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Integrating Sustainability Competencies into Engineering Curricula: Jordan as a Case Study

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***Abstract*—As a result of increasing environmental, social and economic issues, integrating sustainable competencies into Engineering education has become a worldwide priority. In many developing nations, sustainability is still considered a peripheral issue in relation to an engineering program's essential competencies, as seen in many engineering programs. The purpose of this paper is to present a structured framework for integrating sustainability competencies into engineering curricula, using Jordan as a case study. Based on the collaborative experiences of multiple public and private universities in Jordan, the framework will emphasize the design of competency-based curricula, faculty capacity-building, interdisciplinary pedagogy and systematic assessment of learning outcomes. The framework will outline how to integrate sustainability concepts into core engineering courses, project-based learning and applied laboratories and how the framework can be adapted to various institutional and professional contexts. Through the use of this study, sustainability literacy will be developed into outcomes-based engineering competencies that can be measured and acted on, and provide an infrastructure to develop a scalable approach for similar regional and global engineering programs.**

Keywords: Sustainability Competencies; Sustainable Development Goals; Engineering Curriculum; Education for Sustainable Development; Competency-based Learning

I. Introduction

Sustainability is widely regarded as one of the main issues of the 21st century, primarily due to rapid climate change, environmental degradation, resource depletion, and widening social inequality, which has resulted in a growing demand from higher education institutions to prepare graduates who can meaningfully contribute to sustainable development through professional practice, innovation, and ethical decision-making. International policy documents highlight the crucial role education plays in achieving sustainability-related goals and support the approach to developing competencies related to sustainability that emphasizes the application of knowledge [1] [2].

Engineering plays a critical role in facilitating the transition to sustainability by providing systems that support energy generation, water, transport, digital infrastructure, and industrial activity. Consequently, engineering graduates must possess strong technical abilities as well as sustainability-related competencies, including systems thinking; ethical reasoning; interdisciplinary collaboration; and assessment of long-term environmental and societal impact [3] [4]. Currently, these competencies are generally viewed as essential outcomes of modern-day engineering education [5].

Despite this recognition of the importance of sustainability competencies, many engineering programs continue to consider sustainability as a topic separate from or unimportant to engineering practice; typically, sustainability-related content is located in stand-alone courses, electives or other, unstructured methods of delivery and is often not integrated into core engineering learning experiences. Common barriers to effective integration of sustainability-related content into engineering curricula are reported by research studies in engineering education, including overloaded curricula, the inflexible nature of most programs, the inadequate preparation of faculty members, and the lack of appropriate mechanisms for assessing learning outcomes related to sustainability [6] [7].

Jordan serves as an excellent case study for understanding this challenge. Like many developing countries, Jordan faces a myriad of pressing issues with sustainability, including water scarcity, energy security, and high-tech urban development. The Government of Jordan has demonstrated its commitment to achieving sustainable development. However, the challenge of integrating sustainability competencies across the engineering curriculum is ongoing. This paper attempts to address this challenge by introducing a systematic framework for integrating sustainability competencies into engineering curricula, with Jordan as a case study. Specifically, this framework emphasizes developing a competency-based curriculum, building faculty capacity, utilizing interdisciplinary pedagogy, and assessing and demonstrating learning outcomes, providing a scalable model for engineering programs that need to integrate sustainability-related competencies in similar contexts.

II. Sustainability Competencies in Engineering Education

Over the past two decades, sustainability education at the postsecondary level has shifted from being viewed as a conceptual or awareness-driven approach to an attribute-driven one, whereby students are cognitively competent in their understanding and skills in relation to sustainability and can demonstrate measurable outcomes associated with those competencies. Competencies related to sustainability may be defined as collections of knowledge, skills, values and attitudes that provide individuals with the ability to make contributions to sustainable development [3], [8]. The Wiek et al. Model [3] has emerged as one of the more influential competency frameworks for sustainability education and identifies five competencies: Systems Thinking, Anticipatory Competence, Normative Competence, Strategic Competence and Interpersonal Competence. Following the publication of the Wiek et al. Model, subsequent scholarly work has refined and clarified how these competencies should be defined and defined the need for longitudinal, discipline-specific learning outcomes that students can develop in academic programs [9], [10]. Other policy-level competency frameworks, such as the European Commission's GreenComp [11], [12] have further defined the operationalization of sustainability competencies by categorizing them into various domains that describe Values, Complexity, Future-Oriented Thinking and Action-Oriented Engagement. While these competency frameworks provide vital guidelines for educational planners, the framework will need to be contextualized for both engineering education and the integration of sustainability competence into engineering curricula. As compared to many other degree programs, engineering education presents unique challenges with regard to integrating sustainability competence into existing curricula. Engineering programs generally emphasize discipline-specific technical content, meaning there is often little to no opportunity for faculty to deliver interdisciplinary or competency-focused learning experiences. Faculty support in regard to sustainability issues is inconsistent, with many faculty lacking the requisite knowledge and expertise to effectively assess or even address sustainability when teaching. In addition, through a traditional assessment process, Faculty members tend to assess and evaluate students' technical problem-solving capabilities first, and consider sustainability or society as secondary elements of evaluation [6], [13]. As a result of this lack of focus, sustainability competencies are considered more as "buzzwords" rather than being clearly defined as measurable learning outcomes. The research shows that the most effective means of developing sustainability competencies are through the use of experiential or participatory pedagogies such as project-based learning, case studies, design challenges and interdisciplinary teamwork [14], [15]. When sustainability competencies are integrated within and across multiple courses of study and not defined through a single course, students are better able to correlate their learning of sustainability and engineering practice. However, to facilitate the implementation of these teaching strategies, educational institutions will need to support the development of faculty and the development of coherent assessments that are clearly aligned with defined competencies [9], [16].

III. Case Context: Engineering Education and Sustainability in Jordan

Jordan's method for higher learning includes a wide variety of options between public and private universities which have specialized disciplines in engineering. There are many sub-disciplines of engineering, including civil engineering, electrical engineering, mechanical engineering, computer engineering, and software engineering. Engineering programs have historically been centered around providing a high level of technical knowledge to students, mandated by accreditation bodies, and the ever-changing job market. In conjunction with this, the importance of sustainability has been emerging as a key proponent of higher education policy and institutional strategies worldwide. Global calls to integrate sustainability within the structure of higher education to support the processes of teaching, learning, and institutional practice have been on the rise [1], [2].

Although the integration of sustainability principles into engineering education is becoming commonplace in many regions, at the same time, studies conducted in different national contexts suggest that although many educational institutions support the theory and value of sustainability, many do not have a well-defined methodology for the incorporation of sustainability competencies into the overall curriculum and the evaluation of students' learning outcomes relative to those competencies [6], [17]. A similar experience is evident in Jordan. Although many institutions include materials related to sustainability as part of their general education requirement or through extracurricular activities, sustainability principles have not yet been systematically incorporated into the core curriculum of engineering studies.

Jordan's current economic and environmental sustainability concerns constitute a valid rationale for the incorporation of sustainability competencies into its engineering training programs. Areas such as improved energy and water efficiencies, greater deployment of renewable energy sources, waste management, construction projects that are performed sustainably, and responsible digital transformation directly relate to engineering and the day-to-day practice of engineering. To prepare engineers to be able to respond to these current sustainability-related concerns, engineering programs must offer curricula that will link the technical components of engineering and the competencies associated with sustainable practices and ethical behavior [4], [18].

This paper will provide a case study of how Jordan can develop a practical framework for the incorporation of sustainability competencies into its engineering training programs, based on multi-institutional collaboration. This framework will define sustainability competencies in terms of program-level learning outcomes, define methodologies for the incorporation of sustainability competencies across the required core courses and applied learning experiences, enhance and build capacity among faculty members, and enable an ongoing process of identifying a program's specific sustainability competencies and evaluating their effectiveness [9], [16], [19].

The proposed framework draws on the experiences gained through several national and international initiatives that have focused on sustainability and the Sustainable Development Goals within Jordan, including previous studies that focused on stakeholder engagement and the development of policies to implement and sustain initiatives related to sustainability as well as previous initiatives that were collaborative in nature with international partners.

IV. A Framework for Integrating Sustainability Competencies into Engineering Curricula

A clearly defined framework is needed by all engineering programs in order for sustainability to go from being considered as a 'nice to have' to becoming a core educational outcome. This study presents a framework that integrates sustainability competencies into the design of curriculum and pedagogy for engineering education, based on previous research in engineering education and multiple sustainability competency models. This framework has four layers, which integrate sustainability competencies, curriculum design, pedagogy, and how evidence of student learning is assessed. Additionally, this framework is designed to work across all disciplines, and will be scalable and adaptable to different types of academic institutions while remaining relevant to today's engineering education system in Jordan.

A. Sustainability Competency Layer

The first aspect, the development of sustainability competencies, describes how the overall framework has been constructed mainly through the explicit establishment of sustainability competencies relating to intended Learning Outcomes (LOs) at a program level, based upon existing sustainable education frameworks and competency models including the competency models developed by Wiek et al. and subsequent refinement work [3], [9]. This layer includes the establishment of a set of core competencies related to engineering education. The Core Competencies are as follows:

- Systems Thinking Competence - enables students to identify and evaluate Complex Engineering Systems and understand the interaction between engineering systems, environmental systems, and social systems.
- Anticipatory Competence - assists with assessing the impact of engineering solutions over time, risks, and long-term predictive scenarios.
- Normative/Ethical Competence - promotes making responsible decisions based upon sustainability values, ethics, and social responsibility.

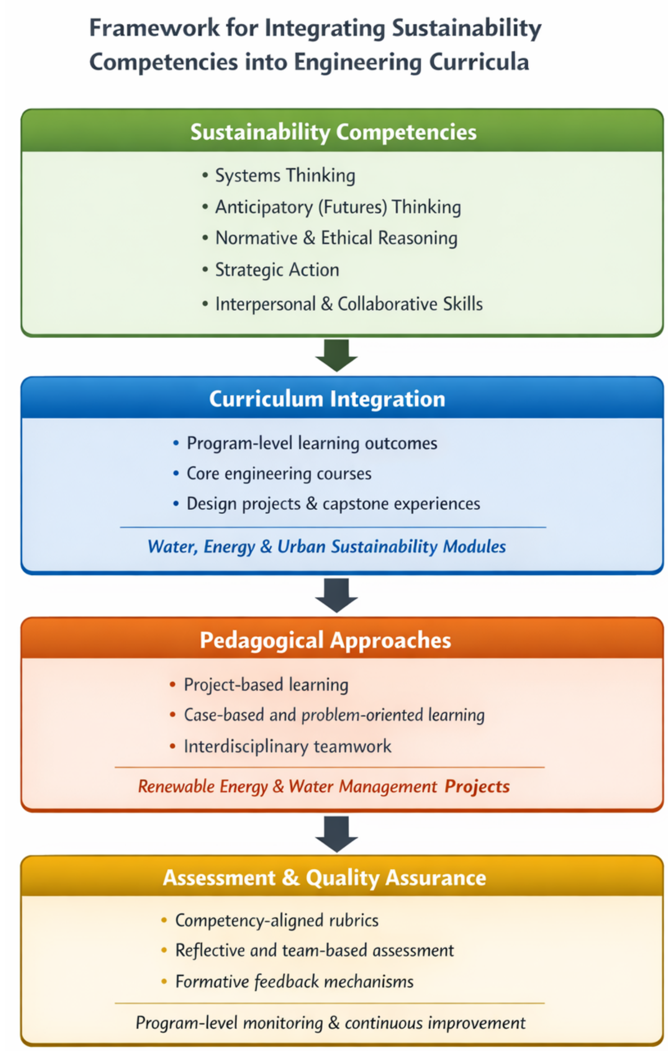

Fig. 1. Conceptual framework illustrating the alignment between sustainability competencies, curriculum integration, pedagogy, and assessment in engineering education

- Strategic Competence - enables students to create and implement sustainability-related engineering interventions.
- Interpersonal Competence - supports teamwork, collaboration, and stakeholder engagement in a multi-level interdisciplinary context.

The core competencies will be established at a level that allows them to be translated into program level LOs and mapped to course-level objectives. The core competency models must be explicitly articulated and defined in order to prevent the implicit and fragmented incorporation of sustainability in engineering curricula [6], [13].

B. Curriculum Integration Layer

The operationalization of sustainability competencies within engineering curricula is done in the second layer of this framework. Rather than introducing sustainability competencies as separate courses, the framework focuses on the integration of sustainability competencies horizontally and vertically throughout the curriculum [7], [16]. The horizontal dimension describes how sustainability competencies are integrated across multiple courses delivered during a specific academic year, whereas the vertical dimension describes how sustainability competencies are reinforced and deepened through continued study over successive academic years. Core engineering courses (e.g., mechanics, circuits, programming, design) provide the main integration points for sustainability-related learning outcomes and engineering technical content. For instance, design courses may introduce systems thinking through lifecycle analysis. Ethical competence is introduced to students through a number of decision-making exercises, such as engineering economics and project management, which are part of the learning process. In addition, capstone projects and final-year design experiences are important because they allow students to combine technical knowledge from UI with sustainability competencies to solve real-world problems [14], [15]. This ability to integrate sustainability competencies at a curriculum level ensures that sustainability competencies are not viewed as an addition but rather as an integral part of the education process that develops simultaneously with technical ability.

C. Pedagogical Layer

Analyzing the third layer of the framework, it is evident that the pedagogical strategies implemented by educators to build skills and knowledge about sustainability constitute a pivotal point in the overall application of sustainable competencies. Research has continually demonstrated that traditional lecture methods do not adequately promote the development of higher-order cognitive skills, such as critical thinking and ethical reasoning [6], [9]. Therefore, the framework advocates for the use of systems centered and active learning methodologies, including:

1) Project-Based Learning (PBL), where students develop solutions to real-world issues by incorporating issues surrounding sustainability.
2) Case-Based Learning (CBL), where students engage in case study activities of industry and discover how to evaluate trade-offs and ethical issues relative to sustainability.
3) Interdisciplinary Teamwork (ITT), where teams of students participate in cross-disciplinary projects that support the development of their skills in an integrated manner.
4) Problem Oriented Laboratories/Design Studios (POL/DS), where theoretical concepts are applied to real-world issues related to sustainability.

The aforementioned instructional methodologies will allow students to interact with issues related to sustainability as a 'real' engineering problem, rather than simply a theory. Further, the methodologies will create opportunities for students to align their expectations of their learning with how they will perform the activities required to complete the assignment, which ultimately provides a framework for meaningful validation of the students' work [10], [14].

D. Assessment and Quality Assurance Layer

Assessment of how well students have developed competencies for sustainability is the fourth layer of the proposed model and is one of the most difficult parts of creating a sustainable education program. Current approaches to assessing students in engineering education primarily evaluate the technical accuracy and numerical correctness of the students' work, therefore it would be impossible to evaluate competencies such as ethical reasoning and systems thinking with traditional approaches [13],[17]. The proposed framework creates a constructive alignment of competencies, activities and assessments as a method to ensure the competency is assessed properly [10]. The following types of assessment may be appropriate for sustainability competencies:

- Design project report rubric-based assessments explicitly aligned to sustainability competencies
- Reflective assessments that address ethical reasoning, stakeholder considerations and long-term impacts.
- Team assessments to evaluate interpersonal and collaborative competencies.
- Development-of-competencies formative assessments for instance through self-assessment peer assessment instruments.

At the program level, aggregated assessment data allow for tracking student progress toward achieving sustainability-related learning outcomes and developing curriculum improvements. In addition to providing an avenue for ensuring continuous improvement for quality assurance for engineering institutions, this function also provides an opportunity for institutions to learn how to integrate evidence-based sustainability into their education program better [9], [16], [17].

E. Integrated Framework Overview

The proposed framework presents a clear framework for tracking the development of sustainability competencies to the measurable learning outcomes which result from an engineering education program. The relationship between each of the four components of the framework is illustrated by Fig. 1 and illustrates that sustainability competencies are directly impacted by the availability and effective alignment of curriculum, pedagogy, and assessment strategies within the engineering curriculum. Fig. 1 is also a conceptual visual representation of how sustainability competencies may be integrated into engineering curricula, supported by appropriate pedagogy, and assessed through aligned methods.

V. Implementation in Jordan: Case Evidence and Examples

This section demonstrates ways to implement the framework proposed in Fig. 1 within Jordanian engineering curricula by using defined competencies within curricula, designed pedagogically and assessed. Implementation reflects collaboration across Yarmouk University, Hochschule Bonn-Rhein-Sieg, Brunel University London, University of Petra, and Al-Ahliyya Amman University and demonstrates a direct relationship to Jordan's sustainability priorities (water security, climate action and waste/resource management) as expressed in national policy [21]–[24].

A. Competencies to Program Outcomes

Based on recognized sustainability competency frameworks [3], [9], five competencies are handed down as learning output for engineering programs:

- Systems Thinking involves looking at engineering systems as socio-technical systems (e.g., water–energy–food–urban linkages)
- Anticipatory Thinking involves looking at future risk/scenario assessment using climate/resources constraints.
- Normative Ethical Reasoning involves justifying trade-offs based on sustainability values engineering ethics.
- Strategic Action involves developing/ implementing workable (technical governance/current) solutions.
- Interpersonal Competency involves working with stakeholders and effectively communicating decisions with transparency.

These outputs can be tied back to national priorities in Jordan, for instance, the National Water Strategy (2023-2040) for Jordan highlights water security as a requirement of climate pressure and governance limitations. So this documents provides an authentic basis for systems and anticipatory outcomes [21], [22]. The National Climate Change Policy (2022-2050) also supports the anticipation and strategic competencies through cross-sector mainstreaming of climate action [23], [24].

B. Curriculum Integration Examples

The emphasis in organizing the course implementation process should be placed on how students will develop their competencies through horizontal and vertical integration rather than merely creating a "Sustainability" course that teaches these competencies [7], [16]. Examples of how the sustainability competencies align to specific areas of knowledge within standard engineering curricula can be created from the following:

1) Core courses (embedded outcomes): :

Thermodynamics / Energy Systems:
Include clear learning objectives for energy efficiency, integration of renewable energy, and life cycle trade-offs on designs; incorporate national climate policy objectives into your design constraints as they relate to those learning objectives [23], [24].

Environmental / Water Engineering (Civil/Chemical):
Connect course content to National Water Security and Demand Management themes; utilize the National Water Strategy to provide additional context when providing case study analyses [21], [22].

Programming / Data Analytics (Computer/Software)
Integrate sustainable digitalization outcomes, i.e., construct designs that consider energy efficient computing, utilize data-driven methods of monitoring energy usage (i.e., leakage detection, forecasting energy needs), and apply ethical data usage principles.

2) Design spine and capstone projects (competency synthesis):: As described in [14],[15], capped roofs have the highest availability to be used as an integration central point. The following Capstone theme examples will apply to Jordan:

- Implement technology to allow for non-revenue water reduction using sensor networks, anomaly detection and pressure management systems in accordance with [21] Water Strategy priorities.
- Integrate PV with demand management technologies (i.e. microgrids, optimisation and forecasting) as required by [23] Climate Policy direction.
- Establish systems for separating/recycling waste and tracking/displaying the data in accordance with [24] National Waste Sector Action Planning and Data Collection requirements.

3) "Micro-modules" across years (low-friction integration):: The introduction of 2–3 week micro-modules built into existing programs can help reduce the effects of curriculum overload by allowing programs to strengthen the vertical progression through the integration of new competencies, while not requiring the program to completely restructure its study plans. Examples of such micro-modules could include "Engineering Decisions Under Water Scarcity", "Carbon Aware Design", and "Circular Economy in Material Selection".

C. Pedagogical Examples Grounded in Jordan

As competencies are developed through practice and implementing active pedagogies provides the greatest opportunity for students to practice developing these competencies [6],[14]:

Project-based learning (PBL):

- Mini-projects using the water-energy nexus are one example of how active pedagogy can help students understand relationships among various aspects of environmental systems. In the mini-project, students have the opportunity to evaluate trade-offs relating to how much energy it takes to pump water, how much water is lost during the pumping process, and costs related to both [21],[22].
- With climate resilience design challenges, students use Future Climate Conditions based on National Climate Policy to develop a new design for an existing infrastructure component such as a building's drainage, or a building's exterior wall) as part of their project/pedagogy [23],[24].

Case-based instruction (Jordan-specific cases): In both waste composition and circularity projects, students analyze what sustainability mechanisms could work best within specified geographical limits and create recommendations for stakeholders to implement in their municipal waste management practices [24].

D. Assessment: From Competencies to Measurable Evidence

The practical challenge associated with evaluating competencies within Engineering Programs on a consistent basis is substantial [13], [17]. The implementation of aligned assessments for each competency through Constructive Alignment (i.e., constructive alignment) [10] allows for competency indicators to be associated with observable evidence of competency development.

1) Competency-aligned rubrics (capstone + design projects):: For example, a single rubric may have rows aligned to each of the five competencies (Systems, Anticipatory, Normative/Ethical, Strategic, and Interpersonal), with levels of performance ranging from Emerging, Proficient, Advanced, etc., as defined below. The following are examples of observable evidence of competency attainment:

- Definition of explicit system boundaries and existence of feedback loops (evidence of systems thinking)
- Comparison of different scenarios and management of uncertainty (evidence of anticipatory)
- Justification of trade-offs considering stakeholder impact (evidence of normative competency)
- Creation of a roadmap outlining how to implement the plan and establishing constraints within which to operate (evidence of strategic competency)
- Evidence of a collaborative environment and effective communication with stakeholders (evidence of interpersonal competency)

2) Reflective briefs and ethical justification memos:: In response to these questions, you will complete a short structured reflection (1 to 2 pages) that will assess both your Recognized Normative Competence, as well as your Professional Responsibilities. Therefore, as you write your response to the above questions, consider: "What are my trade-offs?," "Who benefits or loses by my decisions?," and "What makes my decisions defensible?"

3) Program-level monitoring (quality assurance loop):: Aggregate rubric data across multiple courses may be used to facilitate a curriculum review (e.g., determining which outcomes are underdeveloped and/or will have lower end results and at what year may these be found within a course). Such data may also serve as part of a continuous improvement process (i.e., avoiding "one-offs") to support future sustainability work [16][17].

E. What the Jordan Case Adds

Aggregate rubric data across multiple courses may be used to facilitate a curriculum review (e.g., determining which outcomes are underdeveloped and/or will have lower end results and at what year may these be found within a course). Such data may also serve as part of a continuous improvement process (i.e., avoiding "one-offs") to support future sustainability work [16][17]. The framework presented here also builds on data that have previously been collected and compile from Stakeholder-Driven Studies that have taken place in Jordan which documented GCC Competency Gaps and GCC Curriculum Overload, while providing strong motivation on the part of the Faculty and Students to Integrate SDG Competencies within all Engineering Programs.

Fig. 2 summarizes mean student competency scores (0–100) across curriculum modules against the UNESCO sustainability competencies, showing broadly consistent performance clustered in the low-to-mid 70s with moderate dispersion (±6–9). Across modules, Systems and Strategic tend to score slightly higher than Normative and Interpersonal, which may indicate that the curriculum more strongly reinforces systems framing and action planning than values-based reasoning or stakeholder-oriented skills. The comparatively uniform pattern across technical modules and capstones also suggests that competency development is distributed across the program rather than being isolated to a single "sustainability" course, although the small differences may still reflect how each module emphasizes assessment types and teamwork intensity.

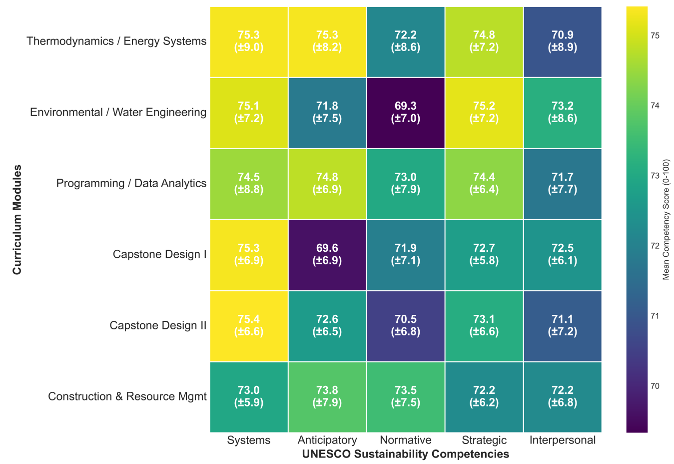

Fig. 2. Module-by-Competency Heatmap of Mean Sustainability Scores (±SD)

Fig. 3 shows a consistent, near-monotonic rise in competency evidence scores across the five-year pathway, with most domains approaching or crossing the 80% mastery threshold by Years 4–5; systems thinking lags slightly relative to strategic and interpersonal growth, which may indicate that integrative reasoning matures later or is assessed more stringently than skills supported by repeated team-based and decision-oriented activities. The narrowing uncertainty bands toward Year 5 also suggests more stable performance as students encounter repeated rubrics, clearer expectations, and cumulative exposure to WEFE-centered design tasks across modules.

Fig. 4 visualizes the modeled response surface for Strategic competency as a function of digital intensity and WEFE integration, with observed project/student points overlaid, indicating a generally increasing trend toward higher strategic scores at higher digital–integration combinations. The spread of points around the surface and the shaded bands suggest non-negligible variability, implying that contextual factors (e.g., team composition, assessment design, or implementation setting) likely modulate performance beyond the two predictors alone.

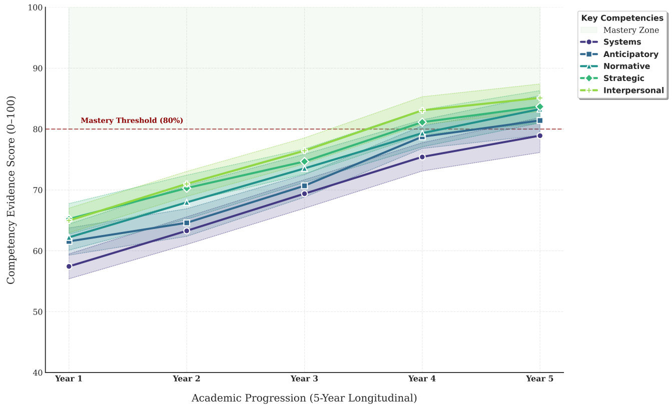

Fig. 3. Longitudinal Growth of Sustainability Competencies Across the Curriculum (Years 1–5)

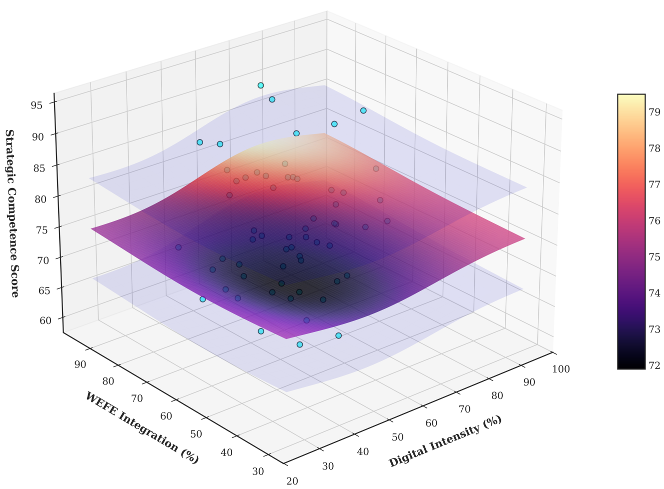

Fig. 4. 3D Response Surface of Strategic Competency vs. Digital Intensity and WEFE Integration (Observed Data Overlay)

VI. Discussion, Limitations, and Future Directions

The present study demonstrates that sustainability competencies can be systematically integrated into engineering curricula through the use of explicit learning outcome statements and integration with course structure, pedagogy, and assessment policies. The proposed framework uses Jordan as a case study to illustrate how national sustainability priorities—specifically water security, climate action, and resource management—can provide guidance for meaningful Engineering education practices. The primary benefit of the framework is its focus on constructive alignment across competencies, courses, learning activities, and assessments, which allows for the movement of sustainability from an abstract goal to a tangible educational outcome.

Though the framework was developed based on multi-institutional academic practices, the proposed work does have several limitations. The study is focused on developing curriculum design and implementation examples instead of on longitudinal measurement of student learning outcomes, nor does the paper make any claims of providing causal evidence of competency acquisition over time. In addition, implementation depth may differ between engineering disciplines and institutions because of variations in curriculum structure, readiness of faculty, and resources available. However, these limitations are not unique to the Jordanian context; many challenges reported with integrating sustainability into engineering education are common to all regions.

Nonetheless, the framework represents an approach that is scalable and context-sensitive for integrating sustainability competencies into engineering programs. The emphasis on incorporating sustainability competencies into existing courses or incorporating them into capstone experiences (instead of adding additional courses) reduces barriers to implementing sustainability while meeting accreditation and institutional requirements. The Jordan case also shows that sustainability integration will be more effective when it is linked to locally relevant engineering problems, allowing for significant potential transferability to other areas facing similar sustainability pressures.

Future research will include systematic assessments of student learning outcomes from acquiring sustainability competencies, including the production and validation of evidence-based assessment instruments; and longitudinal studies on student competency development over a program of study. Future projects will also include examining discipline-specific adaptations of the framework; the role of professional bodies in supporting sustainability competencies; and using digital tools and data-driven approaches to create an engineer's mindset for sustainability, in order to make a meaningful impact.

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