence of subthemes concerning the justifications for addressing environmental issues. In general, 87 responses from students across all schools expressed concerns about society as one of the reasons for resolving these problems. An example of this rationale is articulated by a student from School F, who stated, 'Our world may not be liveable because of deforestation and garbage disposal, so we have to help each other to make the world a better place'. Conversely, 71 responses from all schools emphasised concerns about impacts on the environment. Notably, only one student from School D focused on the impact on the economy regarding agricultural production.

The majority of students address environmental impacts such as living organisms. For instance, a student from School A1 shared a concern about living things, stating, 'There is a lot of garbage. It is impossible to swim in the sea, and animals that want to live in the river as a habitat cannot dwell there'. This student also indicated that environmental issues can impact human lives, ranging from personal to community levels. Concerning social aspects was highlighted by a few students. For instance, a student from School D mentioned, 'Landslides can cause injuries to people and transportation congestion', and a student from School E vividly described flood impacts: 'Floods, damaged houses, cars that are water lodged (stalled), lost licence plates, water entering the house, cars that broke down'. Furthermore, there is a viewpoint regarding economic impacts, as expressed by a student from school A2: 'The soil on which the farmers cultivate their farms is dry, causing them to be unable to generate income and have no water supply'. These themes demonstrate that gifted science students in this study encompassed awareness toward social sustainability as well as environmental sustainability. Economic sustainability was also concerned but not for the majority of students.

The post intervention questionnaire (Phase 1) indicates the reasons for solving environmental issues, their replies indicated similar concerns to those expressed before joining the programme. However, of the 216 responses with rationales, 91 students were still concerned about social impacts, indicating that more students focus on concerns for people in society. 12 and 31 students cared about the impact on the city and the world they live in, respectively. Before joining the programme, only 18 students wanted to minimise the impact on the future, but after joining the programme, 46 students expressed a desire to reduce the impact in the future. This likely means that they want to lessen or stop the negative effects on the environment, society, or other systems as time goes on. This idea is closely related to the concept of ensuring that future generations will have a better quality of life and the resources they need. A student from School D articulated this sentiment, stating, 'Because of those problems, even if we have never experienced them before, other people have faced them. Furthermore, we might experience problems that we have never encountered in the future.'

Interestingly, 26 replies are about dealing with real-life problems, an idea not found in the pre-intervention questionnaire. Students likely expressed that they are becoming aware of the issues that happen in the real world and are assuming responsibility with the aim of making valuable contributions and taking responsibility for the environmental challenge.

According to students' awareness regarding environmental sustainability issues, for example, solutions to environmental issues such as resource usage and changing behaviours. It demonstrated that engaging students with sustainability issues in STEM is promising for fostering connections between children and the natural environment as students become aware of the solutions to the four issues. Significantly, gifted students in this study aware of environmental issue that is align with Önal (2020), gifted students in Turkey also have high level of awareness of issues. This is in line with Hill *et al*.'s (2014) study that engagement with the environmental issue cultivates an awareness of resource consumption that holds considerable educational merit and is significant to develop. While recognising the role of nature in these matters, the proposed solutions primarily emphasised the importance of human action. The findings are also in line with the study of Abdullah *et al*. (2018), which found that the primary school students in Malaysia provide their perception toward protecting environmental issues and see it as important to solve the issue as it is important to humans and future generations. However, Önal (2020) note that their awareness level may not significantly depend on the programme they attend. This research see the potential of the YES! programme to advance their awareness as they show interest and awareness of issues which is positive for learning toward SD.

6.3.3.2 Issues That Students Most Concerned About

The data set from the pre-intervention questionnaires also demonstrates that students in this study are aware of some specific issues they would like to solve the most, providing rationales behind their choices. It became evident that among various concerns such as deforestation, floods, waste problems, droughts, air pollution, and greenhouse gas pollution, waste-management issues, and global warming are the most significant. One student from School G expressed concern about waste in rivers and canals, stating, 'Animals are at risk of dying because of the rubbish.' This sentiment was shared by 117 students from all schools. Following closely is the concern about global warming, emphasised by 61 responses. A student from School D articulated, 'Global warming and garbage in rivers or other places.

because if the world is warm, some animals will not be able to live, and I get hot easily. For the garbage problem, rubbish was dumped everywhere carelessly. Before tossing away garbage, we should think about where we are going to dump it.' Drought and floods received a similar number of responses, with 19 students expressing concern about drought and 21 about floods. Notably, there is no concern regarding the flood issue among students in school C.

Students provide different perspectives regarding the issue they concern the most. This study support by Tolppanen *et al.* (2023) that gifted students show concern along with knowledge and willingness to act than their peers regarding issue like climate change. This finding confirm that they are aware about the world around them, making this activity relevance and support their needs.

6.3.3.3 Students' Awareness toward Local Issues

Students also demonstrate their awareness of local and global issues in their diaries. Ten weeks after the activity ended, students were asked if they stayed informed about environmental issues through the news. As they recognised the local issues, themes regarding these issues are climate change and global warming, PM2.5, fire risks, provincial issues, national issues, waste issues, landslides, polluted water, floods, droughts, food shortages, and low agricultural productivity. 33 students reported following the news, with floods being the predominant issue mentioned by students across all schools. Six students from schools A, C, D, and F were aware of news related to the waste issue. For example, one student shared, 'the news that I have followed is regarding 'Mariam, the manatee,' which is related to the waste issue' (S23). In addition, one student from School E heard about climate change and global warming, while a student from School G was informed about PM2.5. This is interesting as PM 2.5 normally occurs in the northern and central parts of Thailand, but a student from the south still recognised this news. Other issues reported include fire, waste, landslides, unclean water, floods, droughts, food shortages, and low agricultural productivity. At least five students reported that they did not follow the news about environmental issues; others reported issues ranging from local events at the provincial level to national events.

In addition, students' reflections in their diaries from phase 2 indicate that students in this study are aware of the community issue. They identified various issues that the community needed to address, which include waste water management, car use, air pollution emissions, playgrounds, forest and tree conservation, the community's unity, floods, electrical equipment, waste issues, environmental cleanliness, and protection. Out of 40 students, 27 agreed that the waste issue needs attention, with 22 of them being aware of littering behaviour in the community. Additionally, 11 students expressed concerns about waste management, including issues such as waste burning and waste sorting. One student shared their perspective: ‘What had to be changed was how trash was dumped into rivers and the ocean. A lot of people threw their things into the river because they didn't need them anymore, which hurt the animals that lived there. In the same way, littering killed many sea creatures’ (S24). Wastewater treatment is also a community issue. A student (S23) expressed:

> *The releasing of wastewater into the rivers and canals should be improved. Due to my community living near the rivers and canals, the inhabitants release the wastewater into the water source. It can be improved by treating the wastewater before releasing into the rivers and canals. (Student S23)*

Among the other issues identified by students are reducing car use in the community’ ‘Reduce using the car that creates black smoke because the car with black smoke leads to global warming’ (S4). Additional concerns include air pollution emissions, building a playground, forest and tree preservation, fostering unity in the community, improving community electrical equipment, and maintaining cleanliness and environmental preservation in the community.

The environmental sustainability issue within the local context makes the programme meaningful for them. The study agree with the finding of Morris *et al.* (2021) that local issue can enhances students engagement in STEM education and knowledge as they see the link with sustainability issue in the local context. As Hill *et al*. (2014) suggested, children have the right and the capability to be actively engaged in solving a variety of sustainability issues, especially those directly impacting their local community. In this study, students' understanding of landslides, floods, droughts, and waste issues illustrates the relevance of these issues as they perceive them in their daily lives. Selby (2017) proposes teaching children about issues occurring in their daily lives, fostering a connection that encourages critical thinking and responsibility towards issues in close contact. This study see the significant of environmental issues at local context to use as learning content to ensure relevant to students. However, connecting to the global context helps students understand that the issue impacts not only their own community but also at national and international levels.

6.3.3.4 Awareness for Learning Global Issues

Students also demonstrated awareness of global issues. Rationals for learning about the issue from other countries encompassing it generate new ideas, to provide support to affected countries, exchange knowledge of environmental problems, necessary, learn to prepare for the future, apply their solutions to solve Thailand’s problem, and improve their ability to perceive the news. 36 students from all schools reported that it was necessary. They believe it helps in learning about environmental problems and generating new ideas. Seven students from schools A (A1 and A2), B, D, E, and F value it for future preparation. One student expressed, ‘Significantly, because – you never know when floods, earthquakes, or landslides will occur, we must prevent and prepare for them” (S3). The solutions proposed by students can be applied not only to solve Thailand’s problems but also to provide support to affected countries, showcasing the students’ empathy towards victims and people with different cultures. One student stated, ‘Notably so, but we could be of assistance by conceiving of a solution and allowing them to develop it thereafter.’ (S34). Surprisingly, students reported that learning about news can improve their ability to perceive news, indicating their awareness of metacognition, or how they gain knowledge and develop themselves. ‘Significantly, we can have media literacy’ (S17). These perspectives demonstrated that students value learning SD issues and have a positive attitude toward learning global issues as they perceive them as significant and provide benefits.

This finding indicates students’ interest in environmental issues in the real world for both global and local issues. Teaching connection to global context also expand their knowledge of SD. That confirms that the integration of environmental sustainability issues in STEM problem based learning can engage students in accordance with OECD (2018b) which means that when content is relevant to them and they can see the similarities between global issues and their local surroundings, they can learn better and are more engaged. According to Önal (2020), gifted students in their study also exhibit high environmental awareness, positioning them as the potential leader for enhance environmental sustainability in schools. Gifted students in Thailand in this study also demonstrate the capability to extend the leadership for environmental conservation.

6.4 SD Concepts, SDG and Competencies for SD

Through their participation in the YES! programme, the results obtained from the data sources compiled in phases 1 and 2 provide insights into how the STEM programme facilitates students' learning regarding SD. In this section, reflections from both students and teachers are directed towards the potential of the programme to promote ESD. Themes emerged and are described in the following sections to answer research questions one and two, respectively.

RQ1 How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?

6.4.1 Students' Understanding of SD

Prior to enrolling in the programme, their comprehension of the concept of SD was explored to explore their pre-existing knowledge or exposure to the subject matter. Students were provided with concepts of SD in the programme. Therefore, students expressed their understanding of SD after the Yes! programme. According to the analysis of the pre- and post-intervention questionnaires, subthemes regarding students' understanding of SD are discussed.

6.4.1.1 Concept of SD Before Joining the YES! Programme

The data set from phase 1 (pre-intervention questionnaires) indicates that students hold varying perspectives on SD, encompassing notions of environmental development, social development, and development with the integration of both environmental and social dimensions. Among the 175 responses in phase 1, 75 students think sustainability is development beneficial in various areas, while 36 and 30 students regard it as development concerning the environment and social aspects, respectively. One student from School D expressed, '*Development improves ecosystems and provides organisms with a higher quality of life.'* Only eight students stated that it involves both social and environmental development. Similarly, four students stated it is related to economic development. A few students said it is related to problem-solving. Another perspective offered by a student from School E is, *'Sustainable development is a development that resolves all problems and ensures they never occur again.'*

The exploration of students' concept of SD is based on the background knowledge that in Thailand, although there is no ESD curriculum at the basic education level, the term 'sufficient economy' based on the SEP is generally embedded in schools for teaching students about SD (Dharmapiya and Saratun, 2016). Although SD involves the careful management of economic, social, and environmental factors to ensure long-term welfare and prosperity, it is worth noting that its emphasis on the SEP seems to focus on self-immunity and promote economic wellbeing. In this study, students conceptualised SD predominantly from environmental and social perspectives, with fewer considering economic aspects. It corresponds with the study of students' understanding of SD in the UK, which exhibits a variety of concerns around the three pillars of SD (Walshe, 2008), with less emphasis on the economic perspective (Walshe, 2013).

6.4.1.2 Understanding the Link Between SD and Environment

The same data set also indicates students understand how SD is related to the environment, as if they could link the concept they knew about SD based on their background knowledge about the environment taught in science classrooms and the SEP embedded in the basic core curriculum. Out of 202 responses, students expressed that, in their opinions, sustainability is related to the environment in terms of environmental developments in various aspects. Specifically, 109 responses highlighted that environmental development increases the richness of the environment, while 72 students mentioned that it involves solving environmental issues through human action, conservation, and technology development for solutions. 40 responses reported that environmental developments contribute to maintaining environmental stability for the future. Interestingly, 19 students linked the environment and sustainability by associating development with benefits for humanity, such as the development of the earth, a better society, sustainable countries, and the maintenance of the economy. A few of them linked it with the use of resources that do not negatively affect the environment, stating that environmental development is the first thing to be developed. Five students made connections between these terms and other things, such as relating them to projects in Thailand, premises and construction development, and understanding the state of environmental problems and impacts. This viewpoint demonstrates that students have a constructive understanding of environmental protection in relation to environmental sustainability.

Clearly, students' knowledge, values, and attitudes towards learning SD and their understanding of SD objectives and the environment are indeed interconnected. The finding, support that student have some background of environmental sustainability in the way that revolved around environmental protection. These understanding demonstrates the foundation of learning for SD, that embrace ecocentric perspective, favour non-human species, related to environmental conservation (Kopnina, 2012)

6.4.2 Teachers' Perceptions of SD and ESD

The study investigates teachers' perspectives from phase 1 using teachers' interviews and teachers' feedback in the observation form. Teacher interviews in phase 1 revealed that the concept of SD is subject to varying interpretations among individual teachers. Themes regarding teachers' perceptions, including their understanding of SD and ESD have emerged. Teachers' perceptions are discussed in different themes, which are concepts of SD, perceptions about ESD and perceptions about embedding ESD in primary school, respectively, which are discussed in the following section.

6.4.2.1 Concepts of SD

As subthemes presented in Table 29 above, all fourteen teachers were familiar with the concept of SD, but their interpretations varied in scope. Their concepts of SD include connections to social development, economic development, environmental development, and protection, as well as teaching and learning, and solving long-term problems. One teacher, Anan, expressed, *"Resolving a problem for sustainability does not entail resolving the issue this year or the present one... rather, it entails considering the problem five, ten, or one hundred years from now, depending on what we can do to solve the problem in the long term."* Only two teachers provided a comprehensive view of SD, relating it to the three pillars of SD. One teacher illustrated the perception that involves concern about the use of resources for the benefit of our generation and the next generation. Chinda expressed, *"It's about what you can do to continuously maintain a balanced level of holistic potential for now and in the future. However, a holistic system refers to the environment, the economy, society, and everything else that is a factor in our surroundings. It is imperative that we develop it comprehensively".* Another teacher, Kanda, said, *"It involves life, earning for a living, lifestyle, quality of life, and life that coexists with nature.. it is just like the future, which must be maintained, and it is useful to us."*

Clearly, teachers' knowledge of SD varied, ranging from narrow to broad when compared to the universal definition. Three teachers offered their own definition of SD linked to education, emphasising its lifetime application of knowledge, promoting students with knowledge for the long term, providing education for children at the early childhood level, and endorsing hands-on learning related to SDGs 4, this is in line with definitions promoted by the Thai government (OEC ,2021). Arisa mentioned that SD is connected to the government policy that is currently promoting sustainability, stating, *"and it is the policy of the prime minister which is... Thailand must be able to survive. We must survive. We can live on our own. We have to be sustainable.. the way to live sustainably".*

It is common to have a non-holistic view of sustainability, and addressing this is essential when considering the promotion of ESD in the school context. The limitation of teachers' understanding of SD is not unique to this study but has also been observed in various research studies. For instance, Spiropoulou *et. al.,* (2007) found that in-service teachers defined the term 'sustainability' primarily regarding the management of natural resources, with only 42 of 188 teachers linking it to future generations, while the rest focused on protecting the environment and the correct management of resources. Similarly, other research conducted by Gustafsson *et al.* (2015) indicated that Swedish secondary school teachers hold a variety of beliefs regarding SD, defining it in diverse ways, ranging from narrow to broad.

Not all teachers' concepts fully represent concerns related to the three pillars of SD. Even in a country, where the government's policy promotes SD and affects practices in schools, and school curricula are subjected to teaching for sustainability, SD concepts still vary among teachers. However, some Thai teachers report varying concepts of SD, suggesting that several factors may influencing the teachers' own concept of SD. This could be attributed to their teaching experience, involvement in professional development, area of teaching and personal interest. Further investigation is necessary to confirm the factors' existence.

6.4.2.2 Perceptions About ESD

Aside from the concepts of SD, teachers' perceptions about ESD were also explored from the teachers' interview data set (Phase 1). 11 of them said that they had heard about ESD in different ways. Few reported that they gained knowledge from training and experiences, while five mentioned they had not seen ESD in young children. Teachers revealed that they lack detailed knowledge of ESD and how to apply it in teaching and learning. One teacher thought it was already partially taught in science. Two teachers said that teaching SD in school is more related to social studies. Anan expressed:

> *In social studies, we talk about how the future is developed for sustainability and maintain the environment. Making the world a place where people can live, and let nature, woods, and mountains stay. Because in Chanthaburi, there are a lot of woods and mountains there. These are integrated in the course, but there is no practical work.* (Anan)

Two teachers stated that ESD is related to science subjects but is limited. Lalita mentioned, *"In Thailand, we still do not talk much about disaster or learning about sustainability for children studying science."* Another two teachers expressed that ESD is related to the environment and natural resources, providing education for long-lasting learning, respectively. Only one mentioned that ESD is teaching and learning for students, which leads to SD. However, it is not detailed, and it is the role of the teacher to embed it. Anan explained, "*In the Thai* *curriculum, we are not completely talking about it... is not clearly specified. This is for the teacher who will insert it himself. and will not be explained in much detail.*”

In the context of other studies, teachers in the study of Costa *et al*. (2023) who join the STEM – SDGs hands on activity believe that school should promote ESD and they recognised their own role to advance SDGS and SD practice in community. Munkebye *et al*. (2022) indicate that ESD in Norwegian school is often viewed as EE and considered to be part of natural science. Thus, examining the perspectives of educators on SD is crucial and reveals a limited understanding of the teacher's role in SD, despite considerable endeavours to incorporate ESD into the national curriculum and educational policy. Teachers in French primary school indicate the teaching regarding ESD based on their syllabus that allow teachers’ decision on selecting themes and issues (Charif, 2022). To support Thai teacher to integrate ESD, according to a study conducted by Spiropolou *et al.* (2007), it is imperative to enhance teacher expertise and recognise the significance of education in addressing these areas. Strachan (2020) also recommended that pre-service teachers receive training in the acquisition of knowledge, skills, and strategies essential for implementing a global learning pedagogical approach in primary level science education. Similarly, Munkebye *et al.* (2020) highlight the incorporation of ESD into several subjects as teachers received support from Norwegian government with sustainable backpack programme.

6.4.2.3 Perceptions Regarding Teaching Children for SD

From the teacher interview (Phase 1), teachers’ views regarding teaching ESD with young students involved emphasising the value of ESD to promote awareness and attitudes toward SD. Seven of them stated that it fosters awareness and attitudes toward SD. Eight teachers valued SD learning for young students, noting that they are capable of accumulating knowledge for the long-term. Anya mentioned, “*Children should start learning when they are in primary school onward. In particular, I thought it would be better for the child to understand this at a younger age than later when they are older*.” They agreed that young children are capable of learning for SD and emphasised that ESD is related to young students’ lives in some ways. Their perceptions reflected a view of SD that mostly involved social and environmental aspects, confirming that they are less aware of economic aspects, which aligns with their earlier SD concepts.

As there is no official ESD curriculum at the primary school level, environmental education, which provides knowledge about and for the environment, is embedded as units in the science curriculum as in other studies (Laiphrakpam *et al*., 2019), giving this opportunity to promote

SD in gifted education by integrating with STEM education. As discussed in the previous section regarding environmental sustainability issues, the promising educational approach that Thai teachers provide for students to support SD learning focuses on 'environmental facts' through science education and school activities. Additionally, teachers in this study do mention SEP in their understanding of SD concepts, but the integration of SEP is not explicitly mentioned in the science classroom. Unlike teachers in study of Charif (2022) address purpose of ESD in French primary school context that involved students in making decision based on environmentalist, behaviourist, or transmissive standpoints and become eco-citizens. This is may be due to the fact that their syllabus. However, according to students' understanding of SD after joining the activity, it support that the YES! programme embedded a holistic understanding of SD. The practice of competencies along the problem-solving process informs the approach to promoting a foundation for SD compared to the traditional approach teachers in this study have reported, as space for reflection is provided.

6.4.2.4 Attitude toward the YES! Programme Learning Contents

Reflections in teachers observation form (phase 1) illustrate their attitude toward learning content in the YES! programme regarding environmental sustainability issues, which is conducive to actively engaging students in their learning process because it is pertinent to their lives, connected to their personal experiences, and enables them to make connections with information they have encountered in the news or from others, facilitating decision- making and reflection. Aran expressed, 'It is suitable because it is an activity that everyone in society has already experienced, and it teaches students problem-solving skills since they are young (in primary school). When students are aware of the root cause of the problems, they may be able to help solve or reduce them.' The following is an instance of teacher perspectives that offered favourable remarks concerning the programme's ability to enhance students' understanding of SD, as well as empower them. Dina mentioned:

> *It made students think that we had accomplished the mission, and it seemed like a quest to help save the world. Students unintentionally absorbed the activity's objective while they were solving it. It will be extremely beneficial if the activity is added to primary school and kindergarten education.*

Overall, this study collated teachers' views as they play an important role in promoting students' knowledge and understanding regarding SD in STEM teaching and for gifted students. Given that they teach STEM subjects and, based on their background knowledge regarding ESD, there is a need to work hard in this area to integrate ESD into their teaching. Promoting SD with the SDGs and cultivating SD competences, such as integrating problem-solving, is crucial, alongside promoting ESD through the ‘SEP,’ as in accordance with the policy of the Ministry of Education throughout all schools in Thailand (Chiwpreecha and Prateepchotporn, 2020). To encourage teacher to embedded ESD, teacher autonomy is crucial. Based on Charif (2022), The autonomy allow school and teachers defines the content as they can work with partners to adapt the content in their teaching. Moreover, teachers need to aware and develop their ESD competencies (Cebrián and Junyent, 2015) for a successful integration of ESD in schools.

In the next section, the data set indicates the findings to answer research question two, which is discussed.

RQ2 How does the implementation of an integrated STEM-based activities enhance the awareness of sustainable development and improve the problem-solving and collaboration skills among gifted students in science?

6.4.3 Students’ Learning SD Concepts, SDGs and SD Competencies

In corresponding with research question two, the findings derived from the data sources acquired in phases 1 and 2 offer valuable insights into what students know and are aware of about SD through their involvement in the YES! programme. The students' replies under the themes of studying SDGs and applying SD competencies are discussed in the subsequent section, respectively.

6.4.3.1 Concepts of SD After Joining the YES! Programme

The YES! programme provided an overview wherein the concept of SD was introduced to students during the engineers’ training session at the start of the day. Exploring students’ perceptions of SD after joining in the activity provided evidence of conceptual changes. From the data set of Phase 1 (post – intervention questionnaires), positive improvements were observed in their comprehension of the concept of SD according to Table 30 below.

Concept of SD (Pre intervention questionnaires	Concept of SD (Post intervention questionnaires
Social development The Development for beneficial in various area Self-development Economic development Environmental development Social and economist development Environmental and social development	Single pillars of SD (Environmental development, Economic development, Social development) Multiple pillars of SD (Development of economy and society, Development of environment and economy, Development that does not affect the environment economy and society) Developments that benefit our generations without affecting future generations. Development for the benefit of today's people Development for the next generation Development to be sustained in the long term or to the future Development to improve the quality of life Development that does not affect the future Developments that help to solve problems or long-term problems Developed the environment and technology Other definitions (non-stop development, development of ideas, development of unity, worldwide developments , development that next generation does not have to develop further, development that make things better)

Table 30 Students' Concepts of SD

These changes align with the overarching concept of SD outlined in the Brundtland report, which encompasses the three pillars of sustainability (Brundtland,1987), covering the pillars of SD: environment perspective, economy perspective, and society perspective (Hedefalk *et al.,* 2015; Sinakou *et al.,* 2019).

Students reported notable changes in their understanding of the concept of SD, connecting it to the universal principles outlined in the Brundtland report, which encompasses the three pillars of sustainability related to the development of their country. Although not all students can recall the concept of SD, they gained a relevant understanding from the one-day programme. Out of the 184 replies received, students expressed varying perspectives on SD. Notably, 134 of these responses encompassed themes falling within the universal framework of SD, specifically relating to the domains of environment, social, and economic. A student from School C stated, *'Development that considers the environment, economy, and society, along with having sufficient resources for future generations.'* The future perspective is also emphasised, as another student from School E noted, *'It is the development of the country in the present era that does not affect the future.'*

Students developed a broader and more general understanding of SD concepts compared to what was indicated in the pre-intervention questionnaire. The initial focus was on environmental development, social development, environmental and social development, or development that is beneficial in various ways. Understanding the holistic view of 'SD' is fundamental for creating a better future, as it relates to social aspects involving human life, such as the use of resources and how people interact with their surrounding environment. Additionally, it establishes a pathway to finding a balance between people's needs, economic growth, quality of life, and environmental health for both current and future generations. Overall, students perceived SD as environmental and societal. YES! programme may not properly enhance economic knowledge therefore economic factors are still underemphasised. There are few studies on students' sustainability comprehension. Walshe (2008) revealed that students have various views on sustainability, but there is consensus around the three pillars of SD. Walshe (2013) found that students' economic views on SD were rarely considered. Although YES! programme's economic perspective is still underemphasised, it can be seen that this programme, which integrated environmental issues, provided students with environmental facts and social perspectives. Student attitudes toward ESD depend on what they have learned from their teachers and the school (Walshe, 2008). Thus, this programme needs to be more balanced and involve economic aspects in the discussions.

Despite Sinakou and colleagues' (2019) findings that educators and students lack a comprehensive understanding of SD, the YES! programme introduced students to SD concepts and discussed environment, social, and economic issues differently to help them understand SD. Since Thai schools do not have an ESD curriculum, the SD found under the SEP made SD understanding range varies for teachers. Due to a lack of holistic SD concepts, the YES! programme is a successful alternative to promoting SD knowledge in the science classroom.

6.4.3.2 Awareness of SDGs

The YES! programme introduces students to global SD issues comprising 17 global objectives (UN, 2015) as well as described landslides, floods, drought and waste in the river and ocean regarding 6 SDGs (6, 11, 12 , 13 , 14 , 15). First of all, a data set from the post-intervention questionnaire (Phase 1) illustrated overall students' awareness of the SDGs, 12 Goals are what students' interests are including SDG1 No Poverty, SDG3 Good Health and Well being, SDG4 Quality Education, SDG6 Water and Sanitisation, SDG8 Economic Growth, SDG9 Industry, Innovation, and Infrastructure, SDG10 Reduce Inequalities, SDG11 Sustainable Cities and Communities, SDG12 Sustainable Production and Consumption, SDG13 Climate Action, SDG14 Life Below Water, and SDG15 Life on Land. Some students did not remember the names of the goals or recall them correctly but they could provide some key ideas about the goals. This means that at the end of YES! programme, it will have a positive effect on fostering students' knowledge about SD issues through the incorporation of SDGs.

The findings align with what a data set from students' reflective diaries (Phase 2) also indicate that students expressed awareness about SD issues with three themes; SDGs - students want to learn, SDGs - students want to solve and SDGs students think it can be solved as presented in Figure 33.

SDGs	Reasons	SDGs	Reasons
1 NO POVERTY	• Relationship of poverty and country development • Interested in Thailand poverty situation • Interested in the solutions, • To end the poverty	2 ZERO HUNGER	• Issue about hunger in the household • To seek solution to food scarcity
3 GOOD HEALTH AND WELL-BEING	• Quantity of patients in Thailand	5 GENDER EQUALITY	• to decrease the gender restrictions on women • to reduce violence against woman
6 CLEAN WATER AND SANITATION	• Appreciate the value of clean water for all living things	8 DECENT WORK AND ECONOMIC GROWTH	• Related to finance and quality of life • Have less understanding about this goal • Interested in economic improvement
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	• Interested in using technology for development • Have less understanding about this goal	10 REDUCED INEQUALITIES	• Situation of inequality problems
11 SUSTAINABLE CITIES AND COMMUNITIES	• Interested in how to solve related problems • Air pollution • Pollution • World pollution issues • Global warming issue • Community development	14 LIFE BELOW WATER	• Interested in Types of marine debris • Innovation to solve waste problems • Interested in living things
15 LIFE ON LAND	• Adaptation in different locations • Interested in the beauty of nature • Interested in living things • Interested in terrestrial ecosystems	17 PARTNERSHIPS FOR THE GOALS	• Interested in future career paths • Interested in benefits of development partners

a

SDGs	Reasons	SDGs	Reasons
1 NO POVERTY	• To help people who have no income • Situation of many poor people	2 ZERO HUNGER	• To solve issue of poor people
3 GOOD HEALTH AND WELL-BEING	• Concerning self-illness • Value of health and well-being	4 QUALITY EDUCATION	• Factor to development of the country, • Value of equal access to quality education
5 GENDER EQUALITY	• Existence of gender inequalities • To encourage women to recognise self-worth	6 CLEAN WATER AND SANITATION	• Cleanliness of the city • Value of Clean water • Interested in turning contaminated water to clean water
7 AFFORDABLE AND CLEAN ENERGY	• Create renewable energy	10 REDUCED INEQUALITIES	• To eliminated inequalities in society
11 SUSTAINABLE CITIES AND COMMUNITIES	• Impact of floods • To reduce air pollution • To create city and community for sustainability and life	13 CLIMATE ACTION	• To reduce climate change
14 LIFE BELOW WATER	• Caused by human activities • To increase fishermen's income • Impact of issue on environment	15 LIFE ON LAND	• Interested in future career paths • Interested in benefits of development partners
16 PEACE AND JUSTICE STRONG INSTITUTIONS	• Domestic violence and family issue • Number of victims committed suicide	17 PARTNERSHIPS FOR THE GOALS	• Development in many sectors

b

SDG	Rational
6 CLEAN WATER AND SANITATION	Solutions • Water storage • Invention of water filter
11 SUSTAINABLE CITIES AND COMMUNITIES	Express value of issue • The place we live • Our people in community • interested in developing a sustainable community Solution • Development at the local level can improve the country
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Solution • Responsible production and consumption reduce waste
13 CLIMATE ACTION	Express value of issue • The importance of air to life • Impact on humans life
14 LIFE BELOW WATER	Express value of issue • simple and uncomplicated issue • Decrease of impact on humans Solutions • Collaboration for introducing littering behaviour • Participation in waste reduction • Conservation of aquatic animals
15 LIFE ON LAND	Express value of issue • Relatable issue to life • Security of the resource for future • Solvable issue • Helping other living species. • Reduction of factors contributing to global warming Solutions • Waste management and littering • Tree plantation • Conservation of general environment • Animal conservation

c

Figure 33 Students' Awareness of SDGs

(a) SDGs – students are interested in, and (b) SDGs students want to solve and (c) SDGs – students think it can be solved.

From Figure 33, SDGs that students interest for learning comprise approximately 12 out of the 17 SDGs. This indicates that as they learn about the SD issue from the YES! programme, they desire to know more about 6 additional SDGs. Their interest is not limited only environmental sustainability issue. Examples of their answers are provided below:

> *I want to learn about the elimination of hunger because there are a lot of homeless people in the country and most of them are starving and have a lack of food. (A student from School D)*

> *I want to learn about clean water and sanitation because water is the source of life. Also, it is a habitat and food source for almost every living things on earth. If the water is polluted, there will be big impacts on the ecosystem. (A student from School A2)*

Additionally, themes regarding SDGs - students want to solve emerged, and interestingly, almost 14 of the 17 SDGs are involved (see Figure 33) including SDG1, SDG2, SDG32, SDG4, SDG5, SDG6, SDG7, SDG10, SDG11, SDG13, SDG14, SDG15, SDG16 and SDG 17. The reasons they want to solve encompass their awareness regarding all three pillars of SD. Examples of their concerns about social perspectives are gender equality, the quality of life, environmental perspectives, and economics. While students care about impacts on the environment, they encompass the quality of water and air pollution. An example of their concerns about the economic dimension is their concern about fishermen's income. However, the majority of students' awareness is regarding social aspects of the impacts.

For the determination of which SDGs can be achieved, The data set revealed that students believed that SDG6, SDG11, SDG12, SDG13, SDG14, SDG11, and SDG15 could be achieved. All those SDGs are the main target of the programme as they are linked to landslides, floods, droughts, and waste in the river and ocean. Their awareness regarding these SDGs encompasses solutions such as animal conservation, collaboration, and changing waste littering behaviours, as well as rationales such as reducing the impacts of issues and developing local communities. The findings express awareness regarding both environmental perspectives and social perspectives.

Overall, students' reflections indicate that integrating SDGs into the YES! programme enhances students' understanding and recognition of significant global issues, including not only landslides, floods, droughts, and waste in the river and ocean in the YES programme, but also poverty, inequality, climate change, and environmental degradation. Similarly, in the case of Torriano Primary School in London, students who participated in an SDGs programme organised by UNICEF UK shared their views on the SDGs (Oxfam, 2019). Oxfam (2019) illustrated that programme assessments through focus groups allowed students to present their perceptions about the most important SDGs, reflect on their learning in school about and for the goals, and make recommendations to the UK government for further action. These recommendations included increasing the minimum wage, providing electric school buses, implementing a single-use plastic tax, incorporating the SDGs into the curriculum, organising a national SDGs day, and developing a phone app that alerts people to progress on the goals (Oxfam, 2019). Clearly, students in this study benefit from learning about SD by gaining knowledge about SD and being able to reflect on their thoughts regarding SD issues as they express their concerns and motivation fro learning more about SDGs issues.

Bourn *et al*., (2016b) claim that the SDGs for education emphasise the ongoing need to attain inclusive and equitable quality education for all individuals. These goals outline the necessity of accomplishing specific objectives related to educating individuals about global and sustainability themes. Given the establishment of the SDGs, these 17 goals are expected to shape national policy decisions. According to the ECE (2021), the SDGs have had an impact on Thailand's education in terms of developing education to promote people’s sustainability. SDGs should be integrated in teaching and learning in STEM subjects as Costa *et al*. (2023) shows the relationship with SDGS and learning science such as physic and noise pollutions that can enhance students’ knowledge and aware of issues of noise pollution. Tickly *et al*. (2018) argue that it is important to consider SDGs in education and understand how the SDG agenda might impact the curriculum and pedagogy of secondary STEM programmes. This implies that SDGs play a vital role and can be integrated into education to achieve SD.

Integrating SDGs in education can give a clearer picture and broaden sustainability perspectives on several sustainability issues. As SDGs are introduced, allowing students to explore the issues appropriately and discover the cause and impact of the issues, human behaviour related to the issues is integrated into the pedagogical approach. The research finding confirms that SDGs are helpful for promoting SD learning as they provide a broader issue toward SD (Weber *et al*., 2021) and serve as a promising core to incorporate cognitive knowledge, socio-emotional domains, and behavioural domains that promote students competencies for SD (UNESCO, 2017). In the following section, students' SD competencies are discussed.

6.4.3.3 Students Practicing Competencies for Sustainability

According to the literature, for all individuals, regarding ESD competencies (Leight *et al.*, 2018; Wals, 2015, Wiek, 2011; Wiek *et al.*, 2016), this study provided an opportunity for practice competencies by using open-ended question prompts to promote discussion and reflection in groups and individuals. The findings from engineers logbooks illustrated that students are learning environmental issues in this programme. The skills and values related to SD also encourage students to learn and practice competencies for sustainability. This section reports the competencies students express during sustainability discussions and their reflections regarding those competencies from the analysis of data from phase 1.

During sustainability discussion in the YES! programme, students were encouraged to practice competencies for SD by discussing in groups following the prompt questions presented in the engineers' logbook. After that, students who act as scientists recorded their answers in the engineers' logbook. The competencies students practice encompass system thinking, self-awareness, anticipatory thinking, and normative thinking.

The first competency is systems thinking, how the system is interconnected (Leicht *et al*., 2018) and ability to analyse complex system (Wiek *et al.,* 2016), which is evident from themes such as understanding relationships between elements in the system, and identifying causal relationships. In the Drought is coming' activity, students demonstrate their understanding of relationships regarding water issues. They shared ideas about the value of water and the impacts of water shortages on individuals, society, and the economy in the whole class before watching a video clip about droughts in Thailand, presented by a water expert discussing water management. They then selected a sector to discuss the impacts of the imagined drought in Pomelo Town, focusing on a sector they were interested in. The majority of students from every school (33 groups) expressed concerns about the vegetable garden, showing awareness of social, economic, and environmental aspects regarding impacts of issues. For example:

> *If there is no water in the veggie garden, the vegetables will die and people who aren't getting nutrition will also die.* (Group 6, School E)
>
> *There will be no product... product for exportation."* (Group 1, School C)
>
> *Farmers cannot get money for the income.* (Group 1, School B)
>
> *The pomelo town will run out of vegetable for cooking.* (Group 3, School A1)

In addition, the other seven groups from schools A1, B, C, E, and F expressed impacts on nature reserves, emphasising their worries about living organisms. For example, Group 3 from School E stated, 'Animals have no water to drink - aquatic animals have no place to live – animals are extinct.' Six groups from schools A1, C, D, E, and G showed interest in the housing area, focusing on the impact on social aspects regarding people's lives and well-being. Another six groups from schools A1, B, C, and G indicated the impacts of drought on livestock farms, expressing concerns and values related to the economy, social aspects, and the environment. Clearly, this question not only reflected their systems thinking but also captured students' appreciation for different aspects of SD. Student also made their decision to identified drought issue to the units in society, which in this study refers to different sector in Pomelo town.

In activity four, students used a tool to collect waste from the river and ocean. During the sustainability discussion, student groups reflected on why the existing machines available could not fully address the waste issue. Students drew connections between their experiences with the simulation tool and its potential application in real-life situations. They provide reasons why the tools cannot help solving the issue in reality according to the cause of the issue, situation of issue and link with information obtain from the activity. They also considered the tool's capacity to solve the real problem. The major contributing factor identified in 47 logbooks across all schools was human behaviour. Students emphasised that people continue to dispose of waste improperly, as indicated by statements such as 'Because people do not care about waste. Did not dispose the waste in the right place or some people don't have a volunteering mind' (Group 2, School A2). Students also highlighted the unsustainable consumption of products leading to waste, stating, 'Because a lot of garbage is created every day' (Group 2, School F). This unsustainable consumption of products that can transform into waste was further expressed: 'Because people use things that contain garbage as packaging' (Group 1, School B). Only four groups from schools A1, B, E, and G identified concerns related to the efficiency and capacity of the machine. Overpopulation was mentioned as a limiting factor in only one group from School C. Clearly, student can connect their learning into different perspectives.

They are also able to justify norm of society. The reflection of students also encompasses normative competency or value thinking. In Activity 2, students assess social norms and wellbeing regarding what people in Mango City could do to live happier and be less affected by the floods, acknowledging that it appears we cannot deny their occurrence. Themes regarding construction-related solutions, preparation strategies, and changing behaviours are found. In an effort to mitigate flood damage, a total of 36 groups proposed construction-related solutions, including the construction of housing, preventive structures, dams, and drainage systems. These concepts illustrate the utility of STEM in mitigating the consequences of issues and providing remedies for tangible challenges. Even if science is a concern as a contributor to the SD problem, science understanding and STEM can help reduce the problem. This gives the impression that the world is not near its end. Humans can be protected by resolving issues; however, humans can help conserve the environment by modifying their behaviours and people in community can adapt to live with the issues by preparing for the problem.

Fourteen groups, representing schools A1, B, F, and G, proposed preparation strategies for surviving floods. These strategies included self-preparation, food and supply stockpiling, equipment preparation, learning from mistakes, education and learning, adaptability, protection and warning system preparation, and protection method discovery. It indicates that the students have demonstrated an awareness of the significance of community resilience and safety, as well as the necessity of readiness and community support to improve the community's well-being. For example, one group stated, *'Adapt and learn how to endure the floods effectively and safely. We will sustain less damage if we know how to adapt and survive'* (Group 1, School F). Another group mentioned, *'Equipment for disaster response should be prepared, and local residents should be instructed on how to handle these natural disasters. If the equipment is well-prepared to cope with the natural disasters and we know basic survival skills when the disasters actually occur, we will not have to worry about being unable to protect ourselves in time and cause no trouble to ourselves or others.'* (Group 7, School C).

Interestingly, six groups from schools, except for schools D and E, stated that people must modify their behaviour to decrease global warming, while two stated that collaboration is needed. Students value collaboration and believe behavioural changes can improve people's well-being when dealing with floods.

Furthermore, in Waste in the River and Ocean Activity, students suggested government actions, recognising that governments power in creating waste rules, legislation, and programmes that significantly impact society. The students provided recommendations for government action: solve the problem, educate citizens, encourage public campaigns, legislate policies or regulations, organise volunteer programmes, and manage the waste management systems by supporting equipment and funds. Students also recognised the societal norms and values related to community and political power.

Findings also indicate students' anticipatory competence as they practice evaluating future situations. themes found when students justify long term and short term solutions. In the landslide prevention activity, students evaluated their model as a 10-year solution for various reasons. 27 groups from all schools expressed confidence that the model cannot provide a long-term solution due to material and structure lifespans, with five groups from schools A2 and D mostly agreeing. One group mentioned, *'No, less than 10 years because the situation of landslides each year is not the same degree and some equipment might be damaged over time.*' (Group 2, School D).

The complexity of landslides also poses an obstacle, making the barrier unable to last long. Other minority reasons included concerns about the efficiency of the experiment, the need for other approaches, and the requirement for improved surface soil. However, nine groups of students, approximately one or two groups from each school, believed that the solution could last a long time under certain conditions, such as regular repair and maintenance, the use of quality materials, planting more trees, and employing specific technology. One group stated, '*Up to 10 years, but maintenance is required because the barrier will gradually wear out'* (Group 4, School C). They acknowledged that the model has some weaknesses that may need improvement to make it more promising, and they recognised that it is not a sustainable solution, as it requires effort to meet specific conditions.

In contrast, only 13 groups believed that the model was a long-term solution for landslides. They based their belief on the model's strong structure, high-quality and durable materials, the presence of trees to block landslides, collaboration within the team, and the confirmed efficiency demonstrated by test results. This idea was agreed upon by all students from every school but in a small number. One group mentioned, *'It lasts over 10 years. can be used because the tools are made of steel and concrete'* (Group 5, School C). As suggested by Geden *et al.* (2019), anticipatory thinking enables decision-makers to visualise a range of potential future states and recognise indicators that may lead to these states. By assigning students tasks that require them to contemplate the future, evaluate the solutions, and consider the repercussions of environmental issues, this competency can be enhanced.

For self-awareness, students were asked what they could do to solve landslides for the long term at the end of the activity. Then students proposed their long-term solutions, reflecting criticality on their awareness of the issue which encompasses themes such as constructing preventive structures, changing behaviours and accommodating the problem. Their answers regarding constructing preventive structures are found in responses from all schools. As a result, students reflect on the value of STEM and their solutions for landslides in the context of SD, focusing on reducing the issue from a future perspective. Students' behavioural changes involved stopping deforestation, planting trees, improving soil surfaces, and modifying the mountain. Planting trees was a commonly shared initiative by students from all schools except School F. The majority of responses advocating for planting trees came from five groups of students from School C and four groups of students from School A. Some students recognised that human behaviour can contribute to addressing the landslide issue. In addition to behavioural changes and construction, students indicate their solutions to accommodating the problem through migration and settlement. Only six groups from School A, School D, and School F suggested moving away from the risk area. The idea of moving from risky areas also reflects an awareness of sustainability, demonstrating knowledge about the impact of landslides and ensuring the safety of villagers in the long term.

When students were asked about do-it-yourself methods to reduce drought as if they were residents of Pomelo Town, they considered their ideals and beliefs regarding drought reduction. They contemplated how individuals should address the situation. It was revealed that 26 groups from six schools proposed changing habits to decrease global warming and climate change, including planting trees, stopping deforestation, practicing waste management, reducing greenhouse gas emissions, and minimising resource usage. 39 groups suggested water management strategies, such as maximising water utility, strengthening water reserves, reducing water usage, and implementing water conservation practices. Both sets of ideas were presented in all schools and have the potential to alleviate drought, but only the first set directly addresses the problem. Notably, only one group from School C suggested requesting water from the government and employing artificial rain technology, demonstrating their STEM understanding and ingenuity. In the activity regarding waste in the river and ocean, all students demonstrated self-awareness by reflecting on their role in minimising river and ocean waste. Consistently, all groups agreed that modifying behaviours is the best self-help strategy, emphasising the importance of refraining from littering water sources, practicing waste management, maintaining cleanliness, and taking responsibility for the waste they generate.

The data set of phase 2 (Students' Reflecitve dairies) also demonstrates students' expression of SD competencies. First of all, students expressed self-awareness and normative competence by considering family norms and behaviours that need to be changed in relation to the Week 6 question. Significantly, 24 students suggested improving waste management activities such as waste collection, burning, littering, plastic reduction, waste sorting, and food waste to enhance the environment. Five students believe that car usage should be changed, with a similar number supporting a shift in electricity use to save energy by limiting appliance use. The diaries revealed that students expressed self-awareness about SD, gained knowledge about SDGs, expressed their empathy with others, and developed a sense of responsibility for social, economic, and environmental problems.

Four students advocate for forest protection, while two expressed concerns about family drought preparation. Additionally, four students addressed issues such as household expenditures, health difficulties, and neighbour disputes. However, students recommended strategies to improve neighbourhood environmental quality for sustainability. Aside from family context, 27 ideas for rubbish management include improving waste disposal habits and effective waste management. Two of them state:

> *The releasing of wastewater into the rivers and canals should be improved, due to my community living near to the rivers and canals, the inhabitants release the wastewater into the water source. It can be improved by treating the wastewater before releasing into the rivers and canals. (S23)*

> *Reduce the waste burning because waste burning increase CO_2 (S37)*

A minority of students emphasised the importance of prioritising forest and tree conservation, along with community cleanliness and environmental preservation. They suggested reducing air pollution by driving less and consuming fewer grilled foods. To prevent floods, they recommended enhancing drainage systems. Other proposed measures included upgrading communal electricity, improving playgrounds, limiting car usage, and fostering increased community cohesiveness. Figure 34 shows students' concerns related to family and community issues.

Figure 34 Issues in Family and Community that Concern Students

(a) Issues in Family (b) Issues in Community

Students' responses reflect their life experiences and community insights, demonstrating critical thinking and reflection on daily norms. Engaging in cognitive processes such as critical analysis, they appraise issues affecting them and their community. This signifies students' observation of family and community behaviours, comprehension of the issues, and the formulation of appropriate solutions.

'Self-awareness' is encouraged when students reflect on whether the programme inspired them or changed their behaviour (UNESCO, 2017) Students found inspiration in knowledge and skills development, SD, and career awareness. They expressed their motivation, such as, 'Motivate me to learn a lot of things. Then, use what I've learned to help the country become more sustainable' (S28). 31 students reported behaviour changes, with 10 saving the environment and 18 applying their gained knowledge and skills. One student noted, 'I transformed from the one who faced difficulty with invention, but after the school activities, it turned out to be that I am able to invent or solve problems easier' (S9). This suggests that students recognised their growth, thoughts, knowledge, skills, and contributions through participation in the YES! programme.

Even though five students claimed their behaviour remained unchanged, they acknowledged the programme's inspiration, particularly in sustainable development, problem-solving, and collaboration. One student expressed, '*It motivated myself as I want to improve society in order to minimise problems and be more environmentally friendly'* (S21). The majority of students reflected on changes in their behaviour related to solving environemental issues, both through actions they can take individually and motivations gained after attending the programme. This remains a favourable indicator for changing the future toward SD. Some students went beyond knowledge for SD, connecting their thinking and actions to STEM problem-solving and collaboration, which aligns with the programme's main objectives. As one student stated, 'What I have done is that I like working as a team more than I like to do things alone' (S30). Students have inform their change in attitude toward working collaboratively

Students also reflected on their perceptions of environmental issues and how they can actively participate in solving them, starting with actions at home. 36 students expressed their belief that they can tackle waste problems individually and suggested starting at home by implementing waste management practices, proper disposal, and reducing plastic usage. For instance, one student mentioned, *'Put trash in the place marked for disposal. Tell the difference between foam, steel cans, wet trash, and plastic bottles. trash that is put into groups based on its properties, like hazardous, recyclable, and wet rubbish'* (S3). Another student shared, *'Teaching the children in the family to throw the rubbish in the bin. If the waste can be recycled, it should be recycled, as it can help reduce the problem of landfill waste'* (S22).

In addition to waste-related concerns, students identified other critical issues they could address, such as landslides, floods, and drought. They provided reasons why these environmental challenges, including floods (with 14 students), droughts (with 12 students), landslides (with 7 students), and waste in the water and ocean (with 7 students), are considered difficult to solve. For example, one student explained, *'Landslides and floods happen because the soil can collapse at any time, which makes it hard to build containment structures and plant trees on time. Another problem with floods is that the water takes a long time to drain, which makes it long time to drain'* (S4). These reflections demonstrated that students appreciate the value of knowledge sharing and family involvement in solving the issue. They are aware of their capacity and understand their role in participating in sustainability actions. The students have shown they understand various strategies to address environmental issues, especially waste management and recycling.

Students also reflected on the political impacts on society. If they were the prime minister, they would provide policies to address various issues. Among the 33 students concerned about environmental sustianability, 17 were aware of the waste issue and proposed policies on waste management, littering, plastic and foam reduction, promotion of biodegradable materials, invention of collecting tools, launch of campaigns, and legislation to promote and enforce punitive measures. They understand the role of policy, as expressed by one student, '*I will create a policy to develop a better ecosystem, reducing waste dumping into water resources, encouraging the proper disposal of waste, and promoting good behaviour as an example for other people'* (S21). Another student suggested, *'Build museums about how to deal with floods, droughts, and landslides and how to properly sort the waste. Furthermore, apply the* *knowledge in the class lessons of young children to instil it from childhood and make it a habit'* (S3). This is also reflect their normative thinking accordign to understanding of political invovledment of SD. So that, they engage in social norm and value regarding SD while indicating the issues that they would like to address in the larger context.

Evidently, data sets from phases 1 (students' engineers' logbooks) and 2 (students' reflective diaries) illustrate the outcome of the YES! programme in promoting SD competencies. The ability to make connections between concepts regarding the SD issue as well as identify causal relationships illustrated the use of system thinking by students in this study. This is in line with the framework to assess system thinking developed by Demssie *et al*., (2022). They also able to critical analyse the input of issue in different sectors and different dimensions as found in Clark *et al.* (2017). This demonstrates that primary students are able to practise system thinking through the ESD integration intervention, which aligns with the study of Levchyk *et al*. (2021) who found that collaborative learning regarding ESD integration with media education resulted in promoting competencies such as the capacity to establish a causal relationship.

Students also practice self-awareness by suggesting self-solution as the way they justify their capacity to cope with the issue. This is in line with, Lee *et al*. (2013), who found that hands-on engineering learning about SD issues helped students apply classroom learning to outside classroom contexts such as their homes. Students also practice normative thinking by determining, family, community and government-based solutions, showcasing a comprehensive understanding of the issue. The ethical and political decisions are found to align with the study, with students in the UK understanding the SD issue from a 'politics' perspective (Walshe, 2013). The students' 'reflection suggests that these aspects allow students to participate in democratic society, as Eilks and Hofstein (2014) suggest, as well as promote SD in society. They also discussed ways society can improve, such as by inventing waste pickup equipment, changing behaviours and mindsets, fostering collaboration, and promoting social causes. This acknowledgement highlights social awareness and the importance of collaboration. This is in line with many studies indicating that making decisions and moral-ethical judgments is significant for SD (Kopnina, 2013).

As stated in the preceding evidence, this study promotes student discussion, communication, and self-reflection regarding SD in order to develop SD competences, which is consistent with the framework of Demssie *et al*. (2022). Individuals, including children, must possess key competencies that empower them to contribute positively and responsibly to the contemporary world, actively engaging in the required changes (González-Salamanca, 2020). According to group reflections and engaging in discussions, students are able to reflect on their opinions and justify value, norm, system and future as well as themselves. This favourable conclusion is consistent with the findings of Levchyk *et al.,* (2021). With the science knowledge, serves as declarative knowledge (Frisk and Larson, 2011), and the STEM problem-solving approach, students are given the opportunity to develop more ethical and critically informed approaches to decision-making when ESD concepts and practices are embedded within science education (Quinn *et al.*, 2015). This presents a significant benefit to society as a whole in this phase. In this learning, students gain an understanding of the societal social aspects, which informs them that society is responsible for making decisions for environmental sustainability (Eilks and Hofstein, 2014). Moreover, Vare and Scott (2007) assert that to establish the successful practice of achieving SD, knowledge must be taught with the skills and capability to critically evaluate the issue by enhancing critical thinking beyond what is learned from and determined by SD concepts and examining sustainable living's contradictions (Vare and Scott, 2007). As supported by Frisk and Larson (2011), individuals are also required to have values, attitudes, habits, and behaviours. From learning in the YES! programme, students in all schools exhibit these components, which encompass normative, anticipatory, self-awareness, and system thinking competencies.

This study is successful in encouraging students to reflect on their thoughts. Through open-ended questions in engineers' logbooks and group discussions on environmental sustainability, the YES! programme provides students with an invaluable opportunity to consider SD. As the findings indicate several competencies, this aligns with the recommendation of Barth *et al*. (2007) who recommend involving students in sustainability discussions, allowing them to converse with peers and apply critical thinking, and developing SD competences through learning, not teaching.

6.5 STEM Problem-Solving

Through their participation in the YES! programme, the findings obtained from the data sources compiled in phases 1 and 2 provide insights into how the YES! programme facilitates students' learning regarding problem-solving skills. In this section, data sets from both students and teachers are directed towards the potential of the programme to promote problem-solving skills as well as their reflections of their perceptions. Themes emerged and are described in the following sections to answer research questions one and two respectively.

RQ1 How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?

6.5.1 Students' Perception Regarding EHoM

The data obtained from the sticky notes at the back of the engineers' logbook (Phase 1) reveals that students have a positive attitude toward EHoM, which indicates that the YES! programme has positive impacts on students demonstrating the problem-solving skills based on EHoM. Among different themes, according to students' reflections regarding their preferences, the appreciation of EHoM emerged. Examples of their voices are illustrated below.

> *Excited about the things that are made from the design, worried about whether there is something wrong or not. Enjoyed the activities that I had done. It was very fun to use many materials to make the design. Glad to do the activities with friends.* (a student from group 6, school B)
>
> *Solving problems based on Engineering Habits of Mind allows us to be capable to solve problems better.* (a student from group 6, school G)

In students' reflective diaries (phase 2) , data set provided the students' perceptions regarding EHoM and how they can implement it in school. Themes have emerged regarding the EHoM application and EHoM that students are aware of. Students indicated that EHoM can be used for academic purposes such as group work, model making and design, and science subject learning. Students also stated that EHoM can be sued to solve school problems such as preventing COVID-19 infection, drainage systems, waste issues, wastewater issues, helping others, classroom issues, common school issues, and water use issues. Student answers demonstrated that the characteristics of EHoM encompass six EHoM which are creative problem solving (inventing models using creativity), visualising (design and planning), improving (improve from mistakes), adapting (completing tasks even though facing obstacles), system thinking (seeing the elements involved in the issue), and problem finding (identity problems in school).

As EHoM are not fixed traits, Lucas and colleagues explained that students can be cultivated on purpose by teachers using a combination of four principles: making sure students understand the habit, making sure the environment is right for the habit to grow, choosing teaching methods that help students practice and pass on the habit, and getting students to care about and commit to the habit (Lucas *et al*., 2017). The YES! programme made EHoM visible by introducing students to different EHoM before starting the activity, making them understand the different habits in terms of how engineers think and act to solve problems, and using questions to prompt their action and reflection while solving environmental issues. This approach is verified by Finegold and Jones (2016), who argue that these thought processes well reflect perceptions of EHoM demonstrated by engineers who have good problem-solving skills for instructing young people with these abilities.

6.5.2 Teachers' Perceptions of Problem-Solving Skill and EHoM

Throughout the programme, teachers observed how students engaged in the activities, especially their behavioural and emotional engagement in the problem-solving task. Then teachers take part in semi-structured interviews. Themes are student engagement in the problem-solving task and teachers' perceptions toward problem-solving opportunities.

6.5.2.1 Teachers' STEM Implementation

From the interview (Phase 1), data set indicating teachers' experiences of STEM integration was explored. Nine teachers provided examples of 1) their implementation framework such as integration with science, or mathematics, or both science and mathematics and with four disciplines, 2) type of integration such as subject based, STEAM or CC thinking model, 3) their applications such as extracurricular, competition or camp activity, and, more importantly, 4) factors that affect the organisation of STEM activities in their schools including resources, nature of learners, curriculum restrictions.

Nine teachers shared their definitions of STEM education from their perspectives, which involve invention and construction, planning, problem-solving in everyday life, integration of different subjects, processes and steps, and various situations. One teacher said that she had never considered STEM before. This is due to the fact that she has less experience as an in-service teacher. However, among other teachers, only four of them expressed awareness toward engineering that involved planning, problem-solving, and invention. In addition, ten teachers were favourable about STEM in the classroom in numerous ways, while two of them also expressed concerns about STEM. Thana expressed:

> *When we bring in STEM, some children don't just want to meet the curriculum goals. They want to contribute their own ideas to solve different problems, addressing their unique interests. You'll find there is a lot of variety; some may use one approach, while others may use another. This diversity is very positive and shows the value of using STEM as part of learning science. (Thana)*

This study confirms that teachers of gifted students value STEM integration because it benefits their students, similar to Pitiporntapin *et al*. (2018), who found that in-service teachers in Thailand recognise STEM integration's benefits for students' learning as well as some limitations of STEM. This finding aligns with many studies on STEM integration, such as

Stohlman *et al*. (2012) who noted that STEM brings numerous advantages, but it needs more time for preparation and instruction, adding to the teachers’ workload. Additionally, similar to Pitiporntapin *et al.* (2018), some Thai teachers show a lack of knowledge in STEM, whereas those who understand STEM, view it as the integration of several disciplines.

STEM education is already implemented in Thailand (Srikoom *et al*., 2017; Sritrakul, 2018), and is a national priority to better prepare future generations for their future careers (Pitiporntapin *et al*., 2018). As suggested by Stohlman and colleagues (2012) to achieve the potential benefits of integrated STEM education, it is essential to determine how teachers can teach integrated STEM education effectively. Supporting teachers, teaching practices, teachers’ efficacy, and the materials required to implement integrated STEM education are crucial factors to consider. Srikoom *et al*. (2017) found that most Thai teachers think that STEM concepts should be taught as part of a cross-disciplinary course where ideas from science, math, engineering, and technology are all taught together. The lack of understanding of STEM education in Thai teachers also report in study of Srikoom *et al.* (2017). Following that, it is consider that teachers’ prior experiences with STEM integration in the classroom is crucial. Their knowledge of such approaches, as well as their frameworks and types of integration, is helpful in designing more effective STEM activities and determining how to integrate them in the classroom in order to promote students’ learning of SD.

Teachers emphasised the obstacles they faced when attempting to integrate STEM, such as limited resources, and curriculum restrictions. This barriers toward STEM integration is align with Margot and Kettler (2019) that obstacles are such as curriculum and structural challenges, concerns about students and assessment, and the lack of support. Also, this aspects align with study of Laksmiwati *et al.* (2020) that teachers in Indonesia report the limitation to implement STEM education including time, money, and the nature of students including motivation and readiness. These enable me to develop targeted solutions and assistance mechanisms, because the teachers' perceptions of STEM's positive impact on students’ learning have established and strengthened their positive attitudes toward STEM (Srikoom *et al*., 2017).

The findings of this study have convinced that SD can be advanced via STEM and can be successfully integrated in primary science classrooms by demonstrating the use of environmental issue for students to learn application of STEM knowledge, address SD issue and practice problem-solving skills.

6.5.2.2 Teachers' Perceptions Toward Problem-Solving Opportunities

During interviews, teachers shared their thoughts on how the programme promotes problem - solving skills and EHoM. Three themes emerged: the perception of problem-solving opportunity, the value to engaging students during problem-solving activities, learning EHoM. Teachers provided the difficult of implementation of EHoM in STEM problem-solving activity. Thana said that "*It is not difficult because they are a group of students that are already fast learners and have foundational skills for completing the tasks. It is something that can be learned, but it may require students to participate in activities several times and more often."*

Thana also indicates that practice is significant. He said *'This might be the first time that they have experienced it, which may cause them not to learn very quickly. However, if it happens next time, students will have these qualities, and they will learn faster in future activities' (T11)* Among the four teachers who agreed that EHoM can be learned through practicing repeatedly, this reflection suggests that teaching gifted students EHoM is not difficult if opportunities to practicing EHoM are provided. This finding aligns with the perceptions of preservice teachers in the UK of giving students additional time to explore EHoM allowing students to benefit from further studying EHoM at their own pace, through hands-on activities and subsequent self-reflections (Hanson *et al.*, 2022).

However, one teacher expressed concern that the EHoM description is difficult to grasp especially the EHoM itself due to the abstract nature of the terms. For teachers, the concern of EHoM reflect their limited understanding of engineering that Srikoom *et al.* (2017) address the important of engineering in STEM education. This may be attributed to different factors as suggested by Hanson *et al.* (2022). In their study, incorporating EHoM into lesson plans was found challenging due to a lack of experience in preparing for independent inquiry and in selecting topics that facilitate the teaching of EHoM within the lesson plans. In contrast, the participants in the study of Finegold and Jones (2016), revealed that EHoM definition is too general, although its implementation in non-engineering fields is not excluded. However, the positive attitude of teachers in this programme encourages further investigation of embedded EHoM in STEM problem based learning. The professional development regarding EHoM can help teachers see how engineering can be embedded in their practices.

As a result of that, students learn EHoM as well as STEM skills such as invention and design and the knowledge for SD. The voice of students confirms that problem solving experiences in the classroom have the potential to promote students learning in each aspect. This aligns well with the study of Lakanukan *et al*. (2021) where students developed their Problem-solving skills and reflected on themselves regarding the identification of problems and improvement.

The use of EHoM in this programme may also have future positive impacts on their lives. As Burgess and Mayer-Smith (2011) demonstrate, children's experiences affect the way they view the natural world. So, creating classroom experiences with STEM problem-solving can help them see the impact and value of both STEM knowledge that can help solve the issue and the importance of solving environmental issues.

In the next section, the data set indicates the findings to answer research question two, which is discussed.

RQ2 How does the implementation of an integrated STEM-based activities enhance the awareness of sustainable development and improve the problem-solving and collaboration skills among gifted students in science?

6.5.3 Students' Practicing of EHoM

In the context of SD, problem-solving is identified as a crucial skill, encompassing the capacity to systematically and effectively discover, analyse, and tackle complex issues and sustainability (UNESCO, 2017; Wiek *et al*., 2011; Wiek *et al.*, 2016). Integrating problem solving in this study is advocated as a key approach for SD learning. Problem-Based Learning (PBL), as applied to STEM subjects in the YES! programme, enables students to engage in experiential learning to address environmental sustainability issues, requiring the application of STEM problem-solving skills. The analysis of student engineer logbooks, teacher observation forms and teacher interviews provided evidence that students were employing various EHoM.

A data set from engineers' logbooks, photo and drawing (Phase 1) demonstrates students' practise. EHoM encompasses a series of habits of mind, which are problem finding, system thinking, visualising, improving, and adapting. Themes regarding each EHoM are discussed as follows:

6.5.3.1 Problem Finding

Problem finding, in the study of Lucas and Hanson (2014), is defined as the action and skills needed in 'clarifying needs, checking existing solutions, investigating contexts and verifying' (p. 4). In this research, students investigated different contexts and identified environmental sustainability challenges such as landslides, floods, droughts, and river and ocean waste in the scenario given at the start of each activity.

In the landslide activity in phase 1, students identified the reasons why Apple Village is frequently affected by landslides. Across all participating schools, a total of 45 groups identified natural causes as the main factor. Additionally, 19 groups also indicated the village's location as a contributing factor. Students from 7 schools mentioned the geography of the land, human behaviour, and the soil conditions as causes. Two groups, one from school A1 and the other from school G, mentioned the lack of protective measures.

In the third activity, students identified the drought issues in Pomelo town. In the scenario where the town receives no support, only six groups mentioned the economic impacts of the drought, such as a worsened economy, damaged agricultural products, and reduced exportation of products. The most significant concern, noted by 42 groups from all schools, was the social impact, which includes affecting people's professions, making the city unsuitable to live in and affecting people's lives in general. However, 26 groups from all schools also identified environmental impacts, mentioning bad environmental conditions, and their effects on living organisms. Students also described the scenario of drought in Pomelo City, as an arid environment, hot and lacking in water.

Lastly, in activity 4, three prominent themes emerged, representing current problems in Cocoland. Students noted the environmental impacts of waste in rivers and oceans. Only 8 groups (Schools A1, B, E and F) reported the specific impacts of the problem, including: 1) impact of issue (impacts on earning of living of people, death or extinct of the animals, accumulation of microplastic in animals and humans), 2) human behaviour as a cause to the problems (littering improperly, littering into the water resources), and 3) the impacted areas (river, water sources, sea, Cocoland area).

Evidently, environmental sustainability issues are recognised as a kind of 'wicked problems', characterised as one of the engineering problems in the real world (Yearworth, 2015). This makes them ideal for cultivating problem finding skills. Gifted students in this study are able to recognised and identify the issues. These issues are considered complex and seemingly impossible to solve due to incomplete or contradictory knowledge, the large number of stakeholders and opinions involved, the economic burden, and the interconnected nature of the problems (Lucas *et al*., 2014). Additionally, they provide an opportunity to develop knowledge for SD (Wals, 2015). However, the complexity of these issues also allows for creativity and other EHoM to flourish. From engaging with problem, The students were able to find problem and find the strategies and this problem serves as their inspiration that aligh with study of Tank *et al*., (2015). This suggests that the YES! programme has the potential to promote problem-solving skills.

6.5.3.2 System Thinking

System thinking refers to seeing connections and patterns (Lucas and Hanson, 2014). As often highlighted in SD competences, system thinking is essential for learning SD. System thinking in EHoM is applied in engineering problem-solving contexts. Engineers use system thinking to create and enhance complex goods, processes, and solutions. They evaluate how system components interact, how changes in one area affect the whole, and how to efficiently attain desired results and create pathways illustrating the journey of scientific knowledge. The programme's scenarios encouraged students to use ‘system thinking’ for solving problems by understanding the complexity of issues, connecting classroom STEM knowledge, and creating a conceptual map to show scientific knowledge's pathways.

In the landslide activity, students identified the causes and impacts of the issue. However, to develop effective solutions for preventing such events in Apple Village, a deeper understanding of how these impacts are created is essential. Students connect the knowledge regarding the issue from the problem finding questions, the information given in the story, and the science knowledge provided in the classroom. In this case, some groups did not identify why the cause of the landslides impact the people in the village, as they were still thinking about the cause of the landslides. However, some groups were able to identify key factors, which were consistent across all schools. Thirty-three groups noted that landslides affected the village and villagers due to the characteristics of the soil. Factors such as forces, weight, quantity, velocity of movements, and direction of the soil were identified as contributing to the impact of landslides on people. Students stated that people are often unable to escape from landslides, which is why they are significantly impacted by them. This observation pertains to the importance of protecting people to reduce the risk of living in the area.

In the second activity, students identified the interconnection of floods and climate change. Only 25 groups answered the related questions, and the common views among those students are: 1) It relates to global climate change. 2) It relates to a higher global average temperature, and 3) It relates to climate variability. Additionally, students were asked to identify the impact of the floods in the absence of a preparation plan. Students are unable to touch upon the detail of climate change as they may have limited knowledge about this issues.

In the 'Drought is Coming' activity, students built a water storage system to store government-supplied water in preparation for the coming drought. After testing, they were asked to identify the characteristics of a good water management system to solve long-term water scarcity and provide ideas for reducing droughts in response to climate change. They critically evaluated the water storage system, finding what was needed to meet the conditions. 14 groups from school A (A1, A2), B, D and G suggested that the water storage must be installed in a proper area, has more in quantity, contains clean water, and has a good water management plan. 32 groups from all schools identified key characteristics of water storage, stating that it must contain enough water to meet needs, stores water in large quantities, and be sufficient for future shortages. Furthermore, concerning the overall quality of the structure, 23 groups of students provided the following feedback, highlighting the following features: leak-proof, tank-shaped, passes the quality test, constructed from low-evaporation materials, sturdiness, cleanliness, and being equipped with an efficient pipe system. In their analysis, students discern not only the organisational aspects but also the physical attributes and properties of the water storage system in anticipation of a drought. Students in all schools seemed to have similar abilities regarding system thinking.

Students learned about the accumulation of waste in the river and ocean, the Pacific Garbage Raft, and how sunlight degrades microplastics, leading to contamination of microplastics contained in cosmetic and personal care products. Students presented a concept map depicting the path of microplastics discovered in the human body, beginning with the Yoi-Yoi snack wrap discovered in the ocean after identifying the situation in Cocoland. Figure 35 below shows an example of the students' concept map for the journey of plastic waste.

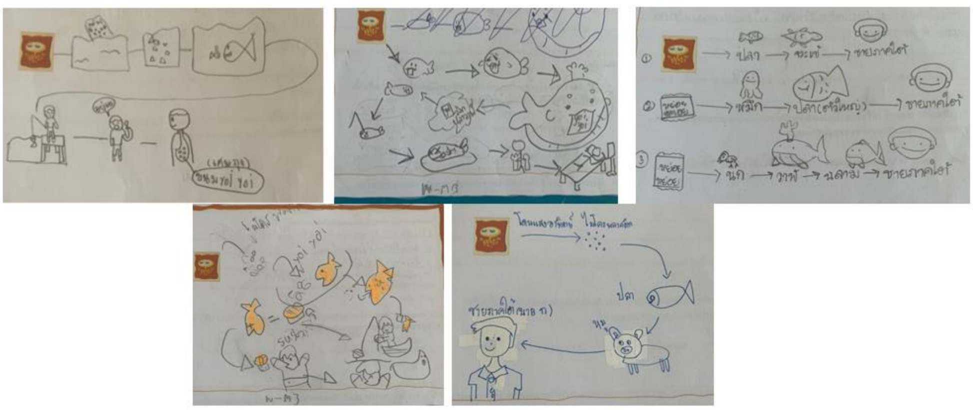


Figure 35 Example of Students' Visual Diagrams Illustrated Their System Thinking

From Figure 35, systems thinking can be exemplified through a visual diagram depicting the effects of a plastic bag on the human body, given that microplastics in the food chain illustrate ecological relations, substance transmission, and the consequences of animal and human consumption. This fostered system thinking involving STEM knowledge and demonstrated the generation of microplastics, plastic degradation, marine living organisms, and the food chain. By examining the food chain, students readily comprehended the energy and nutrient transfer that occurs during animal consumption. This flow carried microplastics, ingested by lower-level organisms, eventually reaching higher-level consumers such as humans and other species. Consequently, the final consumers end up with microplastics in their bloodstreams. The food chain concept map incorporated environmental concerns to encompass a greater variety of organisms. Beside the scientific aspects, by observing how microplastics transfer into their bodies, students may also gain an understanding of how their behaviours can impact society, the environment, and their own health. This knowledge ultimately necessitates sustainable solutions to reduce microplastics, improve waste management, reduce plastic pollution, and develop environmentally friendly alternatives.

Clearly, complex issues presented by the YES! programme foster systems thinking habits of mind for finding solutions and applying STEM knowledge. It is because students in this study were guided through the process of solution discovery by identifying the following attributes of sustainability issues: cause, impact, justifications for impact reduction, anticipated consequence of no solution, microplastics, and food chain concept maps. York *et al*. (2019) argue that with well-designed instruction, this ability can be fostered at a young age. The students' responses support that the YES! programme effectively develops system thinking skills in accordance with strategies proposed by scholars (Wiek *et al.*, 2016; York *et al.,* 2019). This is in line with supporting learning from STEM-PBL through active involvement in EDP which can promote system thinking, according to Abdurrahman *et al.*'s (2023) experimental study with non-STEM-PBL groups of secondary school students.

6.5.3.3 Creative Problem Solving

Creative problem solving is essential to tackling difficulties in the YES! programme. As students tackle the challenges of environmental sustainability, they must gather ideas before choosing a solution. Problem solving is a team sport (Lucas and Hanson, 2014), so students collaborate in engineering teams to solve each activity's problem under the provided conditions and create an original product. Creative problem-solving facilitates group brainstorming, decision-making, and success. Accordingly, ‘ideas of solutions’ and 'innovative artefacts’ as solutions represent students practicing creative problem solving along the YES! programme. Themes regarding creative problem solving emerge, including, solution ideas and final solutions.

A data set from the engineers’ logbook demonstrates student creative problem solving habits of mind during the process of brainstorming. Starting with landslide prevention, students listed long-term solutions and summarised the team’s main solutions. Students provided a variety of solutions, showcasing their creativity. 34 groups agreed on constructing preventive barriers, proposing various structures, including, holes for soil collection, and sandbags. 31 groups stated that relocation is needed, which could involve relocating the whole village or moving houses to create more space between them. 7 groups wanted to improve the strength of houses, while five groups stated the need for slope modification. Interestingly, 45 groups agreed to change habits to prevent the destruction of the environment. 5 groups stated that villagers need to be well prepared. And a few of them wanted to establish a campaign to educate others. In the second flood activity, students offered different solutions and summarised the group’s proposed solutions. The most common idea among 39 groups is managing drainage systems, including a pipe system, the removal of refuse in the filter, and the creation of more water channels such as rivers and canals. 35 groups wanted to construct preventive barriers with sand bags, concrete, and dams. 27 groups wanted to create more space to collect water, such as through reservoirs or dams. Actions regarding preserving the environment were found in 25 groups. This shows the rich variety of strategies to cope with flood issues in all schools.

The data set from photo analysis (Phase 1) also demonstrates students' final solutions as the outcome of making decisions and team collaboration. It was found that solutions vary for each activity. In landslide activity, solutions are preventive barriers, structures to collect the soil, and house relocation. Interestingly, different types of barriers are constructed to encompass, different locations, different layers of barriers, and different structures of barriers. The pattern of the house relocation is also different. Solutions for preventing floods are also different. In this activity, students use different ideas to solve the issue. Their flood prevention strategy encompasses having preventive barriers at different locations, using different types of barriers, using several layers of barriers, and using different choices of materials for barriers, including sandbags, concrete, straws, and wood. Students also created additional structures such as a roof, pipe, raft house, pumping machine, bridge, and structure for elevating the houses. For drought activity, students invent water storage systems that vary in structures and compositions. The format of constructions varies depending on the options of stands, the number of tanks, and how the tanks are organised. The waste collection machines in the last activity also demonstrated different solutions for students. The machines are different in shape, moving system, and trap function.

The outcomes demonstrate that students' approaches to environmental problems differ. Their solutions, based on criteria to assessment their complex problem solving competences, Levchyk *et al.* (2021) Inventive artefact development and creative problem-solving require team discussions and ideation; as a result, they can create creative innovation. Similar to the study of Abdurrahman *et al*. (2023), students who experienced STEM-EDP learning concentrated on creating alternative problem-solving designs based on information processing and investigations, whereas students in the control group concentrated on discussing observation activities and scientific discoveries. Students solutions in the YES! programme demonstrate the outcome of creative problem solving, starting with brainstorming to make decisions in order to resolve the environmental issue, which aligns with the term defined by Lucas *et al*. (2014) and Hanson *et al.* (2022). Creative problem-solving enables students to creatively resolve complex issues and apply STEM knowledge while addressing local and global concerns; this is a means of learning SD. Moreover, students in the activity have the opportunity to select the materials, design the structure of their own choice. It promotes student autonomy, which aligns with what Deci and Ryan (1985) suggested, as students are engaging in making decisions (Deci and Ryan, 1985 in Evan and Boucher,2015)

6.5.3.4 Visualising

Visualising is defined by Lucas *et al*. (2014) as 'Move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions' (p. 4). According to Lucas *et al*. (2014), visualising is closely related to model making. To practice visualisation, the YES! programme encourages students to generate solutions through the EDP in which they plan their solutions from the given materials and draw a design of innovative artefacts as solutions to four environmental issues. To visualise the plan, the architect was responsible for the design in accordance with the team's input. The students rotated responsibilities within the team. The data set from drawing analysis (phase 2) indicates the overarching themes that demonstrate students' visualising, including the illustration of solutions, perspectives, and annotations.

The data set from the students' drawing (Phase 1) from the four activities indicates that the students demonstrated their ingenuity and capacity to assess materials and circumstances by generating numerous designs in order to resolve the issues. According to the drawing, as solutions are illustrated, it was found that students solutions are different in all four activities.

This demonstrate that students connect visualising habit of mind with creative problem solving habit of mind. For example, in landslide activity, preventive barriers were drawn at different locations, such as the back of the village, at the base of the mountain, on the mountain, between the village and the mountain, around the houses, and in an unclear position. Students also provide village composition to help visualise their plan such as soil, house, village area, steep mountain, and cars. House location also varies.

Additionally, the design perspective demonstrates spatial visualisation skills. Their 2D, 3D, and combination of 2D and 3D drawings are exhibits as they help visualise their plan and assist the team in the construction of the artefacts. This is similar to the outcome for fourth grade students in the shoe design study of English (2019). Further evidence of students' comprehension of designs and concepts can be found in the form of annotations which is similar to the study of English *et al.* (2017) that their students created an annotated sketch and then turned into their finished products. Additionally, based on Hanson *et al*. (2022), teachers in their study see the visualising habits of mind as ability to label diagram or undertake imagine of scientific process. Proficiency in elucidating technical principles to peers is crucial for their comprehension of the materials and structure of an invention. Students' attention to details and other components demonstrates a dedication to providing workable environmental solutions, along with soundness, structure, and other attributes.

The act of drawing enables students to articulate their ideas and solutions to their peers, showcasing their astute intellect and capacity to streamline concepts related to collaboration. This aligns with the study of English (2019) and English *et al.* (2017). Students' drawings showed remarkable visual ability and gave the civil engineer and other members the basis for building the artifacts. English (2019) argue that the execution of knowledge-driven decisions regarding design outputs is an essential element, as is the execution of detailed sketches to depict and communicate concepts. Evidently, student drawings in this study serve as helpful tools for students to demonstrate visualising habits of mind as solutions to environmental problems.

6.5.3.5 Improving

Making things better by designing and experimenting is the description of 'improving', another EHoM (Lucas and Hanson, 2014). In this research, the process of improving the solutions during and after construction to reach more effective and sustainable solutions is the main focus.

The data set from the engineers' logbook (phase 1) exhibits students improving. The theme encompasses the changes students made and the idea for changes. In the landslide's activity, students reflected on the changes they made during the construction. Even though some of the groups reported no change to the plan, the student engineer logbook indicates that they made changes different from their initial plans. This was due to the weakness of the former concept in solving the problem, as they 1) identified the problem during construction and 2) had more ideas during construction. They stated that the types of changes were the type of materials, adding prevention structure, increasing structure size, adding more positions of materials, adding more materials, improving the former material, moving the position of materials, relocating the houses, and reducing the size of the structure.

Furthermore, as they constructed the structure and relocated the houses to prevent landslides in Apple Village, they also tested whether this structure could effectively protect the village from such events. Following the question 'From the results, something might have gone wrong in your construction! How can you improve your solution?', students had to identify what needed to be improved in the landslide prevention model. 42 groups stated that solutions were needed. Improvements such as 'adding more types of structures or other methods', 'increasing the prevention structure size', 'increasing the amount of structure', 'increasing the quantity of material', and 'strengthening the wall' are regarded as the outcomes of finding the problem from existing solutions. Others stated that there was no need for improvement. Following this task, students were able to practice verification of occurring problems when solutions were created and implemented, and they were able to suggest ways to improve them.

In the second and forth activities, students reported ideas for improving the artefacts for tackling floods and waste in the rivers and oceans, respectively. Improving is also found in the investigation of students' drawings compared with photos of innovative products. Even though, the majority of students followed their plans for the construction, their artefacts have no significant difference from the drawings. Evidence indicates that some groups improved their work during construction, representing how ideas evolved into their solutions. It was found that their original version has been modified and altered by changes in details, such as the change in materials that were added or reduced by students.

This finding demonstrates that students are able to practice improving using a problem-based approach. The students making changes in their construction provided the improving process during construction; this demonstrates that students' inventions and design development are an iterative process rather than a linear one (Katehi *et al.*, 2009). Thus, students demonstrated improvement from reflecting and learning during the construction, which not only demonstrates the use of ‘improving; but also, the team’s creative problem-solving skills. The outcome is align with the study of Hanson *et al*. (2022)

6.5.3.6 Adapting

According to the description of adapting; making something designed for one purpose suitable for another purpose (Lucas and Hanson, 2014), adapting in this YES! programme observed how students think about adapting their solutions in specific contexts to tackle the issues in real-life situations. This is how students transfer their knowledge to the real-world, which is the ultimate goal of teaching and learning (Lucas *et al.*, 2014).

A data set from engineers’ logbooks (Phase 1) presents evidence of students adapting. Themes regarding ‘real-life context evaluation’ demonstrated students ability to evaluate their own artefacts from real world perspectives to adapt solutions for solving problems in the real-life context, where the real location and materials are different, which required students to apply both their background knowledge and the new knowledge they learned in the YES! programme. In activity 2, almost 41 groups were confident that their solutions are effective if real world materials are utilised, which closely links to real-world structures for strength and type of structures, as well as the efficiency of the experiments.

Students’ answers determined how the solutions to floods and waste issues found in the programme can be adapted in real-life situations. For tackling the issue of flooding, a group from school C considered their solution to be feasible in real-life. *‘Yes, considering that the outcome of the activity from testing meets good criteria. If using actual materials in a real-life, it may help people in the city.’* Another group from School C asserted that their solution can indeed be used to capture the waste in real life situation. *‘The garbage trap nets have finer mesh, which allows for the effective capture of trash in the ocean.’* Students from school A2 added, *'Yes, our innovation got inspiration from the real world.*

According to Lucas and Hanson (2014), there are many skills that foster 'adapting', such as testing, analysing, reflecting, re-thinking, and changing (physically and mentally). Teachers in Handson *et al*. (2022) perceive adapting as ability to adjust their thinking in correspondence with new evidence or purpose such as adapting human teeth for functioning for the need of the shark. To practice adapting in the YES! programme context, students are allow to adjust their thinking by analyse and reflect on their solutions from the problem-solving activities and connect these solutions to the real world during the discussion with peers. The students’ ideas can inform the feasibility of their solutions in real contexts with their own rationales, which demonstrate that the YES! programme fosters the practice of EHoM. However, further study is needed to determine if students are aware of the EHoM they display and whether they can identify these habits.

6.5.3.7 Students' Practicing EHoM In Problem-Solving Tasks

The analysis of observation forms revealed themes and subthemes pertaining to students' engagement in the problem-solving part of the activities and indicated that their actions represented various EHoM based on Lucas *et al*. (2014) framework.

Findings indicate that it is apparent to see the YES! programme having positive impacts on fostering students EHoM, which encompasses system thinking, problem finding, visualisation, creative problem solving, adapting, and improving. Instead of focusing on students' actions, this research explores whether the YES! programme, designed for learning problem-solving skills and SD, can promote the EHoM, which turns out to be positive. Examples of teachers' observation notes on students' actions, representing the practice of EHoM, are illustrated in Table 31.

EHOM	Quotes
Adapting	*Students explained the materials that can be used to construct that can be used for real along with how to use the materials and reasonable costs.* (Lalita)
Creative problem solving	*During the design process, students were consulting and listening to each other's opinions "View from a realistic perspective' in reality (Kirk)*
System thinking	*Students have a systematic problem-solving process, and they connect (link) their knowledge to figure out the cause and effect of the problems that they encountered. For instance, The cliff has a steep slope; when it rains, the soil will become wet, causing it to slide and eventually cause a landslide….*(Arisa)
Improving	*Some students discussed their structure in their group and wanted to improve the new structure by making it higher. Some students thought ahead about changing to a new material that is more suitable. Some students considered about placement of the material which needed to be repositioned. […] In particular sandbag placement.* (Kanda)
Visualising	*Students help each other to check the equipment they got. and jointly analyse each piece of equipment for what it is What principles can be applied? And help design with a new architect as a drawing by trial-and-error Dip your finger into the water. Try placing different devices.* (Lyla)
Problem finding	*In the team, the issue of waste collection from rivers to the ocean was proposed.*(Aran)

Table 31 *Students' Display of EHoM as Observed by Teachers*

According to the interviews, twelve teachers shared how students solve problem. This demonstrate that gifted students practice EHoM. Eleven of them recognised that students use creative problem-solving skills during the programme. Six teachers recognised the improvement and the recognition of problem finding that students exhibited. Three teachers indicated that students used visualisation, while only one teacher mentioned system thinking. This must be considered in the future to provide more space for students to use system thinking.

Apparently, through the process of problem solving, students used EHoM during the problem-solving process, which was similar to what was observed in Lucas *et al*.'s (2020) study, where pre-service teachers in design and technology understood that children were using EHoM when they were collaborating, problem-solving, improving, and adapting during the designing, making, and evaluating stages of their activity. Similarly, gifted students from grade 5 and 6 in study of Karatas-Aydin and Işıksal-Bostan (2023), also demonstrate EHoM based on Katehi *et al.* (2009) such as problem finding, system thinking , visualising, creative , ethics, communication and collaboration when participating in bridge construction. Evidently, the hands on, engineering design based activity and opportunity for reflection their thought allow students practice EHoM.

This study also emphasised the importance of choosing a topic for cultivating EHoM. The outcome of the YES! programme seems to engage students very well with EHoM to solve problems related to environmental sustainability issues. The use of these issues is beneficial for learning EHoM, as problem-based learning, often considered 'messy', should be promoted in education to assist young 'engineers' in developing the cognitive skills, especially EHoM, which are necessary for application in complex real-world circumstances (Lucas *et al*., 2014). Clearly, the YES! programme, which emphasises student-centred pedagogies focused on questioning rather than providing facts as described by Lucas *et al*. (2017), has identified effective ways to cultivate EHoM.

6.5.4 Students Engagement In Solving Problem

The dataset from Phase 1 (Observation form) informs students' engagement during problem-solving, which was observed through the lens of teachers. Several actions and emotions were expressed, and many behaviours regarding EHoM were expressed, as described earlier. For their behavioural and emotional engagement, one teacher described that students engaged in the problem-solving activity and expressed positive emotion after seeing the outcome of the landslide activity. Teacher record that one student said: *'Amazing'. Exactly as we thought, yay our house is not destroyed'.* Other teachers indicated that students were happy and that the outcome of their solution was successful: *'It appeared that the flood waters were able to pass through. There was a happy sound coming from the group. (Lyra)'*

A teacher reported that behavioural engagement was found during the testing of water storage during the drought activity. *'All students support the testing when pouring water and observing the water flow'* (Kanda). Two other teachers who recorded students' feelings as 'exciting from the experiment' and 'exciting during the experiment' in the same activity (Anya and Chinda) confirmed this. In the last activity, in which students seemed exhausted from my point of view, teachers still observed students' high level of engagement. Anya recorded that '*4 people are active, 1 person is still slower than friends'*, while another teacher found *'they helped each other to work very well. While boys 1 and 2 helped to connect equipment, girl 1 stood and watched with interest'.*

However, students expressed some disengagement such as '*the other two expressed boredom and had to be stimulated by group members using open-ended questions'* as reported by Kirk and '*for Tanya (name of student), she tends to not do anything because her friends' opinions don't match her own*' as reported by Arisa. This might be due to the time limitation as the programme runs for a whole day and needs to be completed within the time frame, as it was mentioned as a recommendation by teachers from their reflections during the interviews.

Students in this research are engaged in problem-solving activities as they work toward the issue and solve problems. This engagement aligns well with the study of Morris *et al*. (2019), which found that gifted students in Australia enjoy STEM learning through working on their experiments. This study allowed students to work on activities independently as their behavioural engagement was observed. STEM problem-solving approach promotes students' learning in both cognitive and emotional which is beneficial for gifted students, according to (Ozkan and Kettler, 2022).

6.6 Collaborations

Collaboration is an essential skill for the future and must be cultivated in young children (OECD, 2018; Joynes *et al*., 2019; Lucas *et al.*, 2020), and it is crucial for achieving SD as regarded as one of the SD competencies (Leight *et al.*, 2018). It is because collaboration is an approach to learning about SD (Wal, 2012), recognised as one of the SDGs, which focuses on partnership for the goals (SDG17) (United Nations, 2015). This skill is key to SD because it helps mitigate complicated SD issues that can be addressed among stakeholders. The YES! programme fosters EHoM by promoting collaboration through creative problem-solving and discussion by encouraging reflection on real-world solutions, decision-making, and group sharing. Additionally, students work in teams and roleplay as different professions, fostering team agreements and changing roles. The programme investigates student collaboration themes that emerged and are described in the following sections to answer research questions one and two respectively.

RQ1 How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?

6.6.1 Students' Perception Toward Collaboration

The data set from the pre-intervention questionnaire (Phase 1) demonstrates student perceptions regarding collaboration before joining the activity. The theme encompasses characteristics needed for working in teams and key characteristics for successful teamwork. It is apparent that students understand the factors that contribute to successful teamwork. They are aware that they already have those characteristics, including personalities, attitudes, knowledge, and abilities, as well as teamwork skills that are helpful for supporting teamwork. They also understand what a good team member should be or should do to make the team successful. This self-awareness is important because it helps them work collaboratively both in the real world and in the programme.

The result indicates that students in this study possess a positive attitude towards collaborative learning, Students have favourable attitudes towards working collaboratively with teams, particularly to solve problems, according to their reflections. They value the contribution that each team member makes to the completion of the activities. They acknowledged the value of their contributions to the group and acknowledged the collaborative efforts they have undertaken. This is consistent with the characteristics of gifted students (Taber, 2007). As collaboration is used as the approach to learning in this programme, this serves their characteristics and their interests which align with the development of gifted students according to Renzulli and Reis (2021). Learning about the issues can be integrated using a collaborative approach as recommended by scholars, and it is recognised as one competency for sustainability. In the next section, the data set indicates the findings to answer research question two discussed.

RQ2 How does the implementation of an integrated STEM-based activities enhance the awareness of sustainable development and improve the problem-solving and collaboration skills among gifted students in science?

6.6.2 Students' Attitude Toward Collaboration

The data set of the post-intervention questionnaire demonstrates students' reflections after joining the programme. Students shared their perception of this skill, which encompasses their attitude toward working in teams, the significance of teammates, their contribution, and factors contributing to team success. First, they provided attitudes towards working in teams such as enjoyment and happiness with reasons. The majority have positive feelings towards working in teams. They appreciated their teammates; they stated that they were practising working in teams; they recognised the advantages of teamwork and were aware of the team's problems. A few of them had negative feelings such as stress, tiredness, worry, and fear of failure, some of which were related to team members.

Aside from their attitudes, they exhibit student contributions to the team that reflect action regarding collaborative problem-solving. This includes giving opinions, listening to friends, brainstorming, and helping friends through several problem-solving actions. They also reflect on other characteristics and actions that helped the team during the programme. This demonstrates that the programme created a supportive environment that allowed students to practice collaborative skills.

To explore the value of collaboration in their views, students recorded their perceptions in the diary on week 3 about how collaboration benefits them in terms of self-development. Students stated that collaboration is beneficial for yielding collaborative skills, '*Team problem solving allows me to work with my friends. Have a variety of opinions, learning how to accept the opinions of the majority.*' (a student from school E). Some of them perceived that collaboration helps in gaining knowledge and other skills as one student wrote: '*What helps is that everyone gives opinions and offers ideas to solve problems and helps ourselves to develop, that is, we get opinions from friends in the group and use them to make better adjustments* (a student from school A2). One student said that she can self-improve according to peer advice, '*You will get to know new opinions and know where you were wrong, which needs to be fixed'* (a student from school F).

Students have noted that effective teamwork is key to the group's success in resolving issues. This indicates that the students understand the value of teamwork in problem-solving. They recognised team members who exhibited various traits that proved beneficial for the successful completion of the activity. Students' reflection can demonstrate their self-awareness toward collaboration by reflecting on their performance and that of others, which aligns with Phielix (2012). The students in this study exhibit a positive attitude towards teamwork in terms of gaining skills and their belief about effective groupwork, which is consistent with the findings of Bächtold *et al*.'s (2023) study, which found that students perceive a positive attitude when they engage in cooperative learning opportunities. This programme allows them to work in teams according to group tasks that support collaboration (Cohen and Lotan, 2005). They know what is best for the team and what it means to collaborate, which is the bedrock for future cooperation.

6.6.3 Students' Engagement in Collaboration

The dataset from the observation forms (Phase 1) reported that students were engaged in team collaboration in many ways and exhibited behaviours regarded as collaborative skills. In landslides activity, behaviours were found, such as dividing work and being responsible for their roles, asking for advice, helping each other, making group decisions, discussing and sharing ideas, working collaboratively with others, listening to other opinions, having a good relationship, and being enthusiastic. Students also expressed behaviours such as communicating and sharing ideas, sharing equipment and materials, taking responsibility for their roles, having group agreement, helping each other, having conflicting ideas, and listening to other opinions. Kirk noted that '*After completing the activity, there was a bit of playfulness (students listened to each other's opinions and shared their own ideas'.* Teachers also reported on their emotional engagement, mainly enjoyment during collaboration. Similarly, in the third activity, behavioural engagements were found as Arisa addressed '*The students in the group cooperated very well, but the problem was that they couldn't find a way for the water to flow out and couldn't design a sturdy water tank. However, the students worked together to find a solution, ultimately completing the task successfully*'.

These engagements are discussing and sharing ideas, dividing work and being responsible for the role, motivating others, presenting the work, helping each other (calculation, decoration, team task, testing, explaining), making group decisions, listening to others' opinions, asking for advice, and having a good relationship within the group. However, in this activity, students also expressed some conflicts in their opinions, indicating to a certain extent that they had a negative behavioural engagement. Lastly, in the waste in the rivers and oceans activity, students' behavioural engagement includes dividing work, discussing and sharing ideas, helping each other (construction, clean up), overcoming conflicts, motivating others, having a good relationship, and listening to others' opinions. A conflict of ideas was also reported during this activity as emotional engagement.

The teachers' observations demonstrated that students are working together in terms of both their actions and their emotions. Because certain behaviours are associated with issue-solving, it is possible to refer to those behaviours when employing EHoM in the context of 'collaborative problem-solving.' Students engaged in various activities that allowed them to practice working collaboratively. As students learn to manage collaboration challenges that will benefit their collaborative work in the future, having conflict and coping with these conflicts is crucial.

Therefore, gifted science students in this study can practice collaboration while promoting cognitive skills such as problem-solving and knowledge regarding SD. This opportunity helps support students' needs regarding social-emotional development, as students need both cognitive and affective skills such as being capable of managing relationships, tolerance of self and others, managing criticism, use of sensitivity and constructing uses of humour (Van Tassel–Baska and Baska, 2021). This programme successfully offers students effective training, such as dealing with conflict and peer relationships and learning to understand others and themselves (Renzulli and Reis, 2021).

6.6.4 Teachers' Perceptions Regarding Opportunity for Collaboration

According to the data set from the teachers' reflection notes in the observation form after completed observation (Phase 1), the programme effectively helps students work collaboratively. Teachers reflected that opportunities are provided for working together, which include: students can help each other's through problem-solving and presenting group work, students can discuss and share ideas, students can divide group roles; and they can have role circulation as well as team stimulation.

Another piece of supporting evidence was found from the analysis of teachers' interviews (Phase 1) to gain in depth knowledge about this aspect. Attitude toward the programme regarding collaboration was found under three themes; 1) allow students to practice collaborative skills (share opinions, group decision-making, motivate team members, help each other, students take responsibility for a given role, listen to other opinions, dealing with conflict), 2) facilitate group work opportunities (tasks require group work to be successful, suitable number of group members); and, 3) promote a positive attitude towards collaboration in teams (accomplishing the mission, meeting and learning with new friends, students are good at different things, but can help to accomplish; everyone has the same goal to be achieved). From these themes, it can be seen that the programme provides students opportunities to practice working collaboratively, as it is designed to facilitate a suitable environment for this practice, as well as promote positive attitudes toward collaboration.

'In the first activity, no one had the courage to voice their opinions, but when you

compare it with the last activity. [..] So many thoughts and ideas were expressed. It was like doing activities together broke the ice and unlocked spaces between students. Therefore, in the fourth activity, everyone shared their thoughts without any fears of offending each other, which allowed them to work happily together. (Thana – Semi structure interview)'

'It is a group activity that can promote teamwork quite well. After seeing the observation group, I observed that during the group activity, students prioritised making plans and listening well to each other's opinions. It is an activity that teaches students about teamwork and cooperating in group activities. Furthermore, students can create workpieces on which they can use their shared ideas effectively. (Lalita– Semi structure interview)'

'The activity provided students with the opportunity to work together since there were five members in the group. There were numerous tasks and duties that allowed everyone in the team the chance to engage because if they did not help each other, they would not finish the assignment on time. Moreover, members of the group would encourage one another and divide the work load' (Anan– observation form)

Teachers noticed that the programme was designed as group tasks with the group's goals in mind. Students' behaviours regarding collaboration are found to be positive impacts of the programme to promote collaborative skills. Although, some conflicts arose and some of them showed disengaged behaviours, overall, the programme provided a great opportunity to promote collaborative skills. This is in accordance with what Le *et al*. (2018) indicate: that students engaged in discussions, provided assistance, and engaged in negotiations, all of which demonstrate the development of collaborative skills. Opportunity for collaboration to flourish is found in the engineering based activities for gifted students based on Karatas-Aydin and Işıksal-Bostan (2023) that students display collaboration by asking their peers to confirming their idea. This problem-solving process is allow them to communicate and making decision with group member.

To sum up, from the perspectives of both teacher and students, the YES! programme promote collaborative skills to flourish for the whole process. In the next section, the answers to research question one under the framework element of gifted development are discussed.

6.7 Gifted Development

In the literature study, scholars claim that gifted students have many characteristics (Taber, 2007), and to further cultivate them with knowledge and skills, the programme needs to engage

RQ1 How can real-world environmental sustainability issues be integrated into STEM-based activities for science-gifted students at primary schools in Thailand?

them considering those characteristics and what they are interested in (Renzulli, 2014a). The YES! programme was designed to be an enrichment activity following the enrichment theory (Renzulli and Reis, 2021) and It successfully engages gifted students by offering interest-based activities and advances interdisciplinary content that nurture higher order thinking skills and align with their unique characteristics and learning needs. The data set indicates the findings to answer research question one, discussed in the next section.

6.7.1 Teachers' Attitude Toward the YES! Programme

Data set from the interview (phase 1) informs teachers' positive attitude toward the programme. Firstly, they informed that the programme reaches the learning objectives to promote students' knowledge and skills. Ten teachers reflected that the programme promotes students' knowledge and skills through experiential learning. Kirk said:

> *It is greatly beneficial. I believe that when children actually engage in hands-on activities, they gain a deeper understanding. Sometimes, they might only see things in textbooks or hear explanations from teachers without experiencing the real-life application. Even though their practical involvement might be limited to models we use, at least it instils in them the thought process of 'I see it like this, and if I do it, it might turn out this way.' It benefits children in a way that they learn by doing and experiencing on their own.' (Kirk)*

During the interview, six teachers reflected that the programme fosters students' connections between classroom knowledge and real life. Lyla said, *"It does not just emphasise science and mathematics alone. It also focuses on other subjects, as students might have experienced or learned something like this."* Aside from that, the programme promotes the application of classroom knowledge to activities. The observation form also indicates that students use their STEM prior knowledge. Lyla reported: "*Students collaborate in selecting the objectives for water storage and assist each other in calculating the appropriate quantity of water for each designated area*." Similar to what Anan elucidated, "...*Find a solution by discussing that water flows from a higher to a lower level*."

Fourteen teachers also shared their perceptions of the teaching and learning strategies of the YES! programme. Teachers mentioned students' knowledge and skills as well as the learning content. An example of that is found in the teachers' view that YES! programme provides repetition of learning process that the is beneficial for understanding knowledge and acquiring skills. Arisa said:

> *Because each activity required students to go through a process that they needed to perform repeatedly. Therefore, if students repeat the same methods over and over, they will learn and memorise how to complete the activity from step one to the last. After I observed the second activity, students started to understand what they needed to do. They improved their proficiency with the third activity, and they even became more proficient when it came to the fourth activity. (Arisa)*

More importantly, the programme promotes career aspiration. Teachers also reported that students can acquire knowledge about engineering. The roleplaying of engineers allows students to learn EHoM and immerse themselves in the role and problem-solving situation. They are working within their roles and learning collaboration with teammates who act in another role within the team. This allows students to learn Problem-solving skills and EDP and appreciate the effort of the engineering team which includes many professions such as scientists and architects (Jonassen *et al*., 2006; Trevelyan and Tilli, 2007). Thus, they learned and discovered the aptitudes for the duties of the professions they played. Additionally, eight teachers agreed that the YES! programme can be used to promote gifted students. It suited gifted characteristics as they like challenges, are determined and committed to the task, and are good at thinking beyond what has been taught in the activity.

> *It's appropriate because these kids can develop the extended knowledge quite well. If they have knowledge about sustainability, they can take it further and make it more useful. In the learning of gifted children, they may have a more special perspectives than other groups of children. Because of that, the matter of application of these things is the matter of further development. I think it will probably have better results than other groups.* (Lalita)

The data set from teachers' observation forms (Phase 1) also indicates positive aspects of the programme regarding learning content that allow students to connect classroom learning to real life experiences. What Thana observed is that *"Students attentively listen to the problem scenario and collaboratively analyse disaster situations, providing examples from their own experiences, such as encountering a drought that affected their planted mango trees due to a lack of water."* Reflections from five teachers also agree with Thana. Chinda said: *"It sparks ideas that can be translated into real-life actions in the community in the future."*

Ten teachers confirmed that the level of difficulty is suitable for students at this age who study in grades 4–6. *"I can see that it is not difficult for children. Children will definitely understand that by doing activities, this made it easier for children to understand",* reflected Minta. Interestingly, the case of school D, where students work in mixed years of study, illustrated that the task is achievable through collaboration as they share knowledge and learn from each other. Anan's viewpoint is also as follows:

> *Appropriately, the difficulty is at a learnable level. Because they already have the foundation of this subject, for grade 4, they just came up from grade 3 and have only studied for one semester. It may make them learn some content slower than grade 5 and grade 6 students, but they are in the same group. They may also hear what other members say and what their friends are giving advice about, which will cause knowledge to be shared. Overall, it's suitable for learning.* (Anan)

Teachers also reflect their own practice in school to promote gifted science students' experiences with STEM problem-solving during the programme. The data set from the interview indicates STEM implementation in schools. Examples of these approaches are related to inventions regarding recycling paper, STEM and waste, as well as invention competitions, and most of the interventions pertain to the environment. Students learn problem-solving processes such as STEM including project based and problem-based learning, which was recently promoted in Thailand by IPST Thailand, OBEC and their organisations (Srikoom *et al*., 2017; Sritakoon, 2018). However, EHoM is something slightly different, as it focuses less on process and more on actions and thinking that mimic how engineers use it in life (Lucus and Hanson, 2014) and demonstrate when engaging in engineering design based activity and reflects their thinking (Karatas-Aydin and Işıksal-Bostan, 2023). The programme promotes problem-solving skills by introducing students to EHoM which is not currently applied in Thailand.

6.7.2 Teachers' Recommendation For Implementing the YES! Programme

The dataset from interview indicate teachers feedback on how to improve the YES! programme to achieve the desired learning outcome and how to implement the programme in the school. Their suggestions are regarding the need for improving, implementing, and developing professional development programmes.

Teachers provided insightful recommendations that are valuable to future development and how to better implement the programme in classrooms to promote students' SD, problem-solving, and collaboration. Ten teachers supported the idea that the programme is possible to implement in schools, and nine of them are confident that they can teach the programme to their students. Among the 12 teachers who recommended improving the activities, Anya recommended the use of technology, "*We may use technologies that children now have access to and are up to date. Children may do it in groups by discovering the issue first. This* *will cause children to ask questions, and more doubts will be raised about what they want to know*." Time management is one of the concerns raised by teachers, Thana added: "*Activities on that day are good. But it might also be affected by the fact that the period of time we have is quite limited. This makes the activity quite tight. It affects the child's ideas because sometimes they want to spend more time thinking. So, they are likely to be pressured at the time*." Teachers asked for more development of the programme, and Chinda said: "*I want an activity like this that is consistent with the content in the curriculum in other aspects*."

For school implementation, 10 teachers recommended implementing YES! as an extra curriculum programme such as a one-day camp for gifted students. On the other hand, five of them also stated that it can be taught in classrooms, especially in basic science subjects, while six of them suggested delivering a YES! programme in additional science or mathematics subjects. For the frequency of implementation, six teachers thought that the programme was suitable for one day, while six other teachers wanted to dive into one section every week. Among the four teachers who recommended the framework for implementation, Kirk said: "*If it were implemented in class. It must be a consultation or a meeting with the teachers and the school administration because curriculum preparation is required*." However, there are a lot of possibilities to implement YES! programme in the classroom, as 10 teachers insisted and 9 of them expressed confidence in its implementation in the classroom. Lalita revealed: "*It should be possible because of the issue, which I think should not be beyond our capacities. And there are quite a variety of teachers at the school. We are likely to be able to seek advice from our colleagues*." This is similar to Anan who said: "*Yes, because there is a format and it already provides an example method. It is an activity that is easy to teach. Because the nature of the subject is already interesting. The more you adapt things around you, the more interested your child will be.*" These positive attitudes of teachers provide the benefit of promoting SD learning and STEM in school.

Overall, considering students' and teachers' perceptions informs the programme's future implementation. Following the perceptions and suggestions of teachers, STEM for SD curriculum and design can offer more compelling and pertinent lessons that can be further developed. For example, the YES! programme is successful to make the Engineering (E) in STEM visible. However, it can be integrated more with technology. As González-Salamanca and Salinas (2020) suggested, technology, as a resource, tool, scaffolding, and object of knowledge, is vital to the development of higher order abilities like 21st century skills, especially when modified and redefined. By keeping teachers' perspectives in mind, one can ensure that STEM education for SD remains effective and relevant over time. According to the study by Timm and Barth (2021), one of the obstacles to teaching SD in schools for teachers is that the subjects in school, especially science subjects, are normally taught separately. The interdisciplinary nature of STEM can be a foundation that aligns with the interdisciplinary nature of ESD content.

Teachers' input also influences implementation and informs future STEM education policy as well as ESD promotion in schools. In addition, as suggested by teachers, working collaboratively with teachers can be an effective way to promote and implement STEM for SD for students of varying abilities and levels, and convey the importance of the programme to broader stakeholders such as parents, policymakers, and community members. This collaboration combined with students' voices may lead to curriculum co-design and flexible learning paths, personalised education, foster students' autonomy, interest, and engagement (González-Salamanca and Salinas, 2020).

Additionally, teachers expressed the need for professional development. This feedback can assist researchers in designing individualised teacher training programmes to enhance their practice. Especially the development of teacher training programmes pertaining to EHoM that incorporate engineering visibility in STEM learning in schools, and more specifically in Thailand primary education, where there is no formal engineering curriculum, instead it is integrated into the science curriculum as design and technology units (Lucas *et al*., 2020). The YES! programme which focuses on engineering missions, can foster EHoM at the primary school level. In line with recommendations by Lucas *et al*. (2017), integrating pedagogy with engineering can be applied at Key Stages 1, 2, and 3 in England with the integration of the EDP aside from tinkering and engaging with real engineers, which will be further explored in the future.

In the next section, the data set indicates the findings to answer research question two, which is discussed.

RQ2 How does the implementation of an integrated STEM-based activities enhance the awareness of sustainable development and improve the problem-solving and collaboration skills among gifted students in science?

6.7.3 Students' Perception Regarding the YES! Programme

Environmental sustainability issues were integrated as the main content of the YES! programme, it served gifted science learning with topics students are interested in and concerned with (Schroth and Helfer, 2017). It meet the need of students as it develop important skill, attitude and knowledge to confront with SD issues.

At the end of the day, students reflected with quick responses on sticky notes attached to the engineers' logbook (Phase1). Dataset displays students' perceived about the programme as it provided them knowledge. Themes are including SD concepts, future perspectives, SDGs, environmental problem-solving, practical application of knowledge in daily life, STEM knowledge, self-development, and problem-solving strategies. A student from Group 3 at School D provided the following reflections: *'1) Get to know the meaning of sustainable development. 2)Thinking systematically, finding problems, visualizing, improving, and applying them. 3) I Like to think systematically and take action*.'

In the sticky notes attached to the 26 logbooks, there were 59 references to SD knowledge. A student from Group 4 at School G described it as '*long-term environmental, economic, and social development'*. Among these responses, 33 references from 20 logbooks indicated a desire to address environmental sustainability issues, while 13 responses from eight logbooks indicated they gained knowledge about the factual aspects of these issues. Four groups with ten references mentioned the SDGs. A student from Group 5 at School D stated, '*Long term solution that involved the problem which is 17 problems in total.'* The mentioned SDGs include all 17 Goals, SDG 13 Action on climate change, SDG 14 Life below water, SDG 12 Responsible production and consumption, SDG 11 Sustainable cities and communities, SDG 15 Life on land, SDG 4 Quality education, SDG 6 sustainable water and sanitation, SDG 7 Affordable and sustainable energy. Furthermore, students expressed empowerment to solve problems, as a student from Group 4 at School A1 said, '*Learn that we can solve environmental problems and know about sustainable development'*. However, compared to SD concepts, students are less interested in SDGs.

The post-intervention questionnaires also reveal that learning in the YES! programme provides different aspects of knowledge. This includes not only understanding the causes and effects of the issues, but also gaining insights into solutions. In addition, students acquire scientific knowledge behind the issues, such as plastic degradation and microplastic generation. Additionally, collaborative problem-solving skills are cultivated as students work within their teams, allowing them to generate knowledge about potential solutions to issues like floods.

Students also exhibited varying preferences in relation to the programme, which encompassed problem solving, knowledge gain, active participation, collaborative opportunities, and others. Specifically, aside from their knowledge of SD and SDGs, among the 27 logbooks, students expressed a positive view of the programme, emphasising that they gained significant knowledge about problem-solving. The aspects of problem-solving knowledge they learned are displayed as a word cloud in Figure 36.

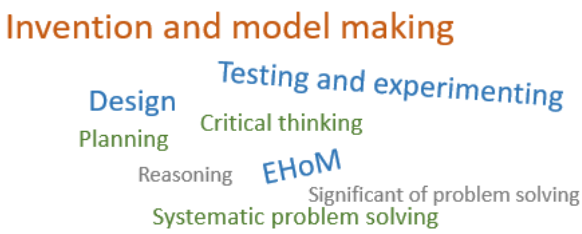


Figure 36 The Reflections of Students' Positive Attitudes.

Additionally, short answers from students' post-intervention questionnaires also reflected their individual opinions. They reflected positive attitudes toward solving problems in the engineering team and having a variety of occupations. In addition, they reflected on their emotions, and 137 of them indicated positive emotions, which are enjoyment, happiness, confidence, gladness, and so on, while only seven students revealed their negative emotions, such as chaos, annoyingness, less involvement, tiredness, boredom, and unhelpful friends.

From the sticky note attached to 51 logbooks, students expressed their attitudes toward the whole programme, their opinions toward SD, and the use of EHoM. Students expressed their attitude toward the programme in both positive and negative ways. 40 logbooks reported their emotional states towards the programme including enjoyment with 102 references, 18 logbooks reported that students were happy with 37 references; and excitement was found in 12 logbooks with 20 references. 14 logbooks stated they would like to join again. A few logbooks revealed that they thought it was good, impressive, proud, and thankful. However, some negative feelings were reported, including tiredness and worries, which were found in 2 logbooks with 6 references. Here are some of the perceptions of students who expressed positive attitudes:

> *'Gain knowledge about science in a fun way and practical knowledge that can benefit your daily life and improve your quality of life.'* (a student, Group 1, school A2)

> *'What I felt in this activity was both the knowledge and the fun of making various inventions'* (a student, group 6, School F)

Even though a few students reported they were worried and tired with the activities, they also reported their positive feelings at the same time:

> *'Feeling happy and tired of learning about natural disasters and what should be done.'* (a student, group 4, school B)
>
> *Excited about the things that are made from the design, worried about whether there is something wrong or not. Enjoyed the activities that I had done. It was very fun to use many materials to make the design. Glad to do the activities with friends.* (student from group 6 school B)

Similarly, the data set from the reflective diary (Phase 2) represents what students perceived after participating in the activities. Students reported on the first week after the activity ended, reflecting on their enjoyment of the programme, and all agreed that they enjoyed the activities. Aside from learning knowledge, they enjoyed working as a team, engaging in hands-on activities that allowed them to solve problems, using creativity, experimenting, and invention. They enjoyed the simulation of environmental problems. They also provided rationale for what they have enjoyed which is mostly the knowledge gained including problem-solving and coping with environmental issues, SD, and knowledge about engineer careers.

Interestingly, what was mentioned about the engineer career in the diaries, informs the integration of role playing in the YES! programme. Argued by Mann and Mann (2017) is the loss of opportunity for students to discover their career opportunity from joining STEM and engaging in fun math and science subjects, as traditional classrooms provide experiences that generate contradictory aspects. Role playing with different career paths in this programme, with the EDP involving EHoM, helps students discover more of their career options according to their subject interests.

On the second week after the programme ended, the question asked whether they had shared experiences with others about the YES! programme. They shared about doing many activities in the programme such as solving environmental and disaster problems, and shared the results of the activities and practical skills they had learned. They also reported that they shared the simulation of environmental issues that simulated the problem and allowed them to role-play as engineers. Which aligns well with the study of Segalas (2010), that roleplaying is the approach to promoting students' skills. Students learned the duties of each engineer by performing the roles and solving problems like real engineers. They report that they acquired knowledge from the activities, enjoyed the activities a lot, and made new friends. The people with whom they shared those perceptions are their family, friends, and teachers.

They also provided self-reflections toward the programme which include having positive emotions such as enjoyment, gladness, pride, excitement, and self-worth. They also recognised that they gained knowledge, developed problem-solving skills, and experienced a variety of tasks benefiting society. These perceptions are what students reported on the day of activity and 1 or 2 weeks later. Students still reported positive attitudes toward the programme as they recognised that YES! brings benefits to them, engaged them with problem-solving scenarios, provided the knowledge for SD and allowed them to collaborate. Students not only reflected on their attitudes toward the programme, but also expressed the value of STEM activities and provided attitudes toward learning STEM to solve the issue as well as their perception of how it is related to SD.

All these reflections of students indicate the impact of the programme on students' attitude and knowledge regarding SD as well as promoting students' problem-solving skills for EHoM. This align with Sanchez-Llorens *et al.* (2019) and Morris *et al.* (2019). The YES! programme is considered a suitable programme for nurturing gifted students. The programme can be served as a type II Enrichment, according to the Enrichment triad model purpose by Renzulli (2014), often encompassing student-chosen activities that encourage them to use their imaginations and develop their practical skills in solving engineering and design-related problems (Renzulli, 2014a). This characteristic was found in the Schoolwide Enrichment Model where gifted students are supported with advanced knowledge and skills that they acquired during problem-solving and creating products (Renzulli, 2014a). Overall, aside from learning SD and solve problem, students in this study are inspired and motivated with awareness of SD and SDGs. This align with Trott (2019) that students are encouraged to learn about climate change.

6.7.4. Students' Engagement in the YES! Programme

For students' engagement and attitudes, aside from students' reflections discussed in earlier sections, the observation forms reflected that the programme engages students both physically and mentally in learning, especially during knowledge and task instruction through the lens of observer teachers. Teachers found that students expressed both emotional and behavioural engagements in all activities. An example of teachers' excerpts provided that students engaged during the knowledge delivering session in the introduction part of every activity.

> *Students raised their hands to answer questions such as describe garbage in 3 words, and students' responses were rotten garbage, smelly garbage, and rummaging through garbage. What is the impact of garbage? and students gave the following answers: It stinks; tourism; animals eat garbage; germs; et cetera. The students' replied to the question 'What is the solution', were to throw garbage in the bin and decrease usage of the items that produce more waste.* (Aran)

In brainstorming, male students are not very interested as female, but when they explained their ideas in mind following their writing, male students are more willing to express. But when listening to the speaker's explanation, one female student writes more ideas into the logbook. (Anya)

In the interviews, teachers reflected on the advantages of the programme and eleven of them mentioned that students had positive emotions and expressed positive preferences, interests, looked happy, and enjoyed themselves, and looked challenged and excited. This positive outcome is in line with the findings of Robert *et al.* (2018), who found that learning about STEM subjects can significantly boost students' motivation. Students also expressed behavioural engagements such as actively answering questions, taking part in the activities, continuing the activity and not wanting to stop. They also focused on inventing and solving problems. Aside from the positive outcomes of the programme, teachers talked about fostering Problem-solving skills and collaboration among students. Twelve teachers expressed a positive attitude toward the overall programme as well as its limitations. .

6.8 Conclusion : Potentials of the YES! Programme: Promoting SD, Problem-Solving Skills and Collaboration

Based on the conceptual framework in Figure 32, the YES! programme integrates environmental sustainability issues as learning themes connecting classroom and real-world knowledge regarding the issues and STEM knowledge. Evidently, environmental sustainability issues are ‘wicked problems’ that present intellectually stimulating tasks (Yearworth, 2015). These issues also provided students with support through periods of difficulty, and acknowledged their achievements and progress in skill acquisition, these are what gifted students need to motivate their learning (Brigand *et al*., 2016). The YES! programme incorporates knowledge for SD, the SDGs, which are global benchmarks to adopt as fundamentals for ESD implementation (United Nations, 2015), and the SD concept which encompasses environmental, social, and economic aspects. The discussions and various tasks in the programme give the students the opportunity to reflect on and practice SD competencies, fostering transformative learning in how students think and act concerning the environment (Wal, 2012). The integration of the STEM problem-solving approach not only cultivates SD competencies but also enhances problem-solving skills and collaboration through repetitive practice on each EHoM that students adopt in each activity, enabling them to create innovative artefacts from visualising ideas, design and construction.

The bricolage approach facilitates the application of a variety of data collection methods. The big picture is created as it provides insights into teachers' and students' experiences, perceptions, and beliefs regarding SD knowledge and awareness and promotes problem-solving, collaboration among gifted students. Bricolage connects pieces of knowledge and informs the impact of the YES! programme, which integrates real-world environmental issues and helps gifted science students in primary science learn through five dimensions following the elements of the conceptual framework. The findings demonstrate the success of the programme's implementation in each element thoroughly from the perspectives of both students and teachers. The findings illustrate students' background knowledge and what they have gained as they learn about the SDGs, the concept of SD and more knowledge about STEM and specific environmental issues in the tasks. It is important to articulate issues the students are aware of as well as their understanding of the value of the environment and natural resources.

The outcome is that YES! programme enhances SD learning from landslides, floods, droughts, and waste in rivers and oceans. These environmental sustainability issues have arisen in Thailand and in numerous other nations. It serves not only as a resource for learning about the issues' facts, but also as an illustration of what sustainability is and how it affects the environment, individual lives, society, economy, country, and our planet. It also aimed to increase students' awareness of sustainability in order to inspire them to re-evaluate their thoughts and actions and become agents of change. According to Dyball *et al.* (2009), addressing this issues requires the cooperation of individual, communities, specialist and government, highlining that collaboration is not just completing the missions in the YES! programme but crucial for achieve SD in real world.

Therefore, the YES! programme can serve as an alternative pedagogical strategy for science educators instructing SD through science education. Evidence from the perspectives of teachers supports a favourable evaluation of the programme's effectiveness in preparing students to learn SD. In addition, Studying teachers' perceptions can influence teachers' decisions to change their teaching approach; they might change their practices when they encounter dissatisfaction with the current methods (Feldman, 2000; Fullan, 1993, cited in Srikoom *et al*., 2017).

Teachers in this study believe that the YES! programme achieves its objectives in fostering students' SD-related knowledge, such as the concept of sustainability, the value of the environment, the consequences of human behaviours, and the significance of sustainable solutions. Moreover, an examination of students' perspectives on SD issues and their justification regarding competency indicates that they are capable of evaluating and rationalising complex scenarios, comprehending the ways in which SD issues relate to the present state of affairs in the nation and establishing links to potential resolutions. Srikoom *et al*. (2017) argue that there is substantial evidence that instructors' use of instructional strategies is influenced by their beliefs and perceptions of them. Due to that fact, from the teachers' perceptions of STEM and the programme as well as SD, it can be concluded that teachers have a positive view toward the integration of STEM for teaching SD, especially problem-solving and collaboration, as they are aware that STEM is effective in fostering these skills.

Along with students attitude and perception toward the YES! programme, their EHoM expression, and collaboration, the YES! programme capable to furnished students with the requisite knowledge and competencies to actively participate in sustainable initiatives. Moreover, it improves their capacity to confront intricate and uncertain futures and enables them to arrive at well-informed decisions. Consequently, they are adequately equipped to tackle and navigate these crucial concerns *(*Leicht *et al*., 2018; Redman and Wiek, 2021; *Wiek et al*., 2011; Wals, 2015). Awareness of the issue also indicates students values and attitudes which are needed for sustainable citizens (Wals and Lenglet, 2016).

6.9 Summary

In this chapter, the Bricolage approach combines the findings, which depict the big picture to answer the research questions. Findings demonstrate different aspects under the conceptual framework, including environmental sustainability issues, SD concepts, SDGs and SD competencies, STEM problem-solving, collaboration, and gifted development. Different sources of data, including students' and teachers' viewpoints, demonstrate how the YES! The programme promotes gifted students' learning SD knowledge, awareness, and essential skills. This supports the idea that integrating environmental issues into STEM problem-based activities engages students in learning with relevant content and complexity for practice skills, making it an alternative approach for fostering gifted students in Thailand. The next chapter discusses the findings' conclusion, implications, and contribution to the field and practical sectors. In addition to a reflection on the researcher's approach to research and methodology, limitations and perspectives for future work are provided.

CHAPTER SEVEN: CONCLUSION AND FUTURE WORK

This chapter begins with an examination of how the research has answered the study questions, then discusses the implications, recommendations, and limitations of the study. The findings of this study and its designed intervention, the YES! programme will enlighten practitioners, policymakers, and researchers engaged in the STEM education sectors within Thailand and globally. This chapter will also discuss the limitations and contemplation of the bricolage approach. In the subsequent sections on the contributions made to knowledge, theory, and methodology, suggestions are made for future investigations that aim to undertake research of a similar nature to the present study, as well as limitations and suggestions for future investigations that aim to undertake research of a similar nature to the present study.

7.1 Summary of the Findings

A summary of the findings is briefly summarised in light of the following two research inquiries:

7.1.1 Answer to Research Question One

> 1) How can real-world environmental sustainability issues be integrated into STEM problem-based activities for science-gifted students at primary schools in Thailand?

The findings from the various data sources collated in phases 1 and 2 indicate that when students engage with environmental issues in the YES! programme intervention, it provides them with relevant environmental issues aligned with the local context for learning about SD. The findings from the data set from phase 1 suggest that students in this study perceived the issues such as landslides, floods, droughts, and waste in the river and ocean through external sources outside their classroom, including News or Television, conversation with parents and personal observation. They understand that the facts of an issue encompass causes, impacts, and solutions that regard environmental and social perspectives. According to Bourn *et al*. (2016) pedagogy for SD learning requires acknowledging and responding to students' perspectives, experiences, and socio-cultural backgrounds.

Findings from pre-intervention questionnaires (phase 1) and teachers' perceptions regarding SD and ESD indicate that learning about real-world environmental sustainability issues in SD needs to incorporate an understanding of SD concepts more holistically according to the three dimensions of SD: environmental, societal, and economic. Teachers' reflection in phase 1 (interview and observation form) provides supporting evidence that suggests that environmental issues were taught regarding different topics.

However, teachers use strategies based on lecturing, which is less related to STEM learning. School initiatives vary, and environmental issues are embedded through the whole school approach under a specific focus among schools. As teachers in this study reveal that they perceive the SD concept and have a limited understanding of ESD, this activity is an alternative option to adopt in the classroom. More importantly, teachers in this study agree that ESD is suitable for young children, and they have positive attitudes toward the YES! Programme learning contents.

Furthermore, when integrated with STEM problem-based learning, the issue's complexity allows students to practise a series of EHoM. The issues allow students to evaluate, find the root cause, identify the impacts, reflect on their thoughts, and evaluate their future perspectives, which is an environment for cultivating SD competencies. Teachers reflect that students engage in behaviours and emotions while solving environmental issues in the YES! Programme.

The YES! programme, provided the opportunity to identify the issue and find solutions, encompassing knowledge across disciplines. According to Brundiers and Wiek (2013), learning from problems through PBL promotes students' ability to understand the problem. The engagement of students in problem-solving tasks demonstrates students practice EHoM. This illustrates the potential to effectively promote EHoM, enable students to recognise problems through the use of scenarios that simulate real-world situations, and prompt them to generate a variety of solutions. Engaging, challenging, and promoting creativity align with the learning needs of gifted students and serve their characteristics (Taber, 2007; Taber, 2015).

According to students' reflections, this confirms that learning about local issues in Thailand through STEM activities is an effective learning theme for Thai gifted science students, which is the foundation for them to learn 'about' and 'for' SD. The environmental issue serves as a source for understanding the knowledge and practice of SD competencies, which are discussed in detail in the next section. Moreover, environmental issues promote reflection and critical discussion, suitable for collaborative learning. Again, the intricacy of the matter presents a problem-solving framework that an individual cannot independently resolve and requires collaborative effort. According to Glancy and Moore (2013), students must be challenged and given rich context to learn problem-solving abilities.

Collaboration is essential to every process, commencing with issue identification, solution brainstorming, solution selection, design creation of artefacts, model construction of barriers, water storage systems, and garbage collection tools, and concluding with testing and discussion. This aligns well with Wiek *et al*. (2016), as the tasks ask them to collaborate. This discovery provides evidence that the teaching and learning strategy of YES! Interventions support students with collaborative skills and a positive attitude toward collaboration. Teachers' reflections on gifted development also support the idea that the YES! The programme promotes problem-solving skills and is suitable for gifted students. Their attitudes demonstrate the programme's advantages and limitations. Their recommendations also suggest how to improve the programme and implement it in the Thai context to provide further practices in schools.

In conclusion, the YES! The programme can engage and promote gifted students' learning for SD and STEM as it is relevant, meaningful and suitable for students. The using of an environmental issue-driven combination of ESD and STEM provided a novel approach to teaching ESD conceptual understanding, problem-solving skills, and collaboration for gifted students, which is in alignment with ESD pedagogy as stated in existing literature (Vare and Scott, 2007)

7.1.2 Answer to Research Question Two

> RQ2: How does the implementation of an integrated STEM-based activities enhance the knowledge and awareness of sustainable development and improve the problem-solving and collaboration skills among gifted students in science?

According to students' reflections, this confirms that learning about local issues in Thailand through STEM activities is an effective learning theme for Thai gifted science students, which is the foundation for them to learn 'about' and 'for' SD. The environmental issue serves as a source for understanding the knowledge and practice of SD competencies, which are discussed in detail in the next section. Moreover, environmental issues promote reflection and critical discussion, suitable for collaborative learning. Again, the intricacy of the matter presents a problem-solving framework that an individual cannot independently resolve and requires collaborative effort. According to Glancy and Moore (2013), students must be challenged and given rich context to learn problem-solving abilities.

Students also demonstrate a heightened understanding of environmental sustainability, expressing concerns that go beyond the issues that are covered in the YES! programme. The environment and society are important to them, and some of them acknowledge the importance of economic issues. Their understanding of the connection between environmental and social repercussions is demonstrated by the students' perspectives on the problems that are prevalent in the community.

According to the findings, learning issues in the YES! programme can be addressed in order to raise awareness of SD, which is consistent with Torkar (2014). In addition, as a result of the YES! programme, especially through the emphasis on six SDGs related to four environmental sustainability issues, the programme has the capacity to instil motivation in students as they express interest in learning SDGs, cultivating knowledge and awareness of SD issues students want to pursue, which is beneficial for making decisions that consider the enduring welfare of both humanity and the environment. Students express the issue illustrated by the YES! programme, which educated students on the meaning and targets of the 17 SDGs, including their connection to environmental issues like landslides, floods, droughts, waste, and other SD issues, representing their awareness of social, environmental, and economic issues. They extend their awareness to the SDGs as well as different environmental issues, which demonstrates that they have a more comprehensive understanding of sustainability.

Moreover, students demonstrate their perspective and exemplify the SD competencies using the engineers' logbook, post-intervention questionnaire, and reflective diary. Students demonstrate anticipatory thinking by evaluating potential future outcomes and the repercussions of potential solutions. Students can evaluate their future perspectives based on the knowledge they learn in the classroom, including SD and STEM. Students can evaluate society's norms, behaviours, and roles that the community and government play, all evidence of normative competency. Self-awareness is displayed when students reflect on their roles in various contexts, lending confidence to participate in the changes. Additionally, system thinking is demonstrated when students connect the knowledge they have gained in the classroom to situations that occur in the programme and in the real world and understand the causes and impacts of the issues and consequences of human behaviour toward the environment, society, and economy. This aligns with Bourn *et al*. (2016), who found that younger students can be ethical with less complex issues, leading to their ability to conduct justification for more complex issues when they are older.

For problem-solving skills, The findings show the development of problem-solving abilities through the use of phase 1 instruments, including the engineers' logbook, inventive artefacts, student drawings, teacher interviews, and teachers' observations, providing evidence that students apply EHoM following EDP (Lucas *et al.,* 2014). Problem-finding is accomplished through the examination of the provided scenarios. Creative problem-solving is exemplified through a compilation of solutions, materials selected, and solution types generated through brainstorming, in addition to the innovative artefacts that showcase these practices by depicting the various solutions that students conceived and developed.

Students demonstrate the ability to visualise by creating a plan depicting a team solution and manipulating materials. Students demonstrate system thinking by analysing artefacts' structures and identifying viable solutions. Students' improvement is expressed by reflecting on their progress and the steps they have taken to develop their artefacts. By recognising these themes, they can identify the experiment's flaws and generate suggestions for improving their solutions. Additionally, the students' critical analyses of how their solutions function in the real world or are constructed using real-world materials exemplify the concept of adaptation. Teachers' observation also demonstrates their emotional and behavioural engagement in this stage.

Students' reflections on the programme showed they are fully engaged in implementing practical solutions and promoting self-efficacy by overcoming challenges and contributing to SD issues. Moreover, regarding the implementation of the programme in schools, the results offer valuable perspectives on how to improve the curriculum and formulate approaches for forthcoming enhancements that specifically target gifted science students, foster their capacity for resolving complex issues, and enable them to act as agents of transformation in the domain of SD.

Lastly, collaborative skill enhancement is demonstrated by evidence from teachers' observations and interviews and students' post-intervention questionnaires, which suggests that the intervention had a beneficial impact on the student's problem-solving skills and learning for SD and collaboration. There is a clear demonstration of behavioural involvement and reflective attitudes towards collaboration, which helps to highlight the importance of teamwork and acknowledge the contributions of the team members. They can also justify what could be improved in the team. From the perspective of gifted development, gifted students are supported by cognitive and affective development engagement. Teachers provide that it supports students in many ways, such as learning content, skills, challenges and engagement. It means that the YES! Programmes can be used as models for gifted development, which meet their needs and promote ESD in school.

In conclusion, the study's findings demonstrate that the YES! The programme has successfully advanced critical SD learning, effectively teaching EHoM components, aligning with Thai policy agendas, creating collaborative cooperation, and promoting reflective practices. STEM education and ESD practices, as well as the overall educational landscape in Thailand, are improved due to their collective contributions. This discovery proves that YES! interventions can be efficacious approaches for students acquiring SD and skills. This aligns with the existing literature (Hopkinson and James, 2009).

7.2 Implications of the Study

From the findings of this research, it can be inferred that ESD, STEM, and gifted education are crucial to a country's sustainability, academic environment, and human resource development. Undoubtedly, educational teaching and learning today, involving researchers and educators around the world, aims to promote students with knowledge and skills for SD (OECD, 2018a; UNESCO, 2017; Wals, 2015) resulting in transformation (Sterling, 2011; UNESCO, 2020). As mentioned in the literature review, ESD equips citizens with knowledge, skills, values, and attitudes that are needed to develop, sustain the country, and overcome global challenges. Since this transformation goes beyond what is taught to how education is provided and its impact on society (Sterling, 2016), an educational approach that combines critical, emancipatory, and relational pedagogy must be established (Wals, 2020).

It is noteworthy that Thailand does not have an officially recognised curriculum on Environmental and Sustainable Development (ESD) in compulsory education (Nuamcharoen and Dhirathiti, 2018; Laiphrakpam *et al*., 2019). In contrast, national policies such as the National Education Act and the National Economic and Social Development Plan are substantially impacted by the Sufficiency Economy Philosophy, which is Thailand's rendering of SD. It is promoted as a whole school approach (UNESCO, 2013; Dharmapiya and Saratun, 2016) and influences Thailand's compulsory curriculum (Didham and Ofei-Manu, 2012). Teacher training should be implemented to equip teachers with tools for embededing ESD in their teaching and engage students in discussion about sustainability and provide safe environment to reflect their thoughts. It is also recommended that ESD be incorporated into national science standards, emphasising ESD competencies.

Although science education has integrated SD content, particularly in areas such as energy, earth evaluation, living organisms, and life processes, there is insufficient emphasis on holistic SD concepts, especially those pertaining to social and economic aspects. The majority of science teachings are devoted to environmental facts and impacts, with little emphasis on promoting the ability to critically analyse SD issues from an SD perspective and empowering students. The study's findings propose educational approaches to bridge these deficiencies, indicating that incorporating environmental sustainability concerns into STEM endeavours can strengthen students' environmental awareness and apprehension. Additionally, collaborating with the community can promote ESD through partnerships and provide students with local knowledge about sustainable development issues, creating connections to both national and global learning.

STEM education is essential for innovation and technological advancement. Incorporating STEM education into school curricula may increase the future workforce's (Bybee, 2010; Kelley and Knowles, 2016), stimulate economic development (Tytler, 2020), and capacity to solve complex problems (Terry *et al*., 2008). which are consistent with the findings of this study. Additionally, the findings of this study indicate that focusing on integrated STEM education in Thailand could create a generation of critical thinkers and problem solvers, boost its global competitiveness, and facilitate the development of gifted students in knowledge, skills, attitudes, and values by starting at the primary school level. Especially for SD, this moving gifted and talent development toward the employment of their capacity for transform the world as Sternberg (2020) identify giftedness as transformational.

This finding represents an additional significant implication of the research. The primary students' participation in the role-play activities, which emphasised problem-based learning in the EDP and EHoM, gained considerable insight and appreciation for the engineering discipline. Moreover, they realised the importance of problem-solving skills and collaboration, which are indispensable in the scientific realm.

This research explores effective pedagogical approaches to improve STEM and gifted education in Thailand while promoting ESD. The goal is to present a framework that meets Thailand's educational demands for classroom practice, especially in gifted classrooms. Furthermore, it creates an enriching educational experience that empowers students with knowledge, attitude, and skills regarding SD to foster gifted students who will shape Thailand's academic future. The main results and insights gained from this study are highlighted in accordance with the key findings. Below, I present the contributions of the study.

7.3 Contribution of Research Findings

This research contributes significantly to ESD by involving young gifted science students in the development of problem-solving skills, collaborative skills, SD knowledge, and key competencies for SD. It highlights the practical application of SD concepts and SDGs in primary education to encourage the development of sustainable citizens. Being exposed to

SD issues early on through STEM-based learning, being able to justify the status quo, thinking about what will happen in the future, and being able to connect what they have perceived with complex situations is important for making decisions about SD, especially when it comes to the issue of environmental sustainability. This research serves country policy regarding the national strategy to promote the country to be ‘a developed country with security, prosperity, and sustainability’ (National Strategy Secretariat Office, 2018), especially promoting eco-friendly and SD growth by engaging young people with SD learning.

The study also emphasises the effective instruction of a STEM problem-solving approach that incorporates EHoM along with the EDP. This afford promotes a comprehensive approach to STEM education for practise problem-solving skills by embedding 'engineering', providing opportunities for learning concepts and knowledge, and at the same time, being empowered, able to make decisions, and having ownership in learning under the facilitation of a facilitator. EHoM helps promote the skills that encourage problem solvers in the way that engineers confront wicked and ill-structured issues, bringing a positive attitude regarding the application of classroom knowledge and the aspiration of the STEM career. This aligns with Thai educational policy objectives pertaining to gifted students and contributes to the achievement of policy objectives regarding gifted provisions (OEC, 2021). The research highlights the importance of integrating sustainable practises into conventional education and the scarcity of empirical studies concerning the efficacy of STEM instruction for gifted children for learning SD.

Furthermore, the study emphasises the successful integration of ‘team collaborations’ within educational settings, which not only improves students' ability to work together but also fosters a climate of collaboration in school. The research incorporates reflective practises through cooperative endeavours involving teachers’ reflection in research and, especially, students’ voices that reflect their learning experiences through diaries, enriching the educational journey for learners and fostering a culture of lifelong learning in STEM and SD education. Based on the overall contribution presented above, this section provides details of the contribution of this study based on particular groups, mainly teachers, students, gifted programme stakeholders, policymakers, and local and community members, as follows:

7.3.1 Revitalising STEM Education, Empowering Teachers, and Enriching Science Learning in Primary Schools

The research findings have significant implications for teachers, primarily concerning incorporating environmental sustainability (ESD) principles into STEM education, specifically by establishing a link between scientific understanding and the Thai science curriculum. Srikoom *et al.* (2013) stated that a significant obstacle in K–12 STEM education is the lack of general classroom guidelines or models for teachers to implement STEM integration strategies. This programme equips teachers to utilise it as an instructional and learning method to educate students in primary schools about STEM and ESD by establishing connections between scientific knowledge and real environmental sustainability issues.

Based on Thai science standards, students have background knowledge regarding the environment; they have no boundaries for learning SD, which focuses on the environment. An analysis of science standards should be conducted to identify connections between curriculum goals and local issues students face. An example of this is provided through the study of the chemical breakdown of plastic in Waste in the river and ocean activity, showcasing the cognitive and affective domains involved in SD learning. This alignment enables teachers to create lessons that address real-world challenges in students' communities, making STEM education more relevant and impactful. Students can understand how scientific information affects them and other species, fosters environmental understanding, and emphasises care and responsibility for non-human organisms.

This research exemplifies how environmental sustainability issues can be integrated into the STEM programme. Environmental sustainability is addressed through the YES! Programme, which encourages students to reflect and develop SD competence. It challenges the complex aspects of sustainability and fosters the development of future problem-solvers. By incorporating scientific methods and engineering principles via EHoM, students gain experience with EDP and the development of sustainable solutions. Role play as engineers also enhance students' preparedness for future STEM professions, fosters STEM application in the classroom, and emphasises the practical application of engineering principles, preparing them for collaborative work in adulthood, despite being primary school students.

In addition to improving students' problem-solving skills, the programme advocates for engineering in the scientific classroom. Teaching methods are enhanced by incorporating SD concepts, SDGs, and ESD competency, and students are immersed in their studies. By school policy, teachers can furnish students with SD knowledge and competencies. Social aspects can be introduced gradually by addressing environmental concerns and facilitating students' understanding of intricate socio-scientific matters via thoughtful reflection and systematic discourse. While economic considerations were not as frequently addressed, certain students conceptualised SD as an umbrella term for the economy, society, and environment. This instance provides teachers with additional proof to modify their teaching in the classroom. The findings suggest that incorporating the YES! The programme can increase students' engagement and appreciation for STEM knowledge and skills, emphasising their impact in the real world.

Additionally, this research presents significant insights into approaches to ensure equitable access to rigorous STEM education that effectively tackles practical issues for students from diverse socio-cultural backgrounds. Moreover, this pedagogical methodology is appropriate for science-gifted and non-gifted students, as it efficiently tackles practical obstacles. Additionally, incorporating SD permits the teacher to segregate the curriculum to better engage non-gifted students. Teachers can create a more accessible and appropriate learning experience that meets students at their individual knowledge and skill levels by differentiating the level of scientific knowledge, adjusting the complexity of problem-solving tasks, selecting suitable materials, and providing additional time for inquiry and support. Through this approach, students in diverse groups can actively engage in learning, expanding their abilities and understanding beyond the limitation of traditional educational methods.

7.3.2 School Students

> *We are increasingly asking if what people learn is truly relevant to their lives, if what they learn helps to ensure the survival of our planet. Education for Sustainable Development can provide the knowledge, awareness and action that empower people to transform themselves and transform societies (*Stefania Giannini, Assistant Director-General for Education (UNESCO, 2020, p. 2).

Undoubtedly, educational teaching and learning today, involving researchers and educators worldwide, aims to promote students with knowledge and skills for SD. (Wals, 2015; UNESCO, 2017; OECD, 2018a), resulting in a transformation (Sterling, 2011; UNESCO, 2020). This highlights the need for education to change to transform individuals and society, and it argues for comprehensive, student-centred, and socially active education that helps students think critically, influence society, and imagine a better future. This transformation goes beyond what is taught to how education is provided and its impact on society. (Sterling, 2016), an educational approach that combines critical, emancipatory, and relational pedagogy must be established (Wals, 2020).

As a consequence, students have the potential to be motivated with a sense of agency, awareness, and responsibility and encouraged to actively participate in building a world that offers greater sustainability and equity. The YES! intervention conducted in this research showed that this approach offers several benefits, including making learning science subjects more useful and interesting and providing a viewpoint on the critical ability to face real-world situations, which is increasingly significant in the STEM domain.

The YES! programme enhances students' understanding of ‘for’ and ‘about’ SD. Students acquire knowledge of the SDGs and SD concepts in addition to the SEP mandated in Thai schools; this demonstrates their interest and concern for the expansive field of sustainability. The results indicated that students know about social and economic aspects and the environment. This exemplifies the benefits of incorporating ESD into STEM education by encouraging students to assume leadership roles in pursuing greater sustainability. This pedagogical effort cultivates in students the capacity for critical thinking, innovative problem-solving, collaborative abilities, social responsibility, and decision-making to facilitate their active participation in the SD process.

The integration of STEM programmes promotes students' autonomy. The Yes! programme empowers students by allowing them to take control of their learning. The scenarios, linked to both SD and STEM, provide opportunities for students to confront complex problems and develop problem-solving skills independently. Tasks such as identifying the mayor of Mango City's speech notes and analysing flood data engage students in systems thinking and motivate them to propose collective solutions. This approach fosters students' interest in science and positions them as active contributors to sustainability, encouraging them to rethink their roles in promoting the well-being of people and the planet.

The integration of engineering discourse and sustainability discourse will expose students to the end-users of the product, who are the local people in different villages, cities, towns, and countries affected by the issue and helped by their solution. Consequently, it allows students to discuss and reflect on the cause of the issue, which involves different human behaviours and how a change in those behaviours can help alter the impact in the long run and possess their adapting ability. Another contribution of this study is the creation of a student agency. This research finding shows that student agency provides students with the ability to solve problems and make decisions without the teacher’s influence while the teacher facilitates the learning process for them. This can fundamentally prepare students to be sustainable citizens’.

7.3.3 Gifted Programme Stakeholders

In gifted education, student academic performance has been developed for years (Van Tassel-Baska and Brown, 2007; Renzulli, 2014b; Chan, 2017). Moreover, the research seeks to cultivate students into effective problem solvers, enhance their confidence and leadership qualities, foster awareness of their untapped potential (Reis and Renzulli, 2004), and equip them with essential skills. Therefore, the benefits for young gifted science students must be considered in improving gifted education programmes in Thailand. The finding informed the gifted programme stakeholders in Thailand that these students can benefit from a comprehensive educational experience that provides them with knowledge and skills and holds substantial significance and meaning. This research can impact gifted education in Thailand in two ways: 1) developing gifted students in Thailand and 2) promoting gifted development in the country.

For the first element, the YES! Programme is an enrichment activity for gifted students that promotes knowledge, skills, and personal growth. Gifted students' performance depends on programme quality and teacher lesson planning to give advanced students the learning experience they require (Dai, 2020), especially their intellectual and cognitive domains, from the matched instructions with their pattern of ability (Sternberg, 1999). The YES! programme's results show that gifted students can develop through learning about SD issues, notably environmental sustainability. Their abilities were developed in their area of interest and their daily and future lives. Due to several compelling reasons, YES! programmes promote STEM abilities with SD contribute significantly to gifted education. Consequently, it is recommended that gifted programme stakeholders contribute to ESD by embedding SD themes into the enrichment curriculum. This can be achieved by addressing students' needs and interests and integrating local community resources to enhance their learning experience.

The findings show that the enrichment programme can be used to empower gifted students by encouraging them to recognise the transformative power of knowledge and abilities in tackling global challenges. Through STEM engagement, the programme motivates and encourages constructive contributions to the world, empowering gifted students to make sustainable decisions and act as agents of change. By preparing them to actively contribute to a changing world, this initiative encourages change agents to transform. This learning prepared them to become future leaders and prepared them to confront global challenges and thrive professionally as they mature and cultivate distinctive societal contributions informed by SD knowledge and awareness.

This programme respects gifted students' voices, centres them on learning, allows them to develop knowledge, and promotes social and emotional support. This correlation between task success and international impact supports the assumption that gifted students can tackle global problems through successful implementation of solutions in practical problem solving. Engaging reflection in both problem-solving and discourse is the strategy, as they reflect their learning experiences. Sharing this with gifted teachers in the school could lead to further programmes to promote gifted students. STEM skills used to solve SD problems improve the value of education and inspire gifted students by showing how their skills can benefit society.

The findings support the idea that this study can drive gifted education in the country. According to Dai (2019), research in gifted areas in Thailand is still limited, as is the practice in Thai schools. Also, Anuruthwong (2017) encouraged research on gifted education in Thailand to examine the supportive system, identification methods, supply of resources, and teaching styles. This research encourages the research movement to promote gifted education and provision in the country. Collaboration with various educational bodies should be strengthened to enhance educational experiences that engage gifted students in learning and foster SD knowledge and competencies. Additionally, this research provided knowledge to support future training for the professional development of Thai teachers to have strategies that focus more on students and promote them according to their capacity and interest. The research is not only targeting the development of cognitive skills but also concerns gifted students' emotional wellbeing. Therefore, stakeholders in gifted education should create safe spaces for students to reflect on their thoughts, provide opportunities for collaboration, integrate professional learning experiences and be involved in making change for a better society.

7.3.4 Curriculum Developer

The findings enhance curriculum materials aligned with educational requirements for 21st-century skills and sustainability. Schools can improve curricula to promote SD integration by incorporating whole-school approaches, such as ESD embedded in national curricula or Thailand's sufficient economy philosophy. Advocating ESD integration in science curricula aligns with educational policies and improves science education standards. This research serves as an illustration for promoting SDGs at the school level and fostering global awareness. Local challenges should be linked to global issues to broaden perspectives and prepare students to address international concerns. Considering the expanding role of digital tools in education, teachers should incorporate them into ESD and STEM learning. As STEM frameworks are advocated, technology should be considered in the programme's subsequent phases.

7.3.5 School Stakeholders and Policy Maker

Implementing STEM problem-solving interventions and promoting SD learning depends on effective professional development for educators. It is crucial to address environmental components in the Thai science curriculum. Lewis and Leach (2007) recommend a dedicated time commitment, well-crafted materials, and ongoing support for integrating social dimensions into science education. From the findings of this study, it can be inferred that clear objectives emphasising the significance of scientific education should guide the development of the YES! Programme for professional development. While fostering ESD competencies, future research should focus on enhancing Thai educators and stakeholders' knowledge and awareness of SD to promote ESD implementation in schools.

Furthermore, incorporating ESD into STEM education requires hands-on learning in the science classroom. Sustainable practices, ESD awareness, and STEM integration expertise among teachers are crucial for ensuring a successful implementation. STEM-specific professional development seminars, as highlighted by Siew *et al*. (2015), can aid teachers in implementing inventive, inquiry-driven STEM approaches. Quality professional development is essential for overcoming obstacles, specifically when integrating relevant STEM activities for students. The implementation of the YES! The EHOM programme is advantageous in this context. Murphy *et al.* (2020) assert that professional development has a substantial impact on increasing the frequency of sustainability instruction, fostering favourable attitudes among teachers, and bolstering their sense of self-efficacy. For the successful implementation of a STEM-ESD programme in schools, significant involvement from policymakers and stakeholders is essential. This includes advocating for effective STEM and ESD practices within the education sector and providing teachers with continuous professional development, updated tools, and support for curriculum adaptation.

7.3.6 The Local and Global Community

The findings of this study demonstrate that Thai students are empowered by their engagement in local issues, which fosters their comprehension of sustainability concepts and potential solutions. This approach fosters their active participation in the development of more sustainable communities and effectively tackles worldwide issues such as climate change. Scholars foster a more comprehensive understanding of sustainability by encouraging students to contemplate their learning and exchange viewpoints on pertinent local and global issues, including justice, diversity, and rights (Hunt, 2012). The YES! programme, designed for practical teaching, made a local impact in the United Kingdom by addressing the landslides issue at a school. Although this project is not part of the current research, it showcase that UK students can learn about sustainability and problem-solving through real-world issues like landslides which also occur in the UK and other countries such as Thailand.

Informal teacher feedback indicates that the activities designed for science gifted students in this research were both stimulating and advantageous in terms of teaching the engineering problem-solving process. Students acquired classroom-applicable knowledge in environmental science and force and motion. Although there may be variations in the frequency and severity of environmental issues between Thailand and the United Kingdom, there is evidence of the YES! programme being implemented in diverse contexts.

The YES! programme goes beyond emphasising the issue's local importance to attract attention on a global scale. During the introduction and knowledge-delivery session, the programme shares global examples, providing students with a global perspective on environmental problems and their role in creating positive change. The discussion session focuses on innovative solutions worldwide, fostering a positive outlook that people globally are actively addressing the issue. This approach encourages positive thinking about the impact of STEM knowledge on avoiding problems, emphasising the significance of individual actions.

7.3.7 Contribution to the Field of STEM Education and ESD

This research contributes to integrating EHoM into STEM education. This research gave an example of an approach for embedded EHoM based on the EHoM framework of Lucas *et al.* (2014) in a STEM problem-based approach together with EDP, especially for young children. The practice of EHoM in this research encourages engineering integration in the integrated STEM intervention, as many scholars address the lack of engineering in research and practice (English, 2016). I agree with Lucas *et al*. (2014) that encouraging EHoM is an advantage in bringing an ‘engineering’ climate to the classroom and creating career aspirations for students in STEM careers, especially engineering. A successful level of integration not only focuses on science and mathematics but also technology as an innovation for solving problems and integrating ESD. This promotes an interdisciplinary learning climate.

For the ESD, this study does not mainly promote students' environmental knowledge regarding the issue, giving it a more engaging approach beyond environmental education, especially in Thailand. Making STEM education more meaningful for students to appreciate the learning in STEM subjects as it can contribute to society, especially sustainability. This research highlights the importance of students’ discussion and reflection in the collaborative learning process, encouraging the practice of competencies for SD, which encourages an approach to promoting transformation across different educational levels.

7.4 Reflection on Methodology: Practical Interventions and Bricolage

The bricolage approach is a foundational component of my research, providing direction for reflection throughout my study. I adopted multiple case studies as an alternative approach to conventional action research to gather various student viewpoints on STEM activities in gifted classrooms. Emphasising reflections on SD, EHOM skills, and collaboration took precedence over evaluating scientific knowledge. Bricolage's approach effectively tackles obstacles encountered while gathering data, including limitations imposed by the classroom environment and disruptions caused by the pandemic. Notwithstanding challenges, the study generates valuable findings regarding STEM education and ESD, which may have implications beyond the Thai context.

The bricolage approach offers nuanced perspectives and flexibility that can inform future developments in educational research, particularly in STEM education. The finding demonstrates that this approach not only yields comprehensive outcomes but also contributes to the enhancement of pedagogical design and instructional practices. This research posits that the bricolage approach provides an adaptive framework for capturing the complexity of students' learning in STEM activity through the investigation of the classroom and beyond. The flexibility to integrate a variety of tools, perspectives, and theories can facilitate the gathering of diverse viewpoints from both students and teachers, as STEM education is diverse and dynamic in nature. Additionally, the incorporating of various perspectives into a big picture provides a holistic view of how students learn and enables the improvement of a more engaging and effective activity. The application of bricolage in this study sheds light on a wider range of classroom realities and diverse learning outcomes and informs the understanding of how they perceive their learning and how the activity enhances learning.

As there are a few research of using bricolage in STEM education, this research encourages the use of bricolage in STEM education research. This study is not only showcasing the potential of bricolage to explore the complexity of classroom learning, this study advocates for more study to adopt bricolage in STEM education, highlighting its potential to enhance research methodology and instructional practice in the field.

7.5 Limitations of the Study

While providing rich insights, this qualitative research has inherent limitations that merit consideration. Using a qualitative methodology raises apprehensions regarding the applicability of results to more extensive settings. Still, the study is valuable because it examined the STEM problem-solving intervention for SD learning in great detail and put it into practice, which provides a more complete picture of how well it might work.

Notwithstanding these advantages, certain limitations must be recognised. A significant drawback is the lack of an evaluation instrument that assesses students' understanding of the Sustainable Development Goals (SDGs). This divide can be attributed to the limited integration of SDGs as educational content into primary science classrooms and national educational policies, owing to their novelty according to Thai science standards (Ministry of Education, 2008; IPST, 2017). The research focuses on implementing Engineering Habits of Mind (EHoM), a facet that Thai primary science standards do not explicitly consider. Although this strategy emphasises the application of STEM knowledge, specifically in environmental science, and introduces alternative teaching methods, it does not seek to compare various pedagogical approaches.

Moreover, the impacts of COVID-19 make it unable to obtain insights regarding students' perceptions of previous STEM problem-solving methods and further discussion on STEM ESD integration, particularly amid disruptions from tools such as interviews or focus groups. Furthermore, the diverse composition of student groups from different grades (4, 5, and 6) and the varying impact of online learning during the pandemic introduce additional layers of complexity. The students' backgrounds, academic years, and the duration of their education can influence their perspectives and prior knowledge, further shaping the diversity of factors impacting the study's outcomes. In summary, the research provides valuable insights into STEM education and ESD. However, its limitations require cautious interpretation and generalisation to other contexts.

7.6 Recommendations for Future Research

In shaping the future landscape of STEM education with a focus on SD, it is essential to consider diverse STEM activities, overcome technological constraints, foster inclusive education, employ a comprehensive mixed methodology, explore international contexts, prioritise professional development for teachers, and empower both teachers and students. The following recommendations for future research aim to enhance the effectiveness of STEM interventions, promote inclusivity, and equip teachers and students with the knowledge and skills necessary for navigating the complexities of a rapidly evolving world.

To begin with, examining STEM activities that serve different purposes necessitates applying numerous tools. The present study employed the bricolage approach to investigate the viewpoints and attitudes of teachers and students regarding STEM education for ESD. Nevertheless, despite the valuable insights offered by data sources such as written work, photographs, and drawings, this could benefit from additional aspects of the decision-making processes, the rationale behind selecting sustainable solutions, environmental ethics, and the in-depth expression of SD competencies.

Furthermore, the accessibility of technology and the repercussions of the COVID-19 pandemic impeded the ability to conduct in-person interviews with students, a widely employed approach in educational research. Additional research could contemplate conducting interviews with students or focus groups to understand their perspectives regarding SD learning better. This could involve examining their reflections on the necessary competencies for SD, EHoM comprehension, and collaborative skills.

Future research should include students from diverse demographic backgrounds, not solely those possessing exceptional scientific aptitude, to advance inclusive education. By customising STEM activities to align with the knowledge of individual students and proficiently conveying the problem-solving process, STEM education can engender greater enthusiasm and drive among all pupils, irrespective of their academic standing. Additionally, it is crucial to conduct further research in gifted education in a more inclusive ways. While existing research suggests that gifted education and talent development can be effective, additional research is required to validate their effectiveness in particular student populations. Research methodology for long-term investigations can also be employed to inform the effectiveness of STEM-ESD programme implementation for the development of students and contribute to SD in the long run.

Further studies that broaden the applicability of mixed methodology may produce innovative outcomes concerning assessing students' problem-solving and collaboration abilities and competency levels. Monitoring the progress of EHoM among students via self-report surveys and assessing their knowledge of SD through questionnaires are advisable. Furthermore, future investigations may apply the intervention and methodology in diverse contexts, potentially broadening their scope to include additional Asian countries or a more extensive area to enable comparative analysis.

Engaging in collaborative research with educators, specifically in STEM fields, is crucial for professional development within the ESD framework. This study aims to enhance the competencies and understanding of educators and instructors to guarantee the successful integration of environmental education into regular pedagogical activities and engagements. Gaining insights into the outcomes of interventions about SD and ESD competency and augmenting educators' pedagogical and subject knowledge is critical for bolstering teachers' professional and personal commitment to SD. This endeavour intends to enable students and educators to function as agents of constructive transformation.

Additional research is needed to obtain supplementary viewpoints from teachers, particularly regarding the professional development linked to the YES! Programme. The pedagogical knowledge and personal commitment of teachers to global concerns can enhance the relevance and purpose of the primary science curriculum, empowering teachers and the students under teachers' guidance to bring about constructive transformations. As a result, a STEM problem-solving approach could be an effective strategy for fostering understanding of SD and promoting gifted science students, preparing them to cope with SD challenges and become future problem solvers. These competencies, values, and knowledge equip and prepare students in light of the uncertain and complex future.

7.7 Reflection on the Research Journey.

As a researcher conducting research in multiple disciplines and accumulating knowledge in STEM education, ESD, and gifted education, I have experienced a challenging journey. This research allowed me to explore knowledge across various fields of interest and work with educational stakeholders, including students, teachers, and researchers. However, as someone with a background in science and professional experiences as a gifted programme coordinator, I found that this journey was broadened by a view of educational practice that was influenced by many factors. It also equips me with the skills and experience to gain insightful knowledge from both professional and academic fields. Based on my experiences, I could use this knowledge to implement and develop a more effective practice for gifted education programmes in my country and promote a more captivating learning activity to encourage students to learn ESD.

7.8 Conclusion

The research successfully integrates Education for Sustainable Development (ESD) into STEM education, emphasising environmental sustainability through scientific knowledge and the Engineering Design Process (EDP). Catering to gifted science students, this student-centred approach, rooted in Thai science standards, is crucial in promoting ESD in Thai schools. The programme fosters STEM education integration by addressing real-world issues, encouraging SD learning, and promoting a sustainable-thinking perspective.

In summary, this study answers all research questions by demonstrating that students obtain knowledge about the SDGs and develop a comprehensive understanding of SD concepts, encompassing environmental, social, and economic dimensions. Students' problem-solving skills in addressing issues such as landslides, droughts, floods, and waste in rivers and oceans are highlighted in the key findings. By contemplating the future, evaluating societal norms, rationalising human behaviour, and reflecting on personal thoughts and values about SD, students demonstrate SD competencies. Their prioritisation of environmental value over economic value demonstrates awareness of environmental sustainability.

Integrating STEM education with an emphasis on environmental sustainability effectively fosters SD knowledge acquisition. Science education provides a comprehensive groundwork for comprehending SD by integrating environmental dimensions and hands-on engagements with sustainability concerns. EDP promotes engineering by fostering EHoM and providing students with the necessary skills to solve problems proficiently. The values, expertise, and competencies that students gain equip them to confront the intricate and unpredictable obstacles that may arise in the future.

APPENDICES

Appendix 1: Pilot Study's Lesson Plan

ACTIVITY	LANDSLIDE PREVENTION PROJECT
ENVIRONMENTAL SUSTAINABILITY ISSUE	Landslide
OUTCOME	• Student learning, solving the problem, and practising problem-solving skill • Student is able to distinguish between long-term and short-term solutions. • Students are able to connect the solution they create and evaluate if it occurs in the real world. • Students work in teams during the problem-solving process
SDGS	Goal 11 (sustainable city) and Goal 15 (life on land)
LEARNING OBJECTIVE	• Students learn the impact of landslides on people and communities. • The student finds the solution to solve the problem for the long term. • Students identify human behaviour regarding landslides and solutions for solving landslides.
SCIENCE BEHIND THE ISSUE	Gravity, Force, Plant root, Value of forest, Cause of landslide
PROBLEM SOLVING SCENARIO	Save the villagers in village A. from the landslides by moving houses and making changes to the slope of the mountain.
INSTRUCTION	1) Introduce the scenario and provide some knowledge. 2) Provide them with the Engineering design process as a set of tasks that they can follow to solve the problem, create a product, and test the product. 3) Discuss their problem-solving process, products, and how they can help solve the problem in the long term and in real life.
SKILL DEVELOPMETN	Problem solving, Design and Collaboration

Appendix 2 : Pilot Phase Study

Pilot phase: Landslide Prevention project

Introduction

A pilot study was undertaken with the aim of developing an educational intervention that is student-cantered and in line with sustainability and STEM learning objectives. The purpose of this age-appropriate study was to evaluate the effect of the intervention on student engagement, attitude, awareness of sustainable development (SD), problem-solving abilities, and collaboration. Prior to broader school implementation, the pilot also assessed students' ability to evaluate the intervention's efficacy and identify implementation issues. The outcomes derived from the pilot study augment the structure, instructional strategies, educational resources, and research instruments utilised in pedagogical and learning interventions. Developed in accordance with a conceptual framework that incorporates STEM problem-solving, environmental concerns in Thailand, and ESD, the 90-minute landslip prevention project exemplifies how to effectively integrate STEM education and education for gifted science students in elementary school. Contributions from participants aid in the modification and improvement of future research.

Research Question

Pilot phase was conducted to inform the design of a pedagogical intervention to promote sustainability learning, problem-solving skills and collaboration, and inform the research approach for the entire research. Research questions for the pilot phase are:

- What is the effect of the pilot phase on teaching SD, problem-solving skills, and collaborative skills to primary school students?
- How can it shape the research design and conceptual framework to promote a better intervention that foster students' knowledge and awareness for SD, problem-solving and collaboration?

Participants of research

The student participants are 160 students who applied for the IPST one-day camp. The participants are students from Thai primary schools, mainly from central regions. They are studying in grades four to six (sixty-four students from grade four; sixty-nine students from grade five; and twenty students from grade six), and they are in the 10–12 age group. There are 73 female and 87 male students, they work in mixed gender groups of seven or eight students, from different backgrounds. When they were assigned a problem-solving task in STEM problem-solving activity, they were divided into two subgroups consisting of three or four members to complete the task together.

Landslide activity

The intervention was centred on mitigating landslides, which was selected due to its substantial long-term environmental concerns. Landslides are widespread throughout Thailand, present significant impacts to the economy, society, and environment. The lesson plan integrated practical challenges into its content, promoting student engagement and the generation of resolutions and the invention of innovative artifacts. Possible approaches included relocating residences to authorised zones or establishing sustainable practices such as planting trees and constructing terraced rice fields.

Students gained an understanding of the causes and consequences of landslides, taking into account both natural and human-induced factors, over the course of the intervention. The hands-on component comprised a village-based landslide obstacle course in which students followed the Engineering Design Process (EDP) (IPST,2014) to resolve the issue. The procedure comprised the design of individual structures, team deliberations regarding the decided solution, and assessments of the solutions' short-term and long-term efficacy. By emphasising the economic aspect of sustainability while operating within the constraints of limited resources and in accordance with SDG 11 (Sustainable Cities and Communities), this all-encompassing strategy sought to impart the understanding of sustainable solutions.(UNESCO, 2015)

The intervention began with an introduction to landslides and student discussions on its causes and effects. Human activity is discussed to assess the landslide's impact toward environment, society and economy, in addition to natural reasons. Students shared their landslide stories. The second part introduced the landslide challenge by describing the villages context. The slope, home and bean model were used for the landslide experiment. Students were asked to investigate the scenario to protect the village. With EDP, students tackle difficulties in teams. To avoid a landslide, they presented the option to the team and designed individual structures before entering the meeting to decide the best solution. Helping each other apply solutions in a collaborative manner, students could voice their thoughts to the team. In the last part, the discussion began. After testing their solutions and observing the scenario, the instructor inquired as to how well the solution they devised worked in the long and short term. The instructional sequences are represented in figure 1 below

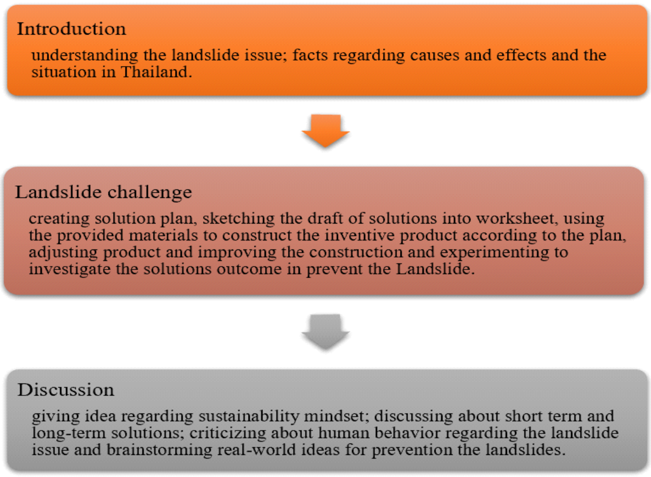


Figure 1 Landslide Activity Sequences

This section analysed the landslide prevention project's impact to inform the design of this thesis and its conceptual framework. The intervention promoted sustainability skills such as problem-solving and collaboration which are emphasised. SD knowledge is supported by cognitive understanding of long-term and short-term outcomes and the intervention's influence on students. Student worksheets collected qualitative and quantitative data pertaining to perceptions and engagement feedbacks about the intervention.

Figure 2a Landslides Worksheet (page 1 – 2)

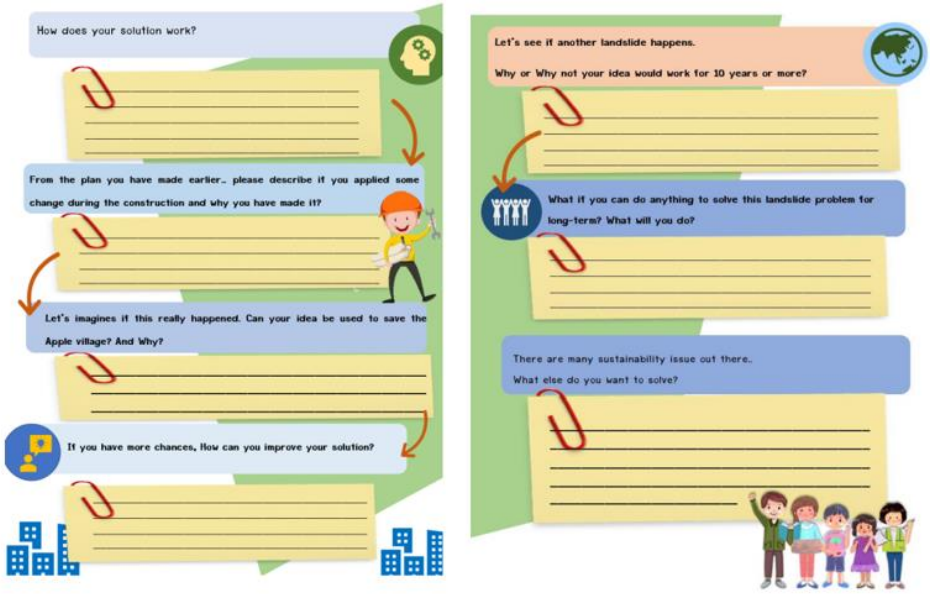


Figure 2b Landslides Worksheet (Page 3 - 4)

Data collection

The students' worksheet is comprised of three types of questions: nine open-ended questions requiring written answers, one open-ended question for answers through drawing, and five yes/no questions where answers are provided by ticking a box. These questions are constructed based on the components of the conceptual framework. To investigate students' attitudes and perceptions towards the landslide issue and sustainability, an open-ended question was used. This type of question is commonly used in educational research exploring attitudes and perceptions, as it provides rich and informative data. Also, this type of question allowed the students to answer with multiple responses without boundaries, whereas the closed-end question allowed one direct answer . It can be used to collected written evidence to reflect students' perspectives on the teaching and learning process . The open-ended questions sought students' opinions on a variety of topics, including problem investigation, problems identified from the given scenario, a solution plan, and what they did to improve the plan for better solutions as spaces are provided for them to reflect their ideas.

Furthermore, students were asked to draw their construction plans to display their solutions for the prevention of landslides. Planning is a part of the EDP that students employ while solving the problem . In educational research, students' drawings offer many benefits, such as revealing their ideas and reflecting on their understanding of the knowledge and concepts in an educational setting . The drawing approach is often adopted to reflect young students' thoughts, especially in primary schools, and was often integrated in science . Therefore, drawing is a helpful tool for students to visualise their problem-solving ideas through sketching. The student can ensure that the plan works and leads to a successful inventive product by following this sketch. The blank space was provided for the students to draw on the worksheet according to question no. 3.

Additionally, Yes-or-no questions were also adopted in the final part of the worksheet. With the time constraint at the end of the programme and the limited space in the worksheet, dichotomous data were collected to discover the basic perceptions of participants regarding teamwork and problem-solving. Five questions were posed to the students, designed to elicit quick responses by simply selecting yes-or-no as their answers. Yes-or-no questions as well as other types of questions, such as open-ended questions are commonly used in educational research that involve students. For example, students were asked yes-no questions and open-ended questions to study their views towards the flipped classroom approach (Butt, 2014). This type of question is a forced-choice question beneficial for making a sensory characterisation .

The list of questions for the students is in table 1 . The answers to open-ended questions were analysed using thematic analysis. Similarly, the students' drawings were analysed using student drawing analysis with thematic analysis. Critical friends who are two instructors also reflected on these pilot phases and analysed them using the thematic analysis method

Items	Type	Learning element
Q1. You arrived here already and now have some time to walk around the village. Form your observation, what is the problem of village A?	Open ended	STEM (problem identification)
Q2. What can you do to help the villager and make village A safe from landslides? Write down the ideas you have and send it to the Government for funding and support	Open ended	STEM (idea generation)
Q3. Unfortunately, because of limited funds, there are few materials provided. Moreover, the Government want to see the best plan of your team. Please draw a plan or design of your team's best idea	Drawing	STEM (planning)
Q4. Is there any change you do during the construction? If you have done some changes, please explain.	Open ended	STEM (Construction)
Q5. Now, a landslide occurs in village A again!!!! What happened? Does your solution work? Please explain....	Open ended	STEM (Experimenting and improvement)
Q6. From the results, something might have gone wrong in your construction!!! What do you want to do to improve in your solution?	Open ended	STEM (Evaluation and improvement)
Q7. Let 's imagines if this really happened. Can your idea be used to solve a real problem? Why?	Open ended	SDG 11 and 15
Q8. Do you think your idea would work for 10 years or more? Is your suggestion a long term solution? Why not?	Open ended	SDG 11 and 15
Q9. Your team has done so well on solving this problem!!! Do you enjoy solving about the real-world problem?	Open ended	SDG 11 and 15
Q10. Is there any other problem like this in your country that you might solve? What is it and how do you know about that problem?	Open ended	SDG 11 and 15
Q11. Did you have a chance to work with your team?	Yes – No	Collaboration
Q12. Did you change your plan during construction?	Yes – No	STEM (improvement)
Q13. Did you despondent at any time, did you want to give up?	Yes – No	Resilience
Q14. Do you think teamwork is useful to solve this mission?	Yes – No	Collaboration
Q15. Do you think you have more confidence to solve real-world problems?	Yes - No	STEM and ESD

Table 1 Questions in Worksheet

Data Analysis

The responses provided by the participants were transcribed and subjected to the six-steps thematic analysis framework from in order to analyse the data collected for the pilot. The process involved in this study encompasses the initial task of familiarising oneself with the responses provided by the students. Subsequently, a coding procedure was employed to discover recurring elements within the participants' viewpoints, as outlined by Clarke and Braun (2013). During the coding process, the authors collaborated with three other coders, consisting of two scholars specialising in the field of Education and one researcher specialising in Computer Science, in order to establish inter-judges' reliability. Intensive discussions with my supervisors were conducted to resolve any issues and reach final agreements. One set of responses was examined as a repeating pattern. We calculated and recorded students' response frequency within a theme. Next, students' comments were collected to illustrate and explain the main themes. Description statistics were used to assess close-ended questions.

Finding: the Impact of STEM – SD Activity

The Landslide Prevention Project involved students in identifying and implementing solutions. 57% of students exhibited advanced problem-solving skills while demonstrating critical thinking in problem identification. Remarkable answers encompassed advanced measures such as afforestation and the erection of barriers. The students independently created ideas, with 92% suggesting solutions and 64% presenting intricate ones. Improvement was demonstrated as two-thirds of students made changes to their plans as a result of group discussions. In the following inquiries, pupils conveyed accomplished resolutions and exhibited a keenness to enhance, showcasing their recognition of sustainable alternatives. The majority deemed their ideas efficacious in real-life scenarios, establishing connections between STEM problem-solving and sustainability.

Students provided the idea of long-term solution, 27% of respondents expressed confidence in the durability of their ideas, while 69% stated that sustainable solutions necessitate ongoing refinement. Students exhibited contentment and pleasure when tackling practical issues, cultivating optimistic mindsets and perseverance. Despite encountering failure, the majority had a sense of pride, contentment, and joy in their accomplishments. Additionally, students demonstrated a keen interest in addressing many environmental issues in Thailand, specifically highlighting air pollution, floods, and the COVID-19 pandemic as primary areas of concern.

Students demonstrated collaboration, adaptability in modifying plans, and perseverance in the face of failure in response to the yes-no questions. The utilisation of teamwork was considered beneficial in addressing the problem of landslides, as nearly 97% expressed assurance in effectively addressing practical difficulties. The practice facilitated the cultivation of self-efficacy by engaging in problem-solving activities.

Conclusion

Students are encouraged to find solutions to protect villagers against landslides, which reflect societal sustainability. After the activities, sustainability options were discussed. The discussion highlighted value thinking as an SD competence for the next phase. Long-term and short-term discussions, such as whether growing trees to cover the slope surface is better to prevent landslides, require further evaluation. The ability to predict the future from the barrier experiment outcome is called future thinking. These components are key competencies for SD which must be fostered.

Evidently, the effectiveness of the STEM problem-solving activity in fostering students' engagement in the pursuit of SD was noted. Nevertheless, in order to determine the most effective method for promoting behaviour change among primary students, it is imperative to conduct future studies. It is noteworthy that primary concerns expressed by students revolved on the issues of air pollution, flooding, and pandemic diseases. This suggests that the use of environmental issue that involved SDGs can be a good starting point to promote knowledge for SD by illustrated examples of local case to bring a sense of relevancy.

Appendix 3: Conceptual Framework Implementation in the YES! Programme

Framework elements		Environmental sustainability issue			
		Landslide	flood	drought	Waste
Environmental issue	Fact of issue	Impact on human safety. The solution to prevent the land degradation and landslide. Long term solution	Impact of climate change and how it related to floods issues. The solution to prevent floods. Long term solution to ensure safety from flood	Impact of climate change and how related to drought issue, different ways to manage water. The solution to ensure the access to water in every sector	impact of human behaviour on creating waste, The linkage between river waste and ocean waste /Linkage to the food chain in the marine ecosystem, /Waste management for long term
	Link with science standard	impact of natural disasters, natural resources, forests, plant roots	impact of the greenhouse effect, the impact of weather, seasonal change, and climate change	impact of the greenhouse effect on the plant and animal life	Impact of human behaviours, marine animal life, food webs, waste management with reduce reuse recycle
Education for Sustainable development	Sustainable development goals (SDGs)	SDG 11 sustainable cities SDG 15 life on land	SDG 13 climate action SDG11 sustainable cities	SDG 6 clean water and sanitization SDG 13 climate action SDG 15 life on land	SDG 6 clean water and sanitization SDG 14 life below water SDG12 Responsible consumption reduction
	Three pillars for sustainability	Environmental: land degradation, deforestation Society: prevent disaster Economy: save cost from reconstructing the city, save money from maintenance of barrier	Environmental: deal with the flood, waste management Society: being resilient and adapted to flood Economy: save public support funds, unemployment, poverty	Environmental: climate change and drought Society: the equality in accessing water sources, Economy: reduce the agricultural product prices, unemployment	Environmental: biodiversity, pollution Society: health awareness, living quality Economy: circular economy (reduce waste for the long term from making the circulation of using the plastic product)
	Sustainability competency	System thinking, Integrated problem-solving, critical thinking	System thinking, Integrated problem-solving, critical thinking anticipatory competency	System thinking, Integrated problem-solving, critical thinking anticipatory competency,	System thinking, Integrated problem-solving, critical thinking anticipatory competency,
STEM problem-solving	Engineering habits of mind (EHoM)	Problem finding, visualizing, creative problem-solving, system thinking	System thinking, Visualising, Creative problem-solving	visualizing, creative problem-solving, system thinking, Improvement and adaptability	System thinking, Visualising, Creative problem-solving
Collaboration	Collaborative problem solving	Brainstorming, communication, construction, feedback giving	Brainstorming, communication, construction, feedback giving	Brainstorming, communication, construction, feedback giving	Brainstorming, communication, construction, feedback giving
Gifted	Promoting Gifted characteristic	Experimental skills	Data assessment skills	Data management skills	Scientific Interest behaviour in new fact about science

Appendix 4: The Young Engineers For Sustainability (YES!) Lesson Plan

<table>
<tr><th colspan="3">STAGE 1 DESIRED RESULT</th></tr>
<tr><th>GOAL OF INTERVENTION</th><th colspan="2">TRANSFER</th></tr>
<tr><td rowspan="6">- Demonstrate awareness for sustainability regarding environmental sustainability issue
- Demonstrate knowledge for sustainability such as understand the fact of issue, see in the cause and impact for environment, economy and society
- Demonstrate ability to justify role of individual behaviour, community and policy for sustainability
- Demonstrate problem solving skill regarding EHoM and create a solution as innovative product with ability to define the problem, visualise the solution, purpose creative solution and carry out the construction to create the product and test the product.
- Evaluate the model construct and justify if it is short term or long term solution to solve problem.
- Demonstrate ability to solve in team</td><td colspan="2">Student will be able to use their knowledge to invent innovative structure as the solution to solve landslide, flood, drought and waste in the water and ocean.</td></tr>
<tr><th colspan="2">MEANING</th></tr>
<tr><td>understanding
- Environmental issue is affect environment, society and economy
- Causes involve human behaviour
- They can help solve problem by change their habits
- Problem solving skills is important to solve problem systematically
- Collaboration is essential to help solving the problem</td><td>Essential question
1) What Is environmental issue and how it affect individual , society, economy and environment
2) What are problem to be solved, what are the solutions.
3) How can we solve problem for long term.
4) How they can help solve the problem</td></tr>
<tr><th colspan="2">ACQUISITION</th></tr>
<tr><td>Student will know
- SDGs, Science knowledge behind the issue and fact about the issue
- The important of sustainability,
- Important to change the behaviour and important to solve problem
- EHoM help solving the problem
- Problem solving process starting from gathering idea, negotiating with peers to get team solutions.
- Possible solutions to solve problem from provided materials
- Solution for long term and short terms
- The important of collaboration</td><td>Student will skilled for
- EHoM problem solving skills (system thinking, problem finding, visualising, creative problem solving, improving and adapting,
- Collaborative problem solving starting from brainstorming , debate, making team decision, make a conclusion, construction.
- Making justification on their solution if it work in real-world or if it is long term solution.
- Critical analyse the individual behaviour, role of society to solve the issue.
- Build the innovative product, test and evaluate the product</td></tr>
</table>

STAGE 2 EVIDENCE	
EVALUATIVE CRITERIA	**ASSESSMETN OF EVIDENCE**
Engineering logbook, Sketch and photo reflecting all steps of problem solving regarding EHoM Observation by teacher also demonstrate their problem solving and collaboration Pre and Pot intervention questionnaire demonstrate their knowledge and perception toward ESD, problem solving and collaboration Dairy demonstrated their perception toward programme, ESD, problem solving and collaboration in longer period.	Performance task 1) Landslide prevention: Invent the structure to prevent landslides from limited resources 2) Are we ready for the flood : invent the different structures to prevent floods that occur from different ways such as flash flood or high precipitation 3) Drought is coming : Invent different water preservations, debate the pros and cons, and Calculate the water amount for every sector. 4) Journey of the waste from the river to ocean: Create the tools to pick up litter and then identify litter with different management approaches. Problem solving task starting from 1) System thinking – discuss in class about the issue 2) Problem finding – define the problem to be solve from given context 3) Visualising – create the sketch of team solution 4) Creative problem solving – purpose the solution, construct the innovative structure. 5) Improving – improve the solution during construction and after test 6) Adapting – evaluate the implementation in real work context Learning SD during Task introduction and Discussion 1) Discuss about issue in class and in team about cause and effect of issue 2) Discuss about solution for long term and short term and solution form different perspectives such as individual level, community level and national level Learning collaboration 1) Doing their work following career role 2) Doing team task as collaborative problem solving

STAGE 3 LEARNING PLAN

Introduction

- Provided background knowledge regarding the issue
- Story telling about the scenario

Problem solving

- Asking them to find problem, purpose solution , create the sketch, construct the innovative product, test the product, improve the product

Sustainability discussion

- Discuss in different aspects such as short term and long term solution, if the solution could work in real world when using real materials, role of individual , society and politics to solve problem.

Appendix 5: Ethical Approval for Pilot Study

College of Business, Arts and Social Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

20 January 2020

LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 31/01/2020 AND 31/07/2020

Applicant (s): Mrs Tawinan Saengkhattiya Mr Mike Watts, Ms Sarmin Hossain

Project Title: Landslide prevention project ; Problem based activity for Sustainable development education in primary level

Reference: 19289-MHR-Jan/2020- 23177-3

Dear Mrs Tawinan Saengkhattiya

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor David Gallear

Chair of the College of Business, Arts and Social Sciences Research Ethics Committee

Brunel University London

Appendix 6: Ethical Approval for Phase 1 and 2

University Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

1 June 2022

LETTER OF CONDITIONAL APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 01/06/2022 AND 30/06/2023

Applicant (s): Mrs. Tawinan Saengkhattiya

Project Title: Learning sustainable development and 21st century skills through STEM problem solving activity in Thai gifted science students at primary school level

Reference: 35522-MHR-May/2022- 39438-3

Dear Mrs. Tawinan Saengkhattiya,

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The Participant Information Sheet (PIS) documents for students are currently unreadable, as the text is too large for the boxes. Please reformat, and send copies to the REC via res-ethics@brunel.ac.uk prior to commencement of the study.
- Please amend contact details for the Chair of UREC on all PIS documents - this should be Dr Derek Millard-Healy (Derek.Millard-Healy@brunel.ac.uk).
- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- **Please ensure that you monitor and adhere to all up-to-date local and national Government health advice for the duration of your project.**

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- If your project has been approved to run for a duration longer than 12 months, you will be required to submit an annual progress report to the Research Ethics Committee. You will be contacted about submission of this report before it becomes due.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Kind regards,

Dr Derek Millard-Healy

Chair of the University Research Ethics Committee

Brunel University London

Appendix 7: Example of School Approval Letter

Brunel University London

College of Business, Art and Social Science

Brunel University London
Kingston Lane Uxbridge UB8 3PH United Kingdom T +44 (0)1895 274000
www.brunel.ac.uk

To Saritdidet School Principal
Topic Request for permission to conduct the research study

My name is Tawinan Saengkhattiya, a doctoral researcher from Brunel Universiy London and academic staff at Olympiad and Genius promotion unit, IPST Thailand. I am currently conducting doctoral research in the Education department with the topic: "Using real-world environmental issues as a tool to enhance awareness of sustainable development and enrich 21st-century skills in gifted science students through STEM problem-solving activities at primary school level in Thailand''. This research is conducted under the supervision of Professor Mike Watts and Dr. Sarmin Hossain from the Department of Education, Brunel University London, United Kingdom

In order to pursue the research scheme, I am writing to request permission to conduct a 1-day STEM activity at Saritdidet School in the period between March – September 2022. As Saritdidet school provides a science programme for gifted science students and the school is the partner of the IPST Genius programme, its students can give rich information for my research. So, I would like to conduct the 1-day intervention in your school with 20 – 30 students who study in the gifted programme and/or selected by IPST genius programme. The data will be collected from students while participating in the intervention under the observation of 1 or 2 teachers. All cost regarding the intervention will be under the researcher's responsibility. The intervention will be able to conduct by following Covid-19 regulation of the school and Thai government. Should you need any further information, please contact me via the email address;Tawinan.Saengkhattiya@brunel.ac.uk.

I believe this research will inform valuable information for developing an enrichment programme to support the gifted students in their STEM learning and develop student awareness for the environment and sustainability. I wish that with your consideration, you may permit the research in Saritdidet school and allow the teachers to take part in the research. The information of the research and the research protocol is attached with this letter. If you agree to give the permission for conducting this research in your school, please fill the permission form below and assign a teacher to be contact person for the research and intervention.

Thank you for your time and consideration in this matter.

Yours sincerely,

Tawinan Saengkhattiya
Doctoral researcher,
Brunel University London

I certify that researcher is ☑ permitted ☐ not permit to do research in Saritdidet school

(sign)...[redacted] Saritdidet School Principal
(Name) [redacted]

Appendix 8: Example Of Student Assent Form (Phase 1)

ASSENT FORM for student แบบแสดงความยินยอมเข้าร่วมงานวิจัย

Note that this form will be in the Thai language only for students to understanding

กิจกรรมวิศวกรน้อยเพื่ออนาคตที่ยั่งยืน Young Engineers for a sustainable future s

นางทวินันท์ แสงขัตติยะ Tawinan Saengkhattiya

I got permission to do the research between 15/05/2022 and 31/10/2022 only

(อนุญาตให้ใช้สำหรับการวิจัยระหว่างวันที่ เมษายน ถึง 31 ตุลาคม 2565)

Students should choose Yes or No to answer all questions กรุณากรอกแบบฟอร์มทั้งฉบับ	YES ใช่	NO ไม่ใช่
Do you read the Information Sheet about the activities and data collection? **นักเรียนได้อ่านข้อมูลสำหรับผู้ร่วมการวิจัยจากเอกสารที่แจกหรือไม่**	☐	☐
Are you free to ask questions about the study? (via asking the teacher, parent and researcher) **นักเรียนสามารถสอบถามข้อมูลเกี่ยวกับการศึกษานี้หรือไม่ (เช่น เปิดให้ถามใน อีเมล์ โทรศัพท์)**	☐	☐
Do you get a clear answer and enough information about the study? **นักเรียนได้รับข้อมูลหรือคำถามที่เกี่ยวกับงานวิจัยหรือไม่**	☐	☐
Do you know that your real name will not use in any paper in this study? **นักเรียนจะไม่ถูกพาดพิงชื่อสกุลในเอกสารใดๆ ที่เกี่ยวข้องกับการวิจัยนี้**	☐	☐
Do you understand that: **คุณได้รับทราบดังต่อไปนี้**		
• You are free to stop joining from activity at any time **นักเรียนสามารถถอนตัวจากการวิจัยได้ทุกขณะ**	☐	☐
• You don't have to give a reason for not joining anymore. **นักเรียนไม่ต้องให้เหตุผลในการถอนตัว**	☐	☐
• You will be okay if you stop joining at any time. You will not lose anything or miss any good things. **การถอนตัวจะไม่ส่งผลกระทบกับนักเรียน และนักเรียนจะไม่เสียอะไร**	☐	☐
• You can stop the researcher from using your data any time up to 31/10/2022 **นักเรียนสามารถขอถอนข้อมูลที่ให้ได้ภายในวันที่ 31 ตุลาคม 2565**	☐	☐
Are you okay to answer the questions and write on the worksheet in the activity? **ฉันตกลงที่จะตอบคำถามและเขียนลงแบบเรียนในกิจกรรม**	☐	☐
Are you okay with the researcher using a fake name when the study paper is open for everyone to read? **ข้าพเจ้าเห็นด้วยในการใช้ชื่อปลอมเมื่อเอกสารถูกเปิดเผยให้ทุกคนอ่าน**	☐	☐
I know how my data will keep secret. **นักเรียนได้ทราบการปิดข้อมูลเป็นความลับแล้ว**	☐	☐
I am okay that the researcher will not share my real name with other researchers in the future. **นักเรียนเห็นด้วยว่าจะไม่ระบุชื่อจริง เมื่อมีการแชร์กับนักวิจัยอื่นในอนาคต**	☐	☐
I am okay to join this study. **ฉันเข้าร่วมกิจกรรมนี้**	☐	☐
Date **วันที่:** ___________________________ Print name of student **ชื่อ สกุล ตัวบรรจง:** ___________________________		

Appendix 9: Example of Parent's Consent Form (phase 1)

CONSENT FORM แบบแสดงเจตนายินยอมเข้าร่วมงานวิจัย

Brunel University London

การเก็บข้อมูลระยะที่ 1 กิจกรรมวิศวกรน้อยเพื่ออนาคตที่ยั่งยืน

Phase 1 School intervention: Young Engineers for a sustainable future

นางทวินันท์ แสงขัติยะ: Tawinan Saengkhattiya

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 01/04/2022 AND 31/10/2022 (อนุญาตให้ใช้สำหรับการวิจัยระหว่างวันที่ เมษายน ถึง 31 ตุลาคม 2565)

The Parent /participant / their legal representative should complete the whole of this sheet.

ผู้ปกครอง หรือ ผู้เข้าร่วมการวิจัย หรือ ผู้แทน กรุณากรอกแบบฟอร์มทั้งฉบับ

	YES ใช่	NO ไม่ใช่
Have you read the Participant Information Sheet? คุณได้อ่านข้อมูลสำหรับผู้ร่วมการวิจัยจากเอกสารที่แนบหรือไม่	☐	☐
Have you had an opportunity to ask questions and discuss this study? (via email/phone for this research) คุณได้รับโอกาสให้ถามคำถามข้อมูลเกี่ยวกับการศึกษานี้หรือไม่ (เช่น เปิดให้ถามใน อีเมล์ โทรศัพท์)	☐	☐
Have you received answers that satisfy yourself and clear all of your questions? (via email) คุณได้รับคำตอบที่พอใจกับคำถามของคุณหรือไม่ จากในช่องทางใดทางหนึ่งเช่น อีเมล์ สำหรับการวิจัยนี้	☐	☐
Do you understand that you will not be referred to by name in any report concerning this study? คุณรับทราบหรือไม่ว่าผู้เข้าร่วมการวิจัยจะไม่ถูกพาดพิงชื่อจริงในเอกสารใดๆ ที่เกี่ยวข้องกับการวิจัยนี้	☐	☐
Do you understand that: คุณได้รับทราบดังต่อไปนี้		
• participants are free to withdraw from study at any time ผู้เข้าร่วมการวิจัยถอนตัวจากการวิจัยได้ทุกขณะ	☐	☐
• You don't have to give any reason for withdrawing ผู้เข้าร่วมการวิจัยไม่ต้องให้เหตุผลในการถอนตัว	☐	☐
• Choosing not to participate or withdrawing will not affect your access to services? การถอนตัวจากการวิจัยไม่มีผลกระทบใดใดต่อผู้เข้าร่วมการวิจัยทั้งสิ้น	☐	☐
• You can withdraw your data any time up to 31/10/2022 ผู้เข้าร่วมการวิจัยสามารถขอถอนข้อมูลที่ให้ได้ภายในวันที่ 31 ตุลาคม 2565	☐	☐
I agree to my children to do the questionnaire and worksheet in this research ข้าพเจ้าเห็นด้วยกับการให้บุตรหรือนักเรียนในปกครองให้ข้อมูลในงานวิจัยนี้	☐	☐
I agree to the use of non-attributable quotes when the study is written up or published ข้าพเจ้าเห็นด้วยในการอ้างอิงที่เฉพาะเจาะจงไม่ได้ สำหรับการศึกษานี้เมื่อมีการตีพิมพ์เอกสาร	☐	☐
The procedures regarding confidentiality have been explained to me กระบวนการการปกปิดข้อมูลส่วนบุคคลได้อธิบายให้ทราบต่อข้าพเจ้าเรียบร้อยแล้ว	☐	☐
I agree that my anonymised data can be stored and shared with other researchers for use in future projects. ข้าพเจ้าเห็นด้วยไม่ระบุชื่อจริงของผู้เข้าร่วมวิจัยเพื่อเก็บหรือแลกเปลี่ยนกับนักวิจัยอื่นในอนาคต	☐	☐
I agree to take part in this study ข้าพเจ้าเห็นด้วยที่จะให้บุตรหรือนักเรียนในปกครองเข้าร่วมกิจกรรมนี้	☐	☐

Signature of Parent ลายมือชื่อของผู้ปกครอง: ______________________ Date วันที่: ______________________

Print name ชื่อ สกุล ตัวบรรจง: ______________________

Appendix 10 : Example Of Teachers' Consent Form

CONSENT FORM แบบแสดงเจตนายินยอมเข้าร่วมงานวิจัย

การเก็บข้อมูลระยะที่ 1 กิจกรรมวิศวกรน้อยเพื่ออนาคตที่ยั่งยืน

Phase 1 School intervention: Young Engineers for a sustainable future

นางทวินันท์ แสงขัติยะ: **Tawinan Saengkhattiya**

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 01/04/2022 AND 31/10/2022 (อนุญาตให้ใช้สำหรับการวิจัยระหว่างวันที่ เมษายน ถึง 31 ตุลาคม 2565)

The participant should complete the whole of this sheet.

ผู้เข้าร่วมการวิจัย หรือ ผู้แทน กรุณากรอกแบบฟอร์มทั้งฉบับ	YES ใช่	NO ไม่ใช่
Have you read the Participant Information Sheet? คุณได้อ่านข้อมูลสำหรับผู้ร่วมการวิจัยจากเอกสารที่แจกหรือไม่	☐	☐
Have you had an opportunity to ask questions and discuss this study? (via email/phone for this research) คุณได้รับโอกาสให้สอบถามข้อมูลเกี่ยวกับการศึกษานี้หรือไม่ (เช่น เปิดให้ถามใน อีเมล์ โทรศัพท์)	☐	☐
Have you received satisfactory answers to all your questions? (via email) คุณได้รับคำตอบที่พอใจกับคำถามของคุณหรือไม่ จากในช่องทางใดทางหนึ่งเช่น อีเมล์ สำหรับการวิจัยนี้	☐	☐
Do you understand that you will not be referred to by name in any report concerning this study? คุณรับทราบหรือไม่ว่าผู้เข้าร่วมการวิจัยจะไม่ถูกพาดพิงชื่อสกุลในเอกสารใดๆ ที่เกี่ยวข้องกับการวิจัยนี้	☐	☐
Do you understand that: คุณได้รับทราบดังต่อไปนี้		
• participants are free to withdraw from study at any time ผู้เข้าร่วมการวิจัยถอนตัวจากการวิจัยได้ทุกขณะ	☐	☐
• You don't have to give any reason for withdrawing ผู้เข้าร่วมการวิจัยไม่ต้องให้เหตุผลในการถอนตัว	☐	☐
• Choosing not to participate or withdrawing will not affect your access to services? การถอนตัวจากการวิจัยไม่มีผลกระทบใดใดต่อผู้เข้าร่วมการวิจัยทั้งสิ้น	☐	☐
• You can withdraw your data any time up to 30/06/2023 ผู้เข้าร่วมการวิจัยสามารถขอถอนข้อมูลที่ให้ได้ภายในวันที่ 30 มิถุนายน 2566	☐	☐
I agree to my children to do the observation, fill the form, and interview ข้าพเจ้าเห็นด้วยกับการกรอกแบบสังเกตการกิจกรรมและสัมภาษณ์	☐	☐
I agree to the use of non-attributable quotes when the study is written up or published ข้าพเจ้าเห็นด้วยในการอ้างอิงที่เฉพาะเจาะจงไม่ได้ สำหรับการศึกษานี้เมื่อมีการตีพิมพ์เอกสาร	☐	☐
The procedures regarding confidentiality have been explained to me กระบวนการการปกปิดข้อมูลส่วนบุคคลได้อธิบายให้ทราบต่อข้าพเจ้าเรียบร้อยแล้ว	☐	☐
I agree that my anonymised data can be stored and shared with other researchers for use in future projects. ข้าพเจ้าเห็นด้วยเมื่อไม่ระบุชื่อจริงของผู้เข้าร่วมวิจัยเพื่อเก็บหรือแลกเปลี่ยนกับนักวิจัยอื่นในอนาคต	☐	☐
I agree to take part in this study ข้าพเจ้าเห็นด้วยที่จะเข้าร่วมกิจกรรมนี้	☐	☐

Signature of participant ลายมือชื่อของผู้เข้าร่วม: ____________________ Date วันที่: ____________________

Print nameชื่อ สกุล ตัวบรรจง: ____________________

Appendix 11: Students' Pre-Intervention Questionnaires

Pre-intervention questionaire

'Young engineer for sustainable future'

Importance please fill in the form at the available space

Section 1 General information

Name________________________ Gender ◯ Male ◯ Female

School______________________________ Age_______ School year_______

Section 2 What do you know about these issues, what is the impact and How do you know that

issue	Do you know the issue and the impact of the issue	where did you know it from
Landslide	◯ No, I don't know ◯ Yes I know Landslide is_________________________________ ____ The impact of landslide is _____________________ ____	◯ I faced it by myself ◯ TV or news ◯ school ◯ others, such as it is from_________________
Flood	◯ No, I don't know ◯ Yes I know Flood is_____________________________________ ____ The impact of flood is _________________________ ____	◯ I faced it by myself ◯ TV or news ◯ school ◯ others, such as it is from_________________
Drought	◯ No, I don't know ◯ Yes I know Drought is___________________________________ ____ The impact of Drought is _______________________ ____	◯ I faced it by myself ◯ TV or news ◯ school ◯ others, such as it is from_________________
Waste in the river and ocean	◯ No, I don't know ◯ Yes I know Waste in the river and ocean is__________________ ____ The impact is __________________________________ ____	◯ I faced it by myself ◯ TV or news ◯ school ◯ others, such as it is from_________________

Section 3 Solving the environmental issues and reduces the impact of it

Why we should solve global warming and environmental issue

____

____

How can a student like you help solve the environmental issue?

____

____

What issue do you want to solve if you have to solve an issue the most? why?

____

____

In your understanding, what is sustainable development?

____

____

How Sustainable development related to envrironment?

____

____

When we talk about the future, What would you like the environment to be?

____

____

What do you feel when you know that you will learn to solve this programme's environmental issue? (for example, worry, excited, confident)

____

____

In the activity, you will work in an engineer team to solve the environmental problem, what do you feel about that? (for example, worry, excited,confident)

____

____

What are the good things in you that can help the team when doing group work and achieving

____

____

What is need from team member to make teamwork successful in the activity?

____

____

Appendix 12: Students' Post Intervention Questionnaires

Post intervention questionnaire

'Young engineer for sustainable future'

Importance, please fill in the form at the available space

Section 1 General information

Name______________________ Group______

Section 2 Sustainable development and environmental issue

After attending the intervention, what have you learned from each activities

- Landslide prevention project

____

____

- Are we ready for the Flood

____

____

- Drought is coming

____

____

- Waste from the river to ocean

____

____

You may not face some of those issues above before. Why do you need to help solve that environmental problem?

____

____

What is sustainable development

____

____

how can student like you help the globe and environmental to reach sustainable development?

____

____

What do you feel after you learn solving the environmental issue in this programme? (For example, confident, fun, happy, sad, tired)

What if you have a chance to learn and solve the problem from the activity like this again. What problem do you like to solve? And why?

As you are one of engineer team solving the environmental problem, what do you feel about working with your team that contain different jobs?

How the Engineering habits of mind help you solve the problem

----

What have you done today that you think it can help the team when doing group work?

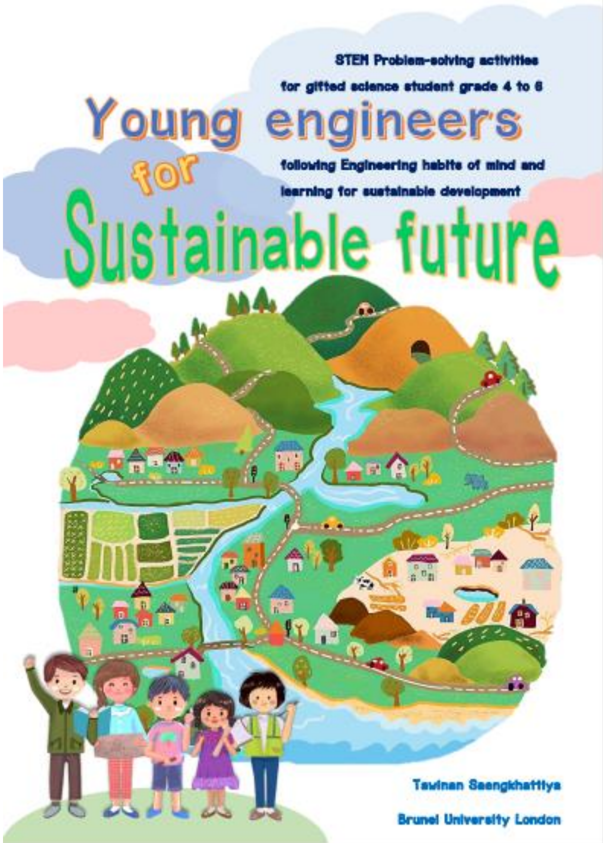
Please tell us what makes your team successful in the mission today?

To improve the mission's outcome, what is your suggestion for the next mission?

Appendix 13: Students' Engineers' Logbook

Questions asking for the reflection of EHoM and SD competencies

Activity	Item (EHoM or *Competence for SD*)
Landslide	1) From your view, why do you think Apple village always face the landslides? (Problem finding) 2) Why the landslides moving through the slope impacts Apple village and villagers? (system thinking) 3) What can you do to help the villagers and make Apple village safe from landslides for the long term? Would you please list the ideas of your team below? In summary, What is the team solutions? (Creative problem solving) 4) From the plan you have made earlier… please list if you applied some change during the construction and why you have made it? (improving) 5) Now, a landslide occurs again!!!! How does your solution work? Please report the result and give short explanation to explain the feeling about the outcome? (Creative problem solving) 6) From the results, something might have gone wrong in your construction!!! How can you improve your solution? (improving) 7) Let's imagines if this really happened. Can your idea be used to save the village? And why? (Adapting) 8) Let's see if another landslide happens. Why or Why not your idea would work for 10 years or more? (Anticipatory competence) 9) What if you can do anything to solve this landslide problem for long-term? What will you do? (Self-awareness)
Flood	1) Please analyse how the situation of Mango city is likely to be? And how it related to climate change? (problem finding/ system thinking) 2) If you live in the Mango City and there is no plan for dealing with flood, what can be occur in the Mango city for long term? (Anticipatory competence) 3) As you are a group of engineers. What are ideas to prevent the flood? (creative problem solving) 4) What is the group decision? (creative problem solving) 5) From the result, How your construction help to prevent flood in Mango City Yes or No, Because? (creative problem solving) 6) What if you can add or develop other system to the flood preparation plan, What do you want to add. (improving) 7) In real life, If there is construction using real world material… do you think your plan can work in prevent flood in long term? (adapting) 8) From the location of mango city and climate change , in your view, what people in the Mango City should do in order to live happily and stay healthy from the impact of the flood? And why (Self-awareness)
Drought	1) from the situation above, with no government helps, what is the problem of Pomelo town? (Problem finding) 2) Circle one of the sectors below and guess what if there is not enough water, what is going to happen in the sector (system thinking) 3) What sector do you choose to construct the water storage system for? and why (Normative problem solving) 4) What is the result (improving) 5) From the result of the test, if you could do to improve the construction, what will you do. (improving) 6) There are many constructions were built for making a better water management system. What is the characteristic of good water management system that may help reduce drought for long term?(system thinking) 7) If you are town people, what can you do in daily life to reduce the drought problem (Self-awareness)
Waste from the river and ocean	1) According to the living things related from eating each other continuously as the food web or food chain. Following this knowledge, Explain how a small debris of snacks were found in the body of a man in the South. (system thinking and visualising) 2) According to the situation of Cocoland in the news… what is the problem of Cocoland at the moment? (problem finding) 3) What are the ideas to reduce the accumulation of the plastic waste like YoiYoi bag in the ocean , in the animal body and human blood? (Creative problem solving) 4) How does the tool work? (creative problem solving) 5) Can the tool collect the waste? To make the better tools. How do you improve your tool ? (Improving) 6) If your tools can be invented with real materials. Is it effective to reduce the problem of plastic waste? And why? (Adapting) 7) there are many tools that used nowadays for manage with waste! Why the problem is still continue. (System Thinking) 8) Can everyone help with this issue? What can you do in term of Ourselves? Society ? Government? (self-awareness and Normative competence)



Young engineers for a sustainable future

Hi, there. Welcome to "**Young engineers for a sustainable future**". This programme is a 1-day intervention developed to learn about sustainable development and solve problems through real-world environmental issues in Thailand. Targeting the missions as a team, you will face four environmental issues: landslides, floods, drought, and plastic waste. Each task comes with motivating challenges for you to find the solutions following a STEM problem-solving approach by adopting the Engineering habits of mind (EHoM) and you will have to create innovative products to tackle the issues.

Each activity has different learning objectives which aim to equip you with knowledge about STEM and different aspects of sustainability regarding UN sustainable development goals. The discussion space will be provided for your team to discuss long-term aspects and let you think about how to behave in daily life to preserve the environment and natural resources for future generations.

Here is the list of missions waiting for you to learn, have fun and find a team solution to the problems which are...

- Landslide prevention project
- Hurry, let's prepare for the flood
- Drought is coming
- A journey of waste, from the river to the ocean

Let get started! All young engineers.

Tawinan Saengkhattiya

Welcome to "Young Engineers" Headquarters

Congratulations!! You are invited to join the young engineers for a sustainable programme. We believe that you are one of the team that can help us, help people and help saving our nations and the planet Earth. We would like to say that your part here is significant and can bring changes to Apple village, Mango city, Pomelo town and Cocoland that are waiting for your solutions. The Government will support you with funding and materials.

Before going to the 4 missions to cope with the environmental issues, you might need to know how the programme works. The rules about how engineers team perform to achieve the goal are listed below.

Engineer team agreement

1. The team consist of 5 different people who work in different jobs regarding STEM (Science, Technology, Engineering and Mathematics)
2. For each mission, you will have to switch roles with your friends.
3. You will mainly help the team following your roles, and when you finish your part, you can help each other.
4. Follow the guideline and feel free to express your idea and discuss with a friend. Be confident that we are sure that you can provide us with loads of ideas for the missions.
5. Be kind, be respectful and be cheerful... then use your knowledge and creativity in the task

Once you are ready... please join the

Let's go

Pre activity: Engineers training for the mission (30 minutes)

The Government is hiring your team for using your knowledge, including STEM or science, mathematics, engineering and technology, and skills regarding problem-solving skills and collaboration skills for solving the problems that occur in Coco Country. The programme consists of four missions that happen in a different part of the Cocoland.

Let's begin by discovering what happened in the Cocoland in two different situation, we assume that you are living in the Cocoland where you have faced the flood in the rainy season this year, and in between, some villages face landslides. When the summertime comes, drought is found around Cocoland, and when you seek freshwater to consume or travel to the beach, the river and the sea are polluted by plastic waste.

Like your friends, their team are also living in the Cocoland but in different circumstance. They can live normally. Their government supplies them with help, and the following year and next ten years, the impact of flood, landslide, drought, and waste pollution has been reduced. They are able to adapt to those lives and become resilient to all disaster. Their lives have changed so much from now.

Listen to how you feel and listen to how your friends feel... then think about what if you live in the other side?

Missions

Mission 1

Landslide prevention project

Learning objectives

- Understand the cause of landslide and the impact of landslide, and determine the situation of the Apple village
- Understand the situation of landslide in Apple village and evaluation the situation if it happens in the real-world
- Identify the solutions, purpose the idea, and create prevention structure with teammates
- Identify and evaluate the short-term and long-term solutions for preventing landslide

Welcome to the Apple village where the first mission is waiting for you. You and your team are required to solve the problem of the Apple village and help the villagers from the landslides issue. There are many things happens during the landslide situation. Let's listen to the villagers' voices from Uncle Boon, Auntie Penny and Grandpa Somsak. Then think about the problem they have met..

Apple Villagers' voice

"The villagers usually suffer from Landslide every rainy season"

Uncle Boon

"Landslide is a nightmare for us. it comes with the muddy - slushy flood that hit our houses, and our cattle were injured as well."

Auntie Penny

"Some years it suddenly hit the Apple village at night. We were unable to move away at that critical moment. Our house is torn apart. However, I don't want to move away from this village because I have lived here since my ancestors."

Grandpa Somsak

Engineers meeting room: Landslide!

From the villagers' voices, you might get some ideas about this issue. In order to create sustainability in the Apple village and help villagers from landslide. Let's discuss together regarding Landslides.

Q: Have you ever heard about the landslide before? How do you know that?

Q: Can you explain what is landslide to friends?

Q: Where is the location that landslide might occur?

Q: What could be the reason for causing landslide?

Before we are going to Apple village. Let's learn more about this issue by listen to the instructor and given information.

knowledge booster tip

Read for more knowledge about disaster at IPST Science book for Grade 6 part 2

Engineer Task: System Thinking and Problem finding

It's now the time to visit the Apple village. Then the landslide is now hitting the Apple village again. Let's observe the landslide phenomena and what happen to Apple village.. Here is the picture of Apple village.

Q.1 From your view, why do you think Apple village always face the landslide issue?

____

____

Q2. .. From the phenomena you have observed, why landiside that move through slope affect Apple village and villagers?

____

____

Engineer Task: Visualising and creative problem solving

At this rate, you may have some idea to help the Apple village.. Let's bring it out!

Q3 What can you do to help the villagers and make Apple village safe from landslides for the long term? Would you please list the ideas of your team below?

- ______________________________________
- ______________________________________
- ______________________________________

Congratulations!!! The engineering team have done so well for this mission.

Good job. Let hands up to show us who take part in giving ideas. drawing the sketch.. build the construction.. and give a hand to friends. The Government have appreciated your help and effort to Apple village.

Mission 2

Are we ready? For the flood

Learning objectives

- Students understand the link of climate change and flood
- Students understand the current situation of flood in Mango city, predict the future flood and seek for long term solutions
- Students understand the impact of the flood on individual, community, and the economy.
- Students identify what can individual and community do to adapt to the life affected by flood by reduce the impact of flood in the future

SOS!! This is an emergency massages from the Mango City which need us for hands and solve the flood problem along with Mango City people. From its geographical position, the Mango City has highly chance to confront with the severe flood. Due to the weather that the amount of rain in rainy season is unpredictable, the heavy rain downpour can cause flash flood and created the forest flood to the city. Also, with high precipitation rate in the city for a very long period, the flood can suddenly occur. The civil engineering has to come up with the idea to prevent the city from that situation.

Engineers meeting room: Flood issue

Before we visit the Mango City and solve the problem, Let's see how we are relevant to the flood issue.

Q: Why we have flood problem?

Q: Why do you think flood is a big problem of Thailand?

Q: Had anyone experience about flood and how you deal with it?

Q: Had you ever seen any solutions for flood before?

knowledge booster tip

Read for more knowledge about disaster at IPST Science book for Grade 6 part 2

instructor will introduce you some scientific knowledge about flood and current situation in Thailand. So, you will learn from those information before working on engineering tasks.

Engineer Task: System Thinking and Problem finding

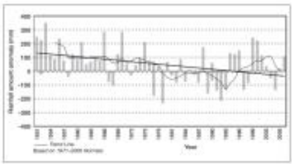
Now the engineers are gathered under the invitation of mayor of Mango City. The Mango City is located in Thailand. Let's go to Meet the Mayor of Mango City, Mr. Tanos.

"Welcome to Mango City, all engineers. I just got the information from the flood monitoring unit. It suggested that next months/ is likely to have heavy rain downpour. As the city had suffered with the floods so many years in different degree which required a lot of money for compensate the living quality and economy. What can the team do to prevent an upcoming flood and the flood for long term?"

Mayor Tanos

Mango City is located alongside the river Candy which is one of the long river in this region. River candy is connected with the other city nearby and with the mainland forest.

here is the graph described annual precipitation rate in the Cocoland which is very similar to Thailand. Mango city is part of the Cocoland.



Source: Department of Meteorology, 2008.

The Mango City's flood information was reported by city council below

Year	Length of rainy period	Date of floods occurring in Mango city	Average precipitation rate (per day) during flood	Water level from the riverbank	Average public fund spent (Unit)
2021	83 days	2-10 June	300 unit	2 metres	4 million
2019	86 days	5 - 20 June	315 Unit	1 metres	3 million
2018	85 days	1 - 10 July	185 Unit	2 metres	3 million
2017	87 days	28 May - 4 June	200 Unit	1.2 metres	3 million
2016	84 days	18 - 22 June	320 unit	1.5 metres	2 million
2015	89 days	20 - 25 June	190 unit	1.8 metres	2 million
2014	95 days	28 June - 3 July	300 unit	0.3 metres	1 million

From the information of Mango City above, please accumulate idea of the team following the questions below.

Appendix 14: Teachers' Observation Form and Observation Guideline

Teacher observation form
Phase 1 School intervention: young engineer for a sustainable future

Teacher name____________________________ School___________________________________
Duration of work_____________ Subject specialist_________________________

Group to observe_________

Observation Guideline

Introduction to research

This study is phase 1 data collection for the research, which studies the development of STEM activities to teach sustainable development, problem-solving, and 21st-century skills. The target group of this research is gifted science students in Thailand at the primary school level. This study evaluates the effect of activity on developing student problem-solving skills and attitudes towards their learning for sustainable development.

The study aims to incorporate environmental concerns into practice at the primary level to promote informal education for sustainable development. In the observation, the teacher is an observer to observe the student's behaviour and verbal and physical expression in various aspects, such as how they engage with intervention, engage in problem-solving intervention, and perform cooperative working abilities during collaboration.

The research outcome will help develop an informal practice for gifted science students to develop a sustainable development mindset at a young age. In addition to this, the activity can offer children more learning opportunities for further development of skills in real-world problem-solving.

Observation protocol: using target student observation in a specific group (5 students in one group)

1. Selected the group to be observed.
2. Observing all those students for a period of 8 minutes for each individual, pause, and then apply this several times during task and off-task with different students.
3. Observing student language, expressing emotion and behaviour, and recording narratively on the observation form based on the aspects listed in the observation criteria
    1. To record their behaviour, try not to interpret the behaviour of the student but to jot down the expression straightforwardly.
    2. To record their conversation that indicates the observation criteria, quotes should be written down as they were said, without adding context or trying to figure out what the child meant.
4. The observation can start from the beginning of the intervention; the introduction is introduced with a scenario and provides some brief knowledge. Following that, students will be asked to do the problem-solving task called 'Engineering Meeting Room' to discuss six aspects of engineering habits of mind, which are: 1) problem identification; 2) system thinking; 3) visualising; 4) creative problem solving; 5) improving; and 6) adapting. They are also joining the sustainable discussion at the end.
5. During the problem-solving and collaboration tasks, the teacher must take a photo to record as evidence. The student will be informed at the introduction of the intervention about the photoshoot, but you must ask them before taking the photoshoot and interrupt them.

Observation criteria

Part	Aspects	Keys behaviour	Signposting for observed
1	Student engagement and enjoyment	Recording students' expression and behaviour showing interest, motivation, enjoyment, or engagement, such as being bored, unmotivated, or ignoring the team task or doing something else.	At the beginning of the intervention, during storytelling, asking general questions, and discussion.
2	Student problem-solving process	Recording students' expression and behaviour during problem-solving following : 1) Problem finding: getting into the problem of the task, exchanging ideas. 2) Brainstorming and finding solutions: getting into the idea to solve the problem 3) Planning: getting into the final solution plan to be followed. 4) Involve in practical work and perform practical work creatively to the plan: getting into the construction and showing the possible solution. 5) Showing the improvement of the idea and/or the improvement of their work Strengthen their analysis and reflective action.	Starting from the problem solving period using the keyword 'engineering meeting room with several tasks such as problem solving tasks, brainstorming tasks, planning tasks, construction tasks, improving tasks, and adapting tasks.
3	Collaboration	Recording students' expression and behaviour that shows the collaborative skills by following: 1) manage their teamwork. 2) asking their teammate for ideas. 3) Share ideas with friends. 4) Listen to their friend's idea. 5) Negotiate their ideas with friends. 6) Help each other do team tasks. 7) Motivate each other to do team tasks 8) Enjoy and maintain a good relationship	Whole intervention with discussion and problem-solving tasks.
4	Intervention qualities	Reflecting the intervention, determining the quality of intervention based on students' expression and behaviour , suitable challenge and problem-solving task, collaborative learning that fits the learning objective, proper knowledge related to the science curriculum, and engagement.	Whole intervention
5	Reflection on intervention	Reflecting towards the instruction for the improvement of intervention	Whole intervention

3.Observation recommendation

1. Stay at least 1 metre away from the student group to ensure space and privacy for students. This is to reduce the pressure on teachers and avoid intrusive data collection.
2. Students have a right not to participate in the intervention and have a right to provide permission for a photoshoot. So, please ask them for permission before taking pictures of children and their innovative products.
3. Do not interact with students, both verbally and physically, as it can interfere with their intervention participation.
4. Consider each child as a person with their own viewpoint, feelings, interests, and socialisation style, as well as their cultural environment, belief system, and values.
5. Make sure you pay attention to children's body language, temperament, and ways of communicating.

Mission 1: Landslide Prevention: Please indicate the evidence and give an example.

1. What is the students' expression or behaviour considering engagement and enjoyment while participating in the instruction part of the landslide intervention?
2. What are the students' expressions or behaviours on the problem-solving task?
3. What is the student? What are students' expressions or behaviours that are considered collaborative skills during the collaboration task?
4. What are students' expressions or behaviours during the 'sustainability discussion'?

Mission 2: Are we ready for the flood? Please indicate the evidence and give an example.

1. What is the students' expression or behaviour considering engagement and enjoyment while participating in the instruction part of the landslide intervention?
2. What are the students' expressions or behaviours on the problem-solving task?
3. What is the student? What are students' expressions or behaviours that are considered collaborative skills during the collaboration task?
4. What are students' expressions or behaviours during the 'sustainability discussion'?

Mission 3: Drought is coming. Please indicate the evidence and give an example.

1. What is the students' expression or behaviour considering engagement while participating in the instruction part of the landslide intervention?
2. What are the students' expressions or behaviours on the problem-solving task?
3. during the collaboration task?
4. What are students' expressions or behaviours during the 'sustainability discussion'?

Mission 4: Waste from the River to the Ocean: Please indicate the evidence and give an example.

1. What is the students' expression or behaviour considering engagement and enjoyment while participating in the instruction part of the landslide intervention?
2. What are the students' expressions or behaviours on the problem-solving task?
3. What is the student? What are students' expressions or behaviours that are considered collaborative skills during the collaboration task?
4. What are students' expressions or behaviours during the 'sustainability discussion'?

Overall reflection of the intervention

1. How appropriate is the intervention that allows the student to have chances to practice problem-solving skills?
2. How appropriate is the intervention that allows the student to have chances to collaborate with peers?
3. How clear and appropriate is the intervention when it delivers the learning objective?
4. How does proper knowledge for learning sustainable development deliver for students?
5. How much of the intervention task connects to the science classroom and fits into the primary science curriculum? Please give some examples.
6. What is the benefit and what is needed to improve this STEM activity to promote learning for sustainable development, problem solving, and collaboration?

Appendix 15: Teachers Interview

Phase 1 School intervention: young engineer for a sustainable future
Teacher interview questions for semi structure interview

Intervention: 1-day programme with 4 environmental problem-solving activities (landslide, flood, drought and Waste from river and ocean)

Participant: Schoolteacher

- 1 -2 teachers with the minimum 1 teacher from each selected school (5 – 10 teachers in total from at least 7 schools)
- They must currently teach science and mathematics courses and teach gifted students in the selected school

Duration: 40 minutes - 1 hour

Objective: to explore teachers' perceptions about Education for sustainable development (ESD), STEM education and ESD-STEM intervention.

Interviewer: Tawinan Saengkhattiya, Doctoral researcher

Interview tools: Zoom application

Session	Topic	Questions
0	General information	Name Background information, such as Education, duration of work, duration of teaching gifted students, and experiences related to professional development
1	Education for sustainable development	Have you heard about sustainable development education? If 'Yes' then ask..... Could you elaborate? Is there any teaching and learning related to sustainability? education in your school. Have you integrated sustainable development education into your teaching? What lessons does it occur in? If 'No', explain the meaning of sustainable development education and ask How do you feel knowing that in other countries, young children learn about sustainability'? Do you think it is important to learn ESD at a young age? Besides ESD, is there any teaching and learning about environmental issues in your school? Please explain the scope of teaching and learning **regarding** that. Is that the whole school approach or a subject-based approach? How **do** you teach students about that topic? Have you applied within a STEM approach? If 'No' Then ask about ESD curriculum within mainstreamed basic curriculum... Is there an environmental element in science subjects?

		Is it possible to adapt your teaching of sustainable development within science content?
2.	STEM problem-solving activities	Could you tell me about STEM activities in your school? Have you ever applied the STEM approach in your class? Could you explain more about that? What do you think are the benefits of this approach? Is there any struggle? How do you learn about STEM activities? Have you ever received any professional development from a school or organisation? What was that about? Was the professional development helpful for you?
3.	The intervention	Have you experienced STEM activities with environmental issues and climate change before? If 'Yes' then ask... Could you explain about that? Do you think it is an advantage or a disadvantage for student learning? If 'No', answer these questions instead. From your observations, what do you think about this intervention? The idea of teaching science or STEM with sustainable development—is it a good idea or not? Do you agree that ESD can be embedded in any subject? Or should it be taught as a separate subject in the curriculum? Do you think it is possible to apply this intervention to the school as an extracurricular activity? Or as a classroom intervention? Do you have any ideas about teaching ESD in your school? Can you teach students with this programme? Would you like to teach students with this programme? What kind of support do you need from IPST?
4.	Collaboration	Do you teach children collaborative skills? What kind of skill do you think it refers to collaborations? What is your technique to increase collaborative skills in class? What is the obstacle you found that affects collaboration among students? What do you think about the collaboration you found in the intervention?
5	Feedback on programmed	What is the positive thing about the programme? What could be improved? And is there any suggestion for using it in the classroom or for further development?

Appendix 16: Students' Reflective Diary

List of Questions in Reflective diary

Aspects	Example of question
Attitude toward the programme	• When thinking about "Young engineers for a sustainable future," do you enjoy the activity? - If yes, what do you enjoy about the activity? And if no, please indicate the reason. • During the past few days, have you told anyone about the "Young Engineers for a Sustainable Future" intervention? • If yes, please tell me what you shared... • Whom did you share with? • Do you think the intervention inspired or made a change in you or not, and how was it? - Have you noticed any changes in your habits since the intervention ended? • What is the change in your habits? please describe..
Perception toward STEM and Self development	• How STEM (Science, Math, Engineering, and Technology) connects with sustainable development • How does "doing STEM problem solving" help you learn science and develop yourself • How does working together to solve problems help you learn and grow? • You have learned the engineering habits of mind. (problem finding, system thinking, visualising, creative problem solving, adapting, and improving). Could you share how it can work in your school life?
Perception toward ESD, SDGs, Environmental issue	• How do you feel when learning science with knowledge for sustainable development • There are more sustainability issues than what you have learned that may be included in STEM activities in the future. - Which of those problems do you want to solve? And why? - Which one interests you the most, and why? • Have you been paying attention to environmental issues while at home? - And what exactly is it about? - Why is it important to educate yourself about global environmental issues? • From the SDGs, you have learned... Which one can you help reach sustainability? Please explain why..
Perception toward their own action at home and community	• Recall what you've learned about floods, drought waste, and landslides. - Which one do you think you should start with to help solve the problem? - How can you begin by addressing the issue at home? - Which of the following is the most difficult to solve, and why? • Think about your home and community. - What behaviours or activities in your family should be changed to improve environmental quality? - Which behaviours should be changed to improve the environment in your neighbourhood? • Do you remember the issue that you have learned about? If you are the prime minister of the country... Which issue do you want to solve first, and what policy do you want to create to tackle those issues?

Appendix 17: Example of Themes Emerging from Pre- Intervention Questionnaires

Pre- intervention questionnaire

Students' Understanding About Environmental sustainability issues

Theme	Subthemes and Codes
Understanding about Environmental issues	**Cause of issues** Landslide • Human behaviours (deforestation) • Nature (earthquake, no tree, gravity, underground hole or burrow, water erosion, heavy rain downpour, force, soil condition, other natural causes) Drought • Human behaviour (issue of water storage system, house structure, deforestation, drainage system • Nature (climate change, forest flood, no tree, the rise of water level, water accumulation, Rain, subsidence, location, global warming. underwater volcano eruption, tsunami) Flood • Human behaviour (deforestation, greenhouse gas emissions, no plantation, no water storage, overpopulations, overused of resources, waste burning, waste in the water and ocean) • Nature (bushfire, climate change, global warming, lack of rain over a period of time or in season, high temperature, low humidity no tree, summer season, soil loses moisture because the water in the soil evaporates Waste in the river and ocean • Human behaviour (industrial factory, no waste management, improper garbage disposal, dispose garbage into water source, generic behaviour) • Nature (wind blows garbage into the sea)
	Impacts of issues Landslide • Environment (animal, ecosystem, forest, soil) • Society (buildings, city and town, people who live in the area, transportation, land damage and decrease the area, Human health and wellbeing, housing, personal asset) Flood • Environment (animal, pathogenic vector, natural resources) • Economy (no people for city movement, no productivity for trading and export, loss money for reconstruction) • Society (damage of infrastructure, food shortage, pandemic disease and hospitality, transportation, trouble for people who live in the area. Disruption of electricity, inhibit professional activity, Human life (Human health and wellbeing, housing, personal asset) Drought • Environment (impact on natural resources and habitat, bushfire, deteriorated soil, dust and pollution, global warming, low humidity, melting ice and glacier, very warm weather, water resources, impact on organisms) • Society (food shortage, low emergency supplied water in the storage, impact at the national level, inhibit professional activity, water shortage, Human health and wellbeing) • Economy (goods price increase, no productivity for trade or export, inflation, reduce the incomes, increase household expense from the rising of electricity bills) Waste in the river and ocean • Environment (natural resources, global warming, organisms) • Society (clean water shortage, source of disease, the city is not suitable for living, no

Appendix 18: Example of Themes, Subthemes and Codes Emerging from Post-Intervention Questionnaires

Post intervention questionnaire

Students' Understanding About Environmental sustainability issues (Landslide)

<table>
<tr><th>Themes</th><th>Subthemes and Codes</th></tr>
<tr><td>Understanding about Landslides</td><td>Knowledge about Landslides
Cause of issue
• General cause
• Human behaviour (deforestation, drilling)
• Nature (rain, plate movement, gravity, no tree, water erosion, slope area, soil condition, geographical location)
• Human and nature

Impact of issue
• Environment
• General impact
• Impact on economy
• Impact on people life (housing, personal properties, life threatening)
• Impact on society (destroyed the village, affect people in the area, affect transportation, affecting people's profession

Solutions
• Change the direction of landslide
• Construct the preventive structure (create the ditch, decelerator structure, stone wall, the protective barrier, mulching concrete, earth anchor)
• General solutions (use stronger equipment, use things in everyday life, should be applied in the situation)
• Other countries' solution
• Protect the environment (avoid deforestation, plant the three to protect the soil, avoid mountain drilling, surface improvement)
• Reduce the force of landslide
• Select the location that are safe from landslide (encourage the villager, keep distance between each house, keep house away from the mountain)
• Find sustainable solutions

General knowledge
• Function of tree roots for preventing landslide
• Characteristics of soil when landslide happened

Attitude toward the issue
• Problem is bigger than expected.
• It is urgent to solve problems</td></tr>
</table>

Appendix 19: Example of Themes Emerging from Students' Engineers Logbook

Example of Themes form Engineers' Logbook (From Photo and Drawing)

Practicing EHoM

EhoM: Visualising	**Activity 1 Landslide (From Photo and Drawing)** **Solutions for Landslides** • Preventive barrier (at the back of village, at the base of mountain, on the mountain, between village and mountain, around the houses, unclear position) • Type of preventive barrier (low height barrier, leans toward the mountain, lean away from the mountain, sparse in different positions, layers on the floors, barrier with supportive structure, upright barrier, cotton barrier, rope pulling barrier) • Other structure (Soil reservoir, bunker) • Village composition (Soil, houses, village area, steep mountain, cars • Houses relocation (no house, one row, unidentified pattern, two vertical rows, two vertical rows with space in between, two horizontal rows, three vertical rows, four rows, unclear relocations, no relocations) **Design perspective** • 2D only • 3D only • Mixed of 2D and 3D figures • Type of 2D figures (barrier, soil, houses, mountain) • Type of 3D figures (village area, barrier, houses, mountain) **Annotation** • Indicate materials use (string, tape, glue, foil, cotton, straw) • Indicate other components (soil, village, mountain, houses) • Indicate type of barriers (barrier, tree, bunker) • Type of materials (one or two materials, three to four materials, more than four type of materials) • Details of materials (no indication of materials, provide some materials, provide detail of all materials) • Others (number of materials use, indicate real life materials, indicate construction method, indicate the benefit of structure, indicate the situation, indicate the benefit of materials)

Appendix 20: Example of Themes Emerging from Teachers' Observation Form

Teachers' Observation Form

Students' engagement during discussion for SD

Themes	Subthemes and Code
Students' engagement during the discussion for sustainable development	**Activity 1 Landslides** Behavioural engagement • Positive (sharing idea, answering questions, asking questing, enthusiasm) Emotional engagement • Positive (happiness, interesting, enjoyment) **Activity 2 Flood** Behaviour engagement • Negative (play with others, talk with each other, got distracted) • Positive (equipment management, participate in discussions, share ideas, answer the questions) Emotional engagement • Positive (pay attention to the activities content, enjoyment) **Activity 3 Drought** Behavioural engagement • Negative (play with others, drawing something) • Positive (discussing and sharing ideas, answering questions, interest to what member present) Students expressions of knowledge and awareness for sustainable development • Giving reason related to economics, society and environment • Discussing for better solution, • Discussing solutions in real situation **Activity 4 Waste in the river and ocean** Behavioural engagement • Negative (some member did not participate, playing during the discussion, talking with others) • Positive (Discussion and share idea, pay attention to the activity, listen to the discussion, raise a hand to answer questions) Emotional engagement • Negative (getting tired, dissatisfaction with other, less enthusiastic) • Positive (sharing idea and discussion, answering questions)

Appendix 21: Example of Themes Emerging from Teachers Interview

Teacher Interview

Teachers' perceptions of SD and ESD

Themes	Subthemes and Codes
Teachers' perceptions of SD and ESD	**Concept of Sustainable development** • Related to social (about the lives of the people, housing development, agriculture, quality of life) • Related to environmental (resource utilization and resource substitution) • Related to economy • Related to social and environment (relationship between humans and the environment) • Related to social, economy and environment (sufficiency economy theory') • Related to solving problem (solving problem for long term) • Teaching and learning (hands on learning, provided education from early childhood, promote students with long term knowledge, apply knowledge throughout life) • Outcome of development (benefit of current generation and future generation, continuously development and secure future) • Relate to political (government policy) **Teacher perception about ESD** • Understanding about ESD (teaching in high school, never implement in teaching, perceive from training, concept, no relevant to science and mathematics, related to social subject, related to environment and nature, curriculum is not clear, depends on the teacher, it is the subject taught that will lead to sustainable development, rarely teach in school (especially with science subjects), • Lack of knowledge about ESD (knowledge about ESD in details and teaching process, knowledge about teaching student for sustainability) • No knowledge about ESD

Appendix 22: Example of Themes Emerging from Students' Reflective Diary

Students' Reflective Diary

Students' perceptions of environmental issue

Themes	Subthemes and Codes
Students' Perception of environmental issue	News related to environmental issue students have followed? • Climate change and Global warming • PM2.5, • Fire, Provincial event, • National events • Waste issue • Landslide • Polluted water. • Flood, • Drought, • Food shortage, • Low agricultural productivity
	Issues that are difficult to solve • Waste on land and waste in rivers and ocean (the complexity and difficulty, people behaviour issue, communication and collaboration needed) • Landslide (Students lack of competent, budget and construction required, the complexity and difficulty, Related to human's behaviour) • Flood (the complexity and difficulty of the issue, collaboration needed, relating in to global warming, the capability of community to solve the issue) • Drought (Related to human's behaviour • , the complexity and difficulty, equipment, water management, people awareness and collaboration)
	Solutions that you can help starting at home • Solution to waste issue (promote how to manage waste, waste sorting, waste management, Reuse, reduce, recycle) • Solutions to the drought (water storage, save water • Efficient use of resources • Consulting community leaders to create policies • Formulating solutions

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