



# LogicGate: A Student-Centred Digital Game-Based Learning Experience

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## Abstract

Although there are many digital educational games, few are designed to fully support and deliver a comprehensive student-centred learning experience. This study develops and evaluates a digital game-based learning experience, designed using the Student-Centred Experience Framework, focusing on how effectively it delivers core student-centred learning principles, enhances student experience, and supports academic performance. A counterbalanced, within-subjects, mixed methods design was used. Thirty-two undergraduate computer science students participated in groups within a simulated classroom environment. Students completed LogicGate, a multiplayer experience designed to teach Boolean logic concepts, and an equivalent paper-based task presenting the same logic circuits. Quantitative outcome measures included the Course Experience Survey, eGameFlow survey, and a custom knowledge test. Qualitative measures included thematic analysis of focus groups and content analysis of open-ended survey questions and voice/text communications during gameplay. Survey results indicated statistically significant differences favouring the LogicGate learning experience over the traditional task for Feedback and Autonomy in eGameFlow, indicating enhanced delivery of student-centred learning tenets linked to these constructs. No significant differences between learning experiences were identified for other constructs after adjustment for multiple comparisons, suggesting non-inferiority of the LogicGate experience to traditional tasks in these other areas of student-centred learning. Qualitative data indicated student experience was positive, particularly the peer learning aspects which are considered a core aspect of student-centred learning, but improvements could be made to onboarding, difficulty, and preparing students for team-based activities. There were no significant differences in student knowledge gain between learning experiences. Developing an experience that includes all aspects of student-centred learning is practical, as effective as traditional tasks, and students particularly enjoy and value peer collaboration in such an experience. However, maintaining an appropriate level of difficulty for disparate groups is a challenge. Addressing student feedback in subsequent versions could support wider deployment.

**Keywords** Digital education · Video games · Student-centred learning · Game-based learning · Serious games · Game design · Higher education



# 1 Background

Student-centred Digital Game-based Learning (SCDGBL) refers to the practice of designing and developing video games based on the pedagogical practice of Student-centred Learning. Research in this area focuses on delivering Student-centred Learning (SCL) experiences for students via the use of digital educational games, the latter being a concept that is commonly referred to as Digital Game-based Learning (DGBL). SCDGBL integrates Student-centred Learning (SCL) methods used across educational levels (Rohrbeck et al., 2003; Wright, 2011) with digital video games, providing an alternative to traditional educational approaches. According to Attard et al. (2010), SCL is a constructivist-based educational model emphasising active student engagement, collaboration with educators and peers, and the development of essential skills such as problem-solving and critical reflection. Greater incorporation of SCL into Digital Game-Based Learning (DGBL) can enhance educational outcomes and advance students' Information and Communications Technology (ICT) competencies (Del Blanco et al., 2010; Samaniego Erazo et al., 2015).

Building upon foundational work by early advocates, like Baltra (1990), it is suggested that digital video games may have the potential to effectively support SCL by aligning DGBL principles, such as *Player Identity*, with core SCL objectives, including *Deep Learning* and *Understanding*, both in and beyond classroom settings (Gee, 2005; Lea et al., 2003). Gee (2003) and Gee (2005) argues that well-designed digital games inherently foster high-quality learning by teaching necessary skills through engaging gameplay, even if the content differs from conventional curricula. Supported by further research, Gee emphasises that games employ methods such as *Cycles of Expertise* and *Sandbox Learning* to equip players with the skills and knowledge required to progress and complete game objectives effectively (Gee, 2005; Hamari et al., 2016). The use of SCL to provide pedagogical underpinning to DGBL, comprising SCDGBL, has potential to facilitate effective delivery of educational content through the medium of digital video games. Coleman and Money (2019) provide an overview of the concepts of SCDGBL, particularly highlighting the seven principles of SCL, and the thirteen principles of high-quality game design for DGBL, as outlined by Lea et al. (2003), Gee (2003) and Gee (2005) respectively. These are presented in Tables 1 and 2 respectively.

## 1.1 Related Work

SCDGBL is an active research area in which several existing games have been presented aiming to create and deliver a student-centred learning experience for students (Barr, 2018; Cózar-Gutiérrez & Manuel Sáez-López, 2016; Emihovich, 2024; Hung et al., 2018; Khamparia & Pandey, 2018; Mohammed et al., 2024; Tonbuloğlu, 2024; Wang et al., 2018). When aiming to develop educational games, the use of game design frameworks can play a key role to ensure that these games are developed to be effective learning tools (Kiili, 2005). In the area of SCDGBL, however, despite much promising research being presented over the last two decades, until recently, there has been no SCDGBL game design framework which could serve as an essential resource for supporting game designers and educators during the development process. Consequently, examples of existing SCDGBL applications include the use of existing games that were not originally intended to be used for educational purposes (Ahmad et al., 2011; Barr, 2018; Ho & Lee, 2023; King, 2015; Purbasari et al., 2021;

**Table 1** Lea et al. (2003) seven tenets of student-centred learning

| Tenet                                            | Definition                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Active learning (AL)                             | Students learning through active involvement and experimentation rather than passive absorption of facts                                                                                                                                                                                        |
| Deep learning and understanding (DL)             | Building in learning on a deeper level, giving students reasons to understand or care by relating or integrating learning to the student's own life or experiences                                                                                                                              |
| Increased responsibility and accountability (IR) | Giving students a measure of control over their own learning, allowing them to take responsibility for actions or situations and with a safety net to help deal with success or failure                                                                                                         |
| A sense of autonomy (SA)                         | Allowing students to engage with work without feeling they are monitored at every stage, and to make choices themselves that are or appear meaningful                                                                                                                                           |
| Teacher and learner interdependence (ID)         | The relationship between students and teachers is important and flows both ways; students should feel they are directing their experience while learning from a teacher, who should look to students for guidance as to their progression speed, level of understanding and the nature of tasks |
| Mutual respect (MR)                              | The importance of students respecting each other as co-workers provides a grounding for collaboration, and for students to learn from and assist one another                                                                                                                                    |
| Reflexive approach to teaching and learning (RA) | The ability for students and teachers to look back on work completed, evaluating not just how they achieved but lessons to be learned from their approach and future improvements                                                                                                               |

**Table 2** Gee, (2003, 2005) thirteen design principles for digital game-based learning

|                     | Principle                                                                                                                                                                                  |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Learner empowerment | P1: Co design<br>P2: Customisation<br>P3: Player identity<br>P4: Manipulation                                                                                                              |
| Problem solving     | P5: Ordered problems<br>P6: Pleasantly frustrating<br>P7: Cycles of expertise<br>P8: Information provision<br>P9: Fish tank learning<br>P10: Sandbox learning<br>P11: Skills as strategies |
| Understanding       | P12: Systems thinking<br>P13: Meaning from experience                                                                                                                                      |

Watson et al., 2011), and in cases where specific SCDGBL games were created, the use of a design framework was not mentioned (Lutfi et al., 2021; Neville et al., 2009; Owston, 2009; Sierra & Rodríguez-Conde, 2023; Sung & Hwang, 2013; Yang, 2015). This may explain why previous studies have found that many current educational games do not fully incorporate all principles of SCL (Coleman & Money, 2019), causing students to miss out on several key benefits of traditional SCL techniques. In particular, certain social aspects of SCL, such as peer learning within Active Learning, Mutual Respect, and Teacher and Learner Interdependence, are often lacking.

Recognising the lack of an existing SCDGBL framework, and the potential consequential effects of this on SCDGBL applications that are developed within the domain, Coleman and Money (2024) developed the Student-centred Experience (SCE) Framework. The foundations of the framework are set on the seven tenets of SCL (Lea et al., 2003) and the

13 principles for digital game-based learning (Gee, 2003, 2005). Figure 1 presents the SCE Framework. To follow is a brief summary of the framework. For a detailed description, please refer to Coleman and Money (2024).

The Student-centred Experience Framework is a game design framework that has been designed for and focused upon the creation of Student-centred Learning experiences through digital games. It draws from the established MDA framework (Hunicke et al., 2004) and utilises these lenses as shown at the top of the framework. The framework utilises the Digital Game-Based Learning Principles, as key touchstones, with each principle featured as a grey box and positioned under the lens it most heavily impacts (Gee, 2005). These principles are further categorised into their larger categories shown on the left, to guide game designers and educators on what broader aspects of games design they most contribute to.

Student-centred Learning is more strictly embedded by the use of the tenets of student-centred learning (Lea et al., 2003). These are shown along with the associated DGBL principles that provide opportunities for their implementation if tackled effectively. The framework highlights that all principles can be integrated effectively if addressed with intent from an early design stage.

The focus of the SCE framework is on offering guidance to games designers at an early stage on the creation of serious games that draw benefit from the established and effective techniques of Student-centred Learning to create engaging experiences for students that yield effective learning. It informs the designer of opportunities to take advantage of rather than prescribing a particular type of game, and by doing so provides an accessible way to incorporate established pedagogical theory into an effective design regardless of the intended game genre or target market.

### 1.1.1 Problem Statement

The SCE Framework provides a valuable resource for designers, educators, and researchers to start developing educational games that fully incorporate all principles of SCL. However, in the SCDGBL field, to date, there are no example applications that have been developed using the framework. Furthermore, there is no existing empirical evaluation of the effectiveness of the framework and its ability to support the development of a SCDGBL application that incorporates all seven SCL tenets and adheres to the thirteen design principles of digital game-based learning.

## 1.2 Research Aims

There are several aims to this study. First, present LogicGate, a digital game which provides students with a SCDGBL experience, designed using the SCE Framework. Second, to empirically evaluate the LogicGate game and the extent to which it delivers a SCL experience, compared with an equivalent traditional, paper-based student-centred task. This is a mixed methods study which explores the relative performance of the application, and student perceptions of the application and its potential use as a learning tool. Specifically, the following research questions are addressed in this study:

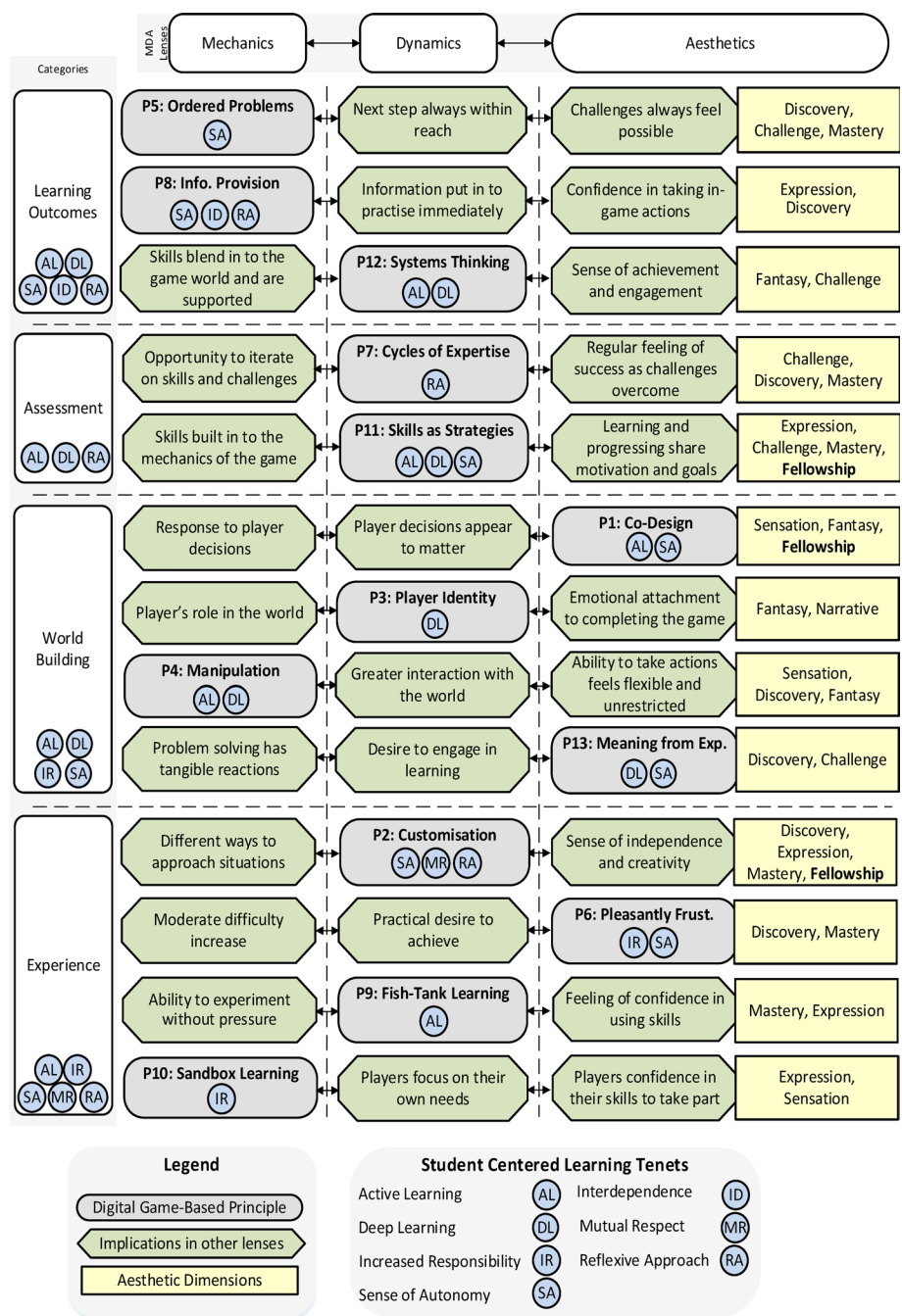


Fig. 1 The student-centred experience framework Coleman and Money, (2024)

*RQ1:* To what extent does the LogicGate System deliver all seven tenets of Student-centred Learning in comparison to a traditional, paper-based student-centred classroom task?

*RQ2:* To what extent does the LogicGate System provide an engaging gameplay and learning experience in comparison to a traditional, paper-based student-centred classroom task?

*RQ3:* To what extent does the LogicGate System improve student knowledge in comparison to traditional learning experiences?

*RQ4:* What are students' views on SCDGBL as a vehicle for their learning?

Section 2 presents the LogicGate system, which includes the system architecture in Sect. 2.1, and a map of the game world and a full application walkthrough in Sect. 2.2. Section 3 presents the methods used to evaluate LogicGate, followed by the Results in Sect. 4, discussion in Sect. 5 which includes implications and recommendations for deployment in practice. Conclusions are drawn in Sect. 6.

## 2 The LogicGate Game

### 2.1 System Architecture

LogicGate forms a Student-centred multiplayer educational experience based on a modified version of the popular game Minecraft. It provides students with a SCDGBL experience designed to engage with all aspects of Student-centred Learning, and be deployed as a part of a course that teaches Boolean logic concepts such as AND, OR, NOT and XOR. The LogicGate game is not open-source, as it was developed for use within teaching and incorporates proprietary university assets. As such, the full system is not currently publicly distributed. However, the game was designed and implemented following the SCE framework, and the development process is fully reproducible. Researchers and educators can therefore develop similar games by following the SCE framework, adapting its stages to their own educational context and learning objectives. Wherever possible, we have described the design decisions, mechanics, and pedagogical alignment in detail to support replication. The architecture of the LogicGate system is presented in Fig. 2.

The *LogicGate Client* (based upon Minecraft Java edition) provides the basis for the experience and a majority of core gameplay functions and aspects were preserved from basic Minecraft deployment. A number of features within this provide the core *Gameplay* experience: *Movement* is the ability of the game to handle student movement, as well as any mobile objects that operate within the game such as carts used for travel. The *Minecraft Rendering* engine is a bespoke system produced by Mojang, which works using the OpenGL system and handles objects including the blocks that make up the world, decorative objects such as leaves and the UI elements that allow student interaction. Models within Minecraft are typically rendered as blocks, which are typically square and use a 2D texture map for each side, however provision exists for more complex models such as pistons and levers. Input handling is covered through the client and is customisable to a student's wishes, allowing them to set which keys are active and control the sensitivity of the mouse for movement etc. *Redstone Logic* is the system most explored and expanded within the

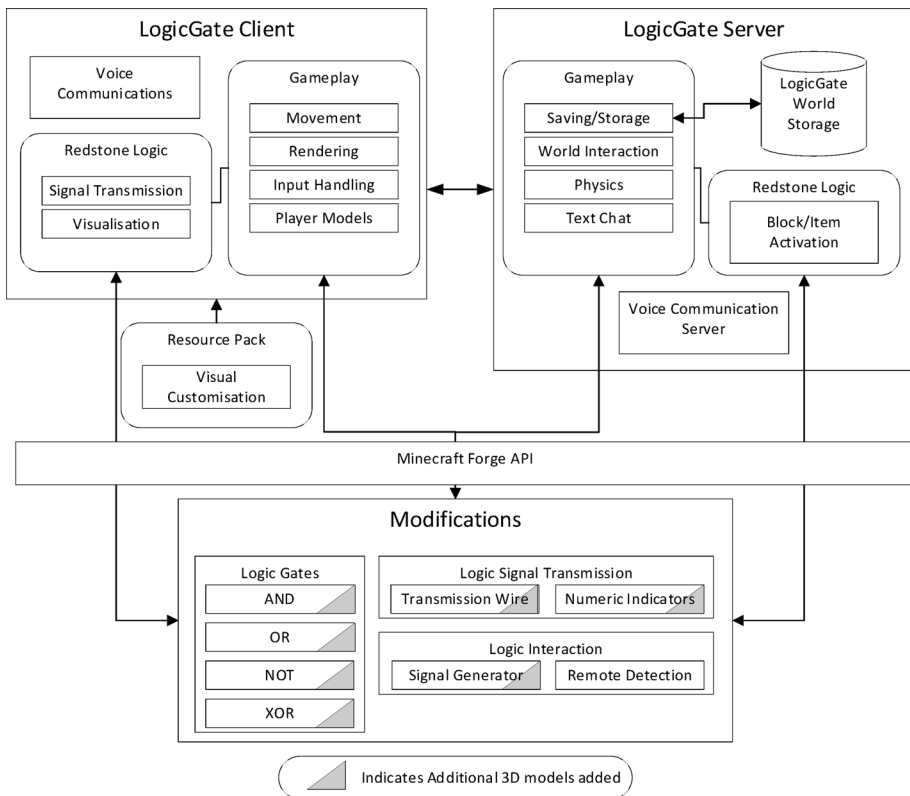


**Fig. 2** System architecture of the Logicgate system

LogicGate system: Within the base game Minecraft makes provision for *Signal Transmission*, allowing a signal to be sent across a short distance through the in game item ‘Redstone Dust’. Blocks are able to read this simple signal and use it to turn on or off. Further provision is made for *Visualisation*, with Redstone Dust lighting up to indicate a signal being sent. The LogicGate client utilises voice communication software which is associated with the client package; the open-source system Mumble was used to both handle communication between students and teacher, and to record this communication for later analysis.

*Resource Packs* provide a simple method of customisation, being a collection of textures that replace existing ones in the game. While not able to make changes to behaviour, this functionality was used within the LogicGate system to provide a clearer look and feel, therefore drawing attention to and increasing readability of the puzzles.

The *LogicGate Server* is a separate application, typically run on a different machine. Within the LogicGate system it holds the sole copy of the world and handles all *Saving/Storage*, passing this data to clients as required in  $16 \times 16 \times 128$  areas of the world referred to as chunks. Upon receiving information from the client about a user’s actions, the server will check the World Interaction to ensure the actions sent are correct, before updating the *LogicGate World Storage* as necessary. In a multiplayer setting the server handles calculations for the game’s *Physics*, ensuring blocks which are affected by gravity fall and water flows as the game requires, and updating clients in turn with the new world state. The Text

Chat functions of the game are handled by the server out of necessity, passing messages between clients and maintaining a log of such messages for future review. The server console allows such messages to be sent directly from the server if required. In a multiplayer setting the Server handles the *Block/Item Activation* aspects of Redstone Logic, checking a signal is present and activating entities the signal is transmitted to. The LogicGate Server also handles the voice communications, allowing students to communicate.

The *Minecraft Forge API* provides a further way to modify the behaviour of Minecraft. The Forge project sits around the core Minecraft program and provides an API for Modifications, often referred to by the community as ‘mods’ written in Java, to change game features. This API runs at a low level which opens up almost all game features to modification, from adding new in game items to changing core concepts such as score systems or the behaviour of light. The API provides a core aspect of the LogicGate system, as it allows the addition of not just the core modification but a number of publicly available supporting modifications that contribute to the overall system.

A number of *Modifications* provide the enhancements to Minecraft that enable the LogicGate system: These modifications add formal *logic gates* that mirror the function of such gates in reality. Adding concepts such as NOT, AND, OR, XOR, NAND etc. is core to teaching logic. Further modification work provides the LogicGate system with *Transmission Wires* as a reliable way to transmit signals a long distance, circumventing the original limits and enabling more complex puzzle design. It includes *Power Generation and Storage* to expand upon the logic signals and the 3D models to ensure these additions are fully realised within the system and visualised within the game world. These additional cosmetic blocks allow more customisation, such as more obvious signage to prompt students and more diversity and clarity in design.

For researchers and educators seeking to develop experiences like this, there is a wealth of guidance available for the development of such modifications, some skill with Java is required; however there is a keen community that is open to work with educators and academics and can help bridge this gap. The design follows the SCE Framework and guidance on the development and deployment of games in a similar vein can be found in the documentation for that (Coleman & Money, 2024).

## 2.2 Game Map and Walkthrough

This section presents a bird’s-eye view map of the game world (see Fig. 3) highlighting significant features within the LogicGate System. Up to three participants begin in the upper section (Sandbox Learning Area) and proceed from top to bottom, encountering challenges along the way.

The remainder of this section provides a detailed description of each of the areas of the game-world in turn, highlighting the DGBL principles that have been used in-line with the SCE framework.

### 2.2.1 Sandbox Learning Area

The Sandbox Learning Area is where students first find themselves upon joining the game. In this area students are free to experiment with controls and get used to moving within the game world, making use of the area’s namesake P10: Sandbox Learning. Figure 4 shows

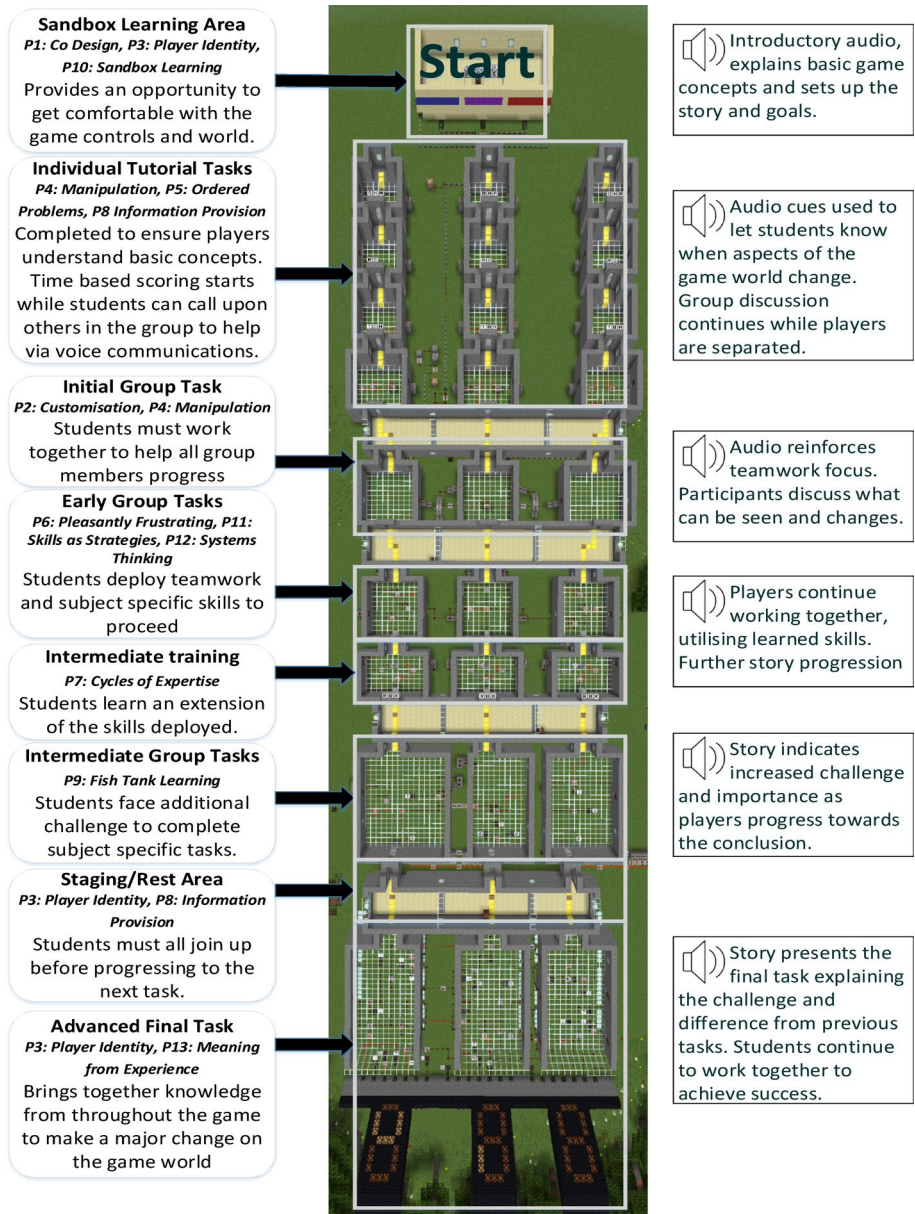


**Fig. 3** Annotated map of the game world within the Logicgate system

the Sandbox Learning Area, featuring the media player as well as part of the introductory message to students.

Students receive an in-game “information storage” item, shown in Fig. 4 on the lower right, which when used progresses the story and provides further instruction as to how to proceed to the next stage, as well as introducing the teamwork aspects of the game. Students



**Fig. 4** The sandbox learning area showing in game information storage and media player

are in the same area at this point, further reinforcing the multiplayer nature of the game. This area in particular seeks to deliver upon P1: Co-Design as students can decide which path to send each team member down, P3: Player Identity as their roles mechanically and in story are introduced, and P4: Manipulation, as students get used to affecting the world around them.

### 2.2.2 Individual Tutorial Tasks

This sequence of four small sections provides students with an individual tutorial section, where each student is gradually introduced to the basic logic gates: AND, OR and NOT and asked to use and interact with these in the world. As they do so the student is given information on the use of that gate which they can return to and refer to in future. Figure 5 shows one of these Tutorial Areas including the switches a user can interact with and the exit/goal.

While each student must complete these tasks, the communication system remains active throughout, and students are encouraged to seek and offer help from and to other members of their team. At the beginning of this section the time-based scoring is introduced, offering students a further incentive to proceed through the game. Throughout this section, students are introduced to the audio-visual cues that their actions have changed something within the game world, most particularly a distinctive effect was used to indicate the door opening and prompt students that they had successfully solved the puzzle (Collins, 2008). Within each room students are provided with an in-game reference containing information on the logic concept the room is addressing, which can be stored and referred to any time during the experience. This serves as timely and lasting P8: Information Provision, as students are taught new skills as they are put into practice to proceed. The final room within this section offers a challenge utilising all three types of gates, this offers an increase in difficulty

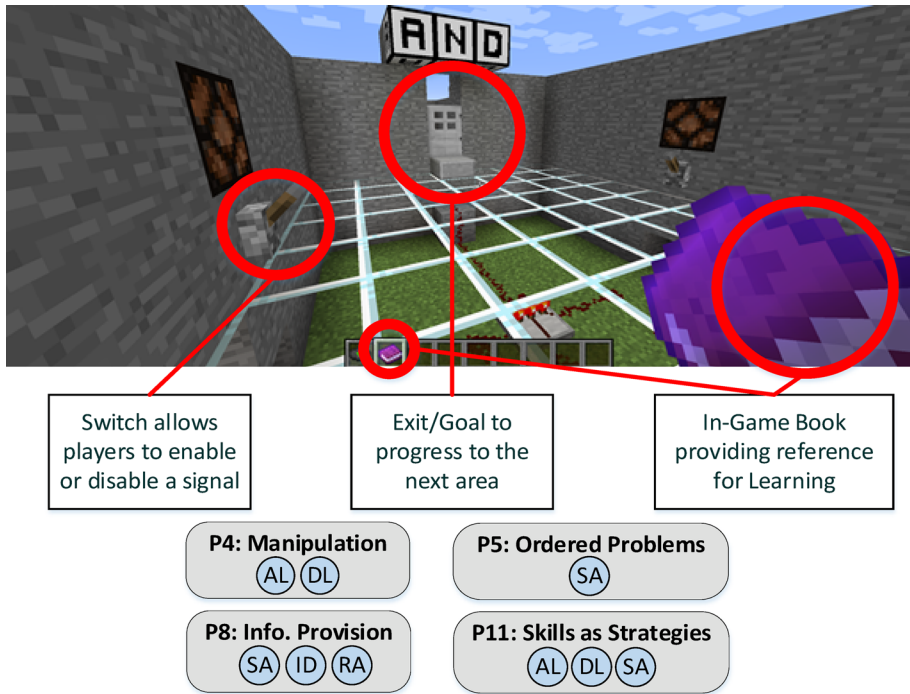


**Fig. 5** Introductory tutorial task area for one student teaching the basic use of AND gates

over the single gate challenges while remaining approachable. Over this section several aspects in particular are delivered upon, including P4: Manipulation as the puzzles and world respond to the students; P5: Ordered Problems as students face first the single gate then combination challenges; and P11: Skills as Strategies as students' logic abilities come to be used to progress faster. Towards the end of the section, students receive a further in-game "information storage" item with which to unlock the next part of the story and receive further instruction.

### 2.2.3 Staging/Rest Area

A number of these areas are found through the game. These areas, decorated as the Sandbox Learning Area, serve a number of purposes: They provide an area for students to further experiment, if desired, with some of the game mechanics outside of the puzzle areas. Figure 6 shows one of these Staging/Rest Areas, depicting a further media player as well as the areas participants must stand on.

These areas require all members of a group to be present to progress, forming a checkpoint to prompt students who get there before their peers to help their groups out through discussion and in some cases through returning to the earlier rooms to make changes to the puzzle. The rooms feature the in-game media players which allow students to play and re-play story elements if desired. These areas focus on P8: Information Provision allowing students to review media; P3: Player Identity as story sections reinforce the student's role

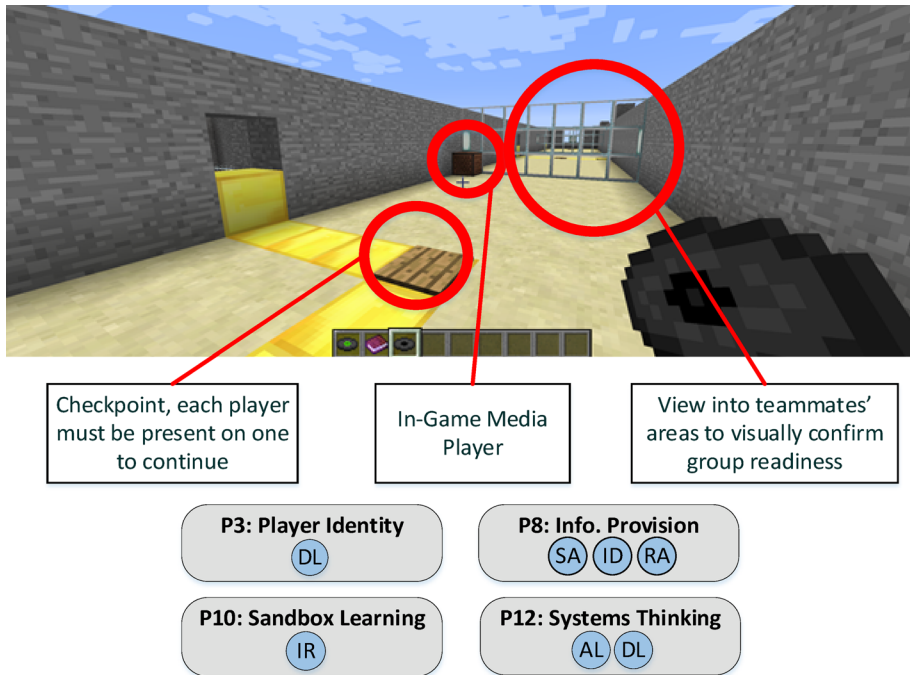


**Fig. 6** Staging/rest area

and motivation; P12: Systems Thinking as the skills are given in-game meaning; and P10: Sandbox Learning as students can further experiment with their skills.

### 2.2.4 Initial Group Task

This first group task asks participants to work together to solve a simple puzzle. This task does not lean heavily on the subject specific knowledge but instead focuses on the team discussing and working together to progress. Figure 7 shows the initial group task viewed from the air; each participant has access to one of the rooms and must cooperate in order to open the three doors shown above.

The task provides an introduction to the major teamwork focus and forms the first point where a puzzle cannot be completed without help from teammates. The area seeks to operationalise the principles of P4: Manipulation, as students' actions have effects on not just their own but other students' visible rooms, and of P2: Customisation, as students can choose how to handle the teamwork and how they experiment. This area is followed by another rest area for participants to catch up.

### 2.2.5 Early Group Tasks

The early group tasks ask participants to work together, utilising the skills gained from the Tutorial Tasks and the teamwork skills gained from the Initial Group Task. Figure 8 shows

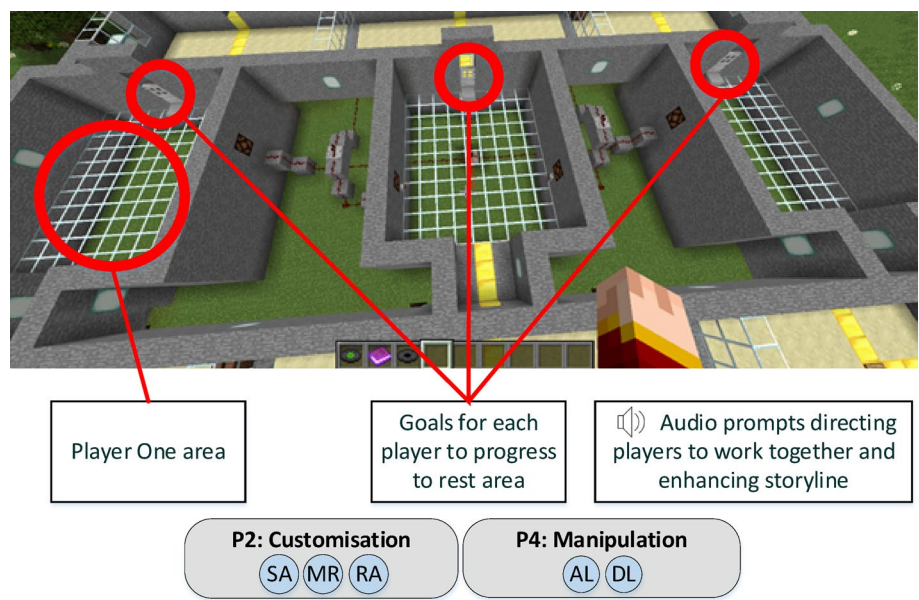


Fig. 7 Aerial view of the Initial group task showing three parallel rooms, one for each participant

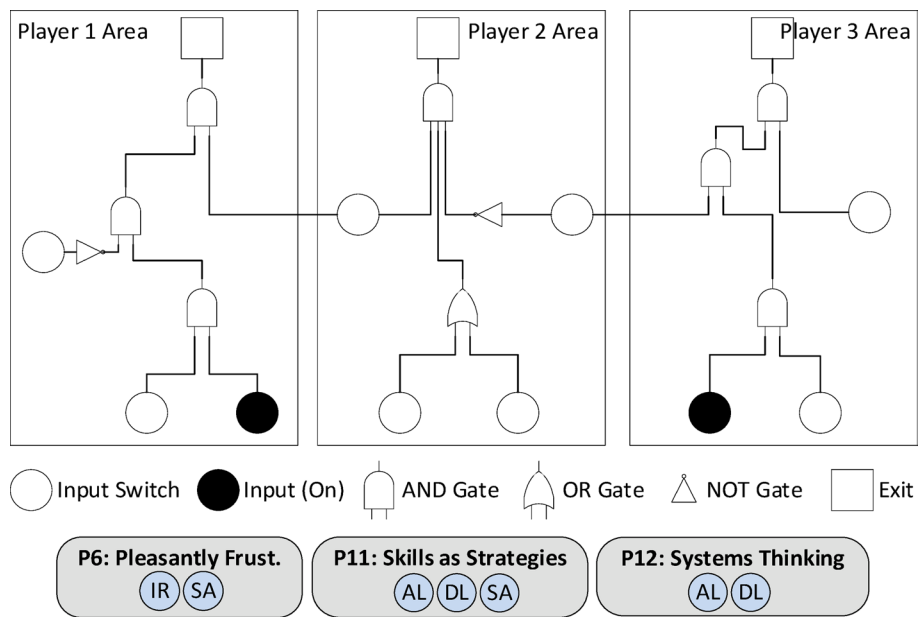


Fig. 8 Circuit diagram for the first subject specific group task

the first circuit participants are tasked to complete, indicating the areas individual students have access to see and interact with.

Participants use their subject knowledge to solve group puzzles and allow themselves and their teammates to progress. This area particularly focuses on P11: Skills as Strategies, where the learned logic skills are applied as strategies to complete the puzzles, P12: Systems Thinking as the concepts of Logic introduced form a fundamental and interactable part of the game world, and P6: Pleasantly Frustrating as the challenges step up. The teamwork component of the game promotes stronger students helping weaker ones, while weaker students have easy access to the help of peers to progress.

### 2.2.6 Intermediate Training

During this section, students are introduced to further subject specific content in the form of more advanced XOR gates. This takes the form of an individual puzzle as seen in the Introductory Tutorial Tasks section, where students have access to support through the voice communication system. In addition to the principles utilised in the Initial Training, this area puts into practice P7: Cycles of Expertise. Having navigated the tasks utilising the initial logic gates, the skill of solving puzzles is advanced through the introduction of additional gates, providing a further challenge and extending the breadth of possible puzzles and solutions for students to explore.

### 2.2.7 Intermediate Group Tasks

Integrating students' understanding from Early Group Tasks with the new skills gained in the Intermediate Training, this area provides further challenge to students as they progress. Figure 9 displays a section of an intermediate level task, showing a part of the circuit.

The storyline reinforces students' continued success while the difficulty of puzzles is increased. P9: Fish Tank Learning is in evidence here, as these tasks are designed to allow students to make, identify, and correct mistakes without significant consequence, encouraging experimentation to refine understanding. The area provides additional instantiation of P5: Ordered Problems, supporting students' learning with a new set of challenges taking a step up in difficulty; P6: Pleasantly Frustrating as the challenges faced are more difficult but remain within a student's reach; and P8: Information Provision as students put into practice the knowledge just gained on new logic gates.

### 2.2.8 Advanced Final Task

The final task is set up both through storyline and visually to present a more impressive area for students. Figure 10 shows the entrance to this task, including part of the text prompt.

This final challenge provides a major conclusion, and the culmination of the storyline goal presented through the audio overlay. Students must work together and utilise knowledge from all previous sections to solve the challenge and complete the storyline. In particular this area provides for P3: Player Identity as the culmination of both the students' learning and of the ongoing story that the students are exploring, this area offers a conclusion to the SCDGBL experience, identifying to players that they have mastered the topics at hand and have achieved their goal. P13: Meaning from Experience is then fulfilled as students are

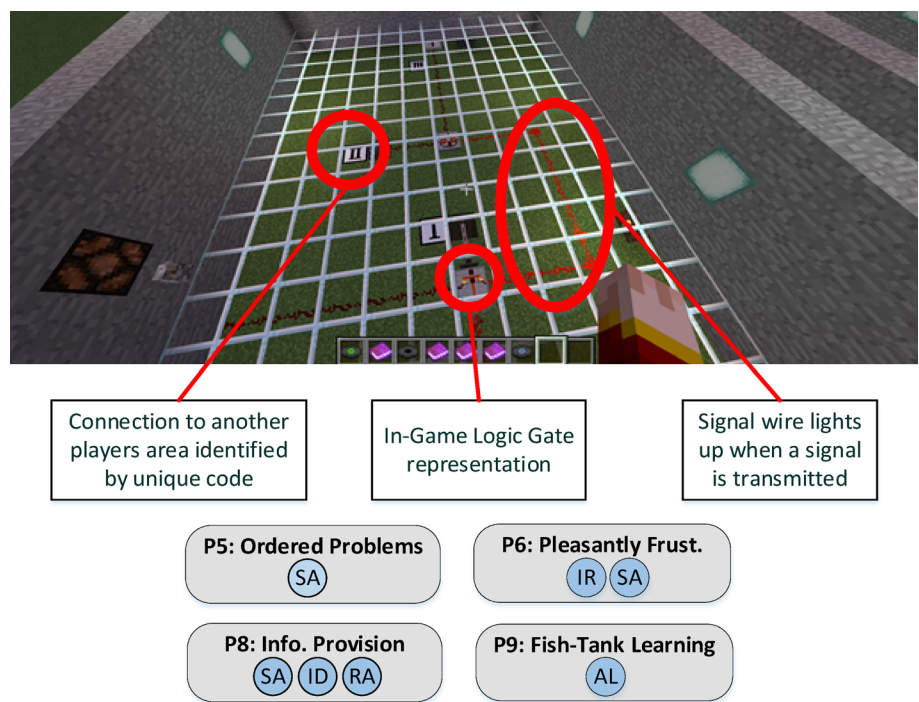


Fig. 9 A section of an intermediate subject specific task area viewed from above

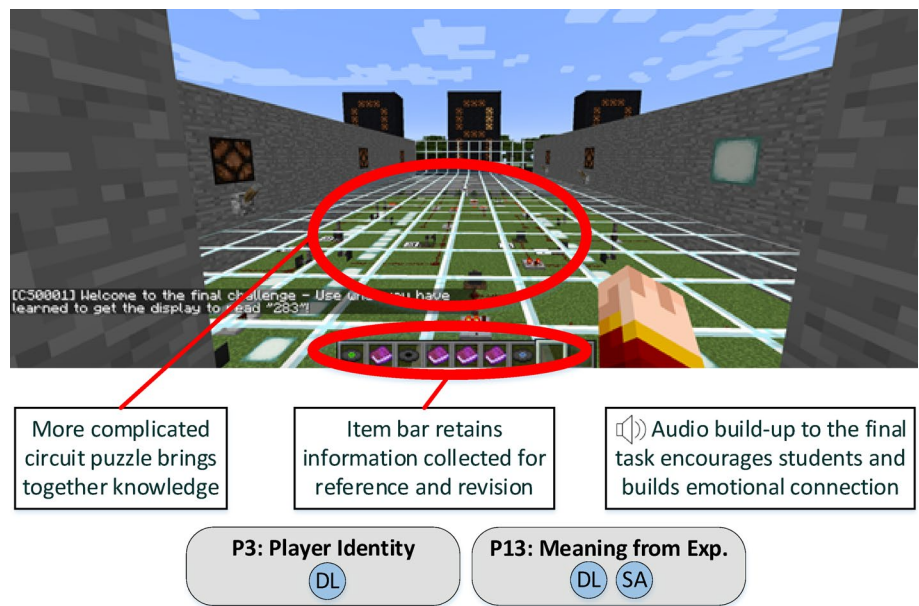


Fig. 10 The entrance to the final task as viewed by student 2

able to reflect upon their experience with the game and with each other and to associate this with their learning. In addition to these principles, a number of other principles are carried forwards from previous group tasks as established game elements continue to be present in the way students are accustomed to.

The next section looks at how the design of the study was formulated and updated to accurately test the LogicGate System.

### 3 Methods

This section provides details of the mixed methods data collection and analysis methods used to address the specific research aim of this study. Figure 11 presents the participant data collection and analysis procedure for this mixed methods study.

#### 3.1 Outcome Measures

To measure how effectively the LogicGate System delivered an SCDGBL experience (RQ1) a combination of two validated surveys was utilised. The Course Experience Survey is an evaluation tool designed to fit a number of learning environments that addresses many of the core concepts of Student-centred Learning (Hyo-Mi et al., 2018). The tool has been validated across a range of subject areas including educational foundations, mathematics and engineering, disciplines which cover the topic area of Boolean Logic, with Cronbach alpha values for subscales ranging from 0.72–0.93. It addresses features such as student–teacher relationships, group discussions, student responsibility and offers a view into students’ perceptions of their learning experience around these topics (Hyo-Mi et al., 2018). The eGameFlow survey provides further information on a number of Student-centred Learning tenets, addressing particularly students’ *Sense of Autonomy*, *Increased Responsibility and Accountability*, *Mutual Respect* and *Active Learning* (Chen et al., 2018; Fu et al., 2009). eGameFlow has been comprehensively validated (Cronbach alpha = 0.942 for whole instrument, all subscales >0.8 per Fu et al. (2009)), used before in game-based learning evaluation (Chen et al., 2012; Iten & Petko, 2016), as well as within wider user experience research, and includes an optional module, utilised during this study, for use in assessing educational content (Chen et al., 2018; Fu et al., 2009). Table 3 provides a mapping between the Course Experience Survey and eGameFlow survey constructs and SCL Tenets and provides explanations for the proposed connections.

The use of eGameFlow is also vital in the evaluation of students’ engagement with the learning experience (RQ2) where supported user experience metrics such as Goal Clarity, Immersion and Feedback allow an understanding of where the experience is best delivering, and identification of areas for improvement (Chen et al., 2018).

A class test was devised based upon knowledge tests used routinely within the undergraduate course to assess the extent of knowledge improvement (RQ3). A knowledge test administered pre- and post-learning experience is frequently deployed to identify knowledge improvement when evaluating educational games, as demonstrated within the review presented in (Coleman & Money, 2019). The test comprised a selection of multiple-choice questions derived from the course content, following the same format and style as summative assessments taken by students during their formal examination periods in this module.

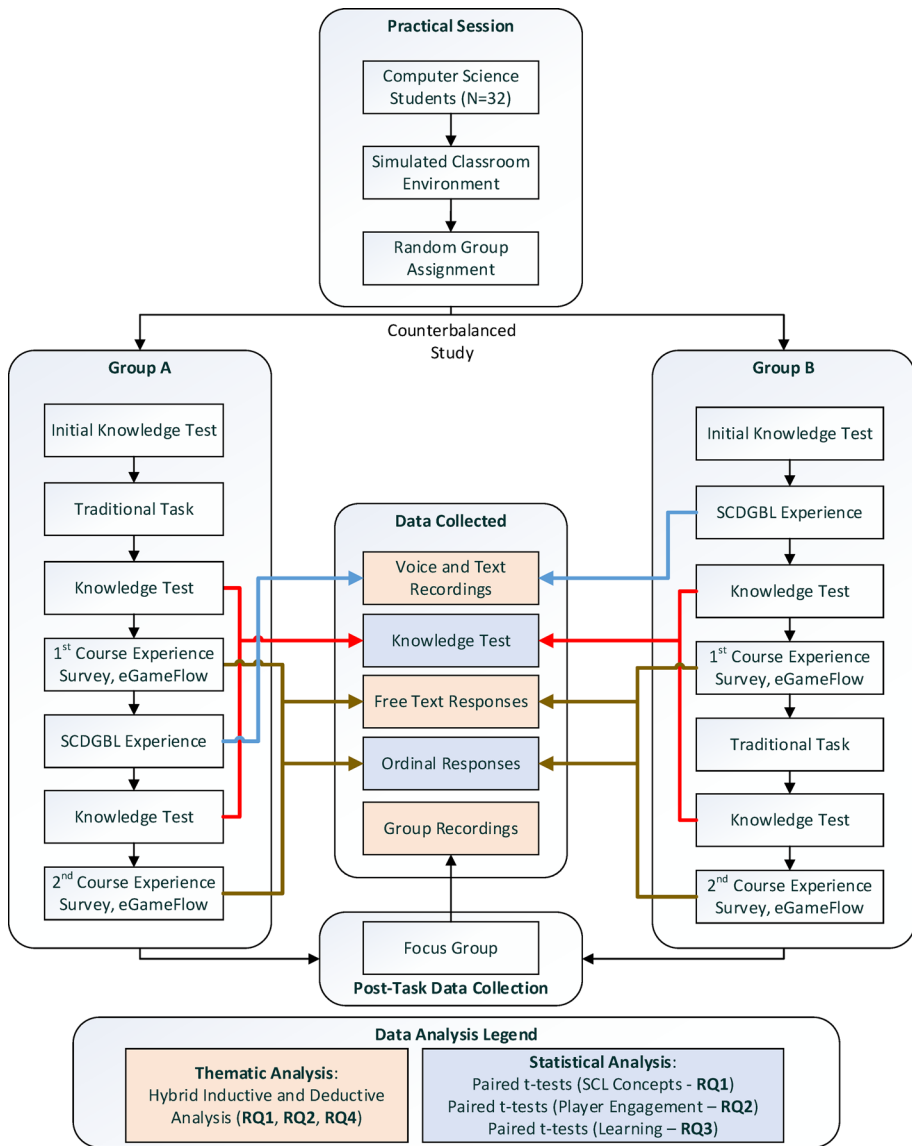


**Fig. 11** Counterbalanced mixed methods data collection and analysis procedure

When comparing between learning experiences, expressing an individual's knowledge gain as a gap score for pre versus post learning intervention can mitigate the impact of individual differences in baseline topic knowledge (Theobald & Freeman, 2014). Students' views of SCDGBL experiences as a vehicle for their learning are explored through focus groups (RQ4); the outcome measures within the surveys were augmented with data from these focus group sections to provide valuable contextual information for survey findings and a more nuanced perspective of the student learning and gameplay experience (RQ1, RQ2).

**Table 3** Course experience survey/eGameFlow constructs linked to student-centred learning tenets

| eGameFlow construct      | SCL tenets                                                                                  | Explanation                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Concentration            | Active learning (AL)                                                                        | Questions within this construct deal with students' active engagement in the task, making this construct a clear fit for the tenet of Active Learning. Further to this, Concentration is an important component of flow within games Csikszentmihalyi, (1990), representing a key metric of user experience alongside active engagement with learning Bober, (2008).                  |
| Goal clarity             | Increased responsibility and accountability (IR)                                            | Clear and specific goals are important to allow students to identify what they are expected to achieve, and to provide milestones against which to measure their achievement. Through this student take responsibility for modifying their performance where milestones are not met Garris et al., (2002); Whitton, (2014).                                                           |
| Feedback                 | Reflexive approach to teaching learning (RA)                                                | Timely feedback on work done allows a student to learn from their mistakes quickly and improve, showing a Reflexive Approach Garris et al., (2002).                                                                                                                                                                                                                                   |
| Challenge                | Active learning (AL)                                                                        | This construct deals with the package of challenge and the support provided to students to overcome this. Using skills to overcome difficulty is an example of Active Learning in action Whitton, (2014).                                                                                                                                                                             |
| Autonomy                 | Sense of autonomy (SA) (Increased responsibility [IR])                                      | Questions in this construct deal specifically with a student's Sense of Autonomy, making this a natural fit, in addition there is some cross-over with Increased Responsibility through the questions on control and impact which are known to interact positively with motivation Garris et al., (2002) Whitton, (2014).                                                             |
| Immersion                |                                                                                             | The Immersion construct does not directly map to an SCL tenet but provides information on player engagement and user experience Garris et al., (2002).                                                                                                                                                                                                                                |
| Social interaction       | Mutual respect (MR)                                                                         | Questions addressing student communities and collaboration provide a strong crossover with the tenet of Mutual Respect, as students work together Whitton, (2014).                                                                                                                                                                                                                    |
| Knowledge improvement    | Active learning (AL)                                                                        | Knowledge improvement is an outcome of Active Learning, engaging in gameplay activity by itself does not constitute effective learning. Through a student's knowledge improvement, an in-game activity can be meaningfully identified as Active Learning Annetta, (2010).                                                                                                             |
| CES construct            | SCL tenets                                                                                  | Explanation                                                                                                                                                                                                                                                                                                                                                                           |
| Complex thinking         | Deep learning                                                                               | Students are asked about their synthesis and application of knowledge, providing a clear demonstration of Deep Learning Dalton, (1998).                                                                                                                                                                                                                                               |
| Contextualisation        | Deep learning                                                                               | Contextualisation deals with the application and relation of knowledge to students' everyday lives providing a clear example of Deep Learning Dalton, (1998).                                                                                                                                                                                                                         |
| Instructive conversation | Teacher and learner interdependence (Id) (Reflexive approach to teaching and learning [Ra]) | Questions on the relationship between students and teachers naturally fall to Interdependence, this is supported by the standards of effective pedagogy considered to underpin this construct, where conducting instruction through conversation allows students to negotiate with teachers and peers to meet their academic and social needs Dalton, (1998); Doherty et al., (2002). |

**Table 3** (continued)

| CES construct                     | SCL tenets                                       | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------|--------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Joint productive activity         | Mutual respect (MR) (Active learning [AL])       | This construct asks about how students work together, providing a natural fit for Mutual Respect, particularly as the underlying theoretical foundations for this focus on goal-directed collaboration between students and teachers Doherty et al., (2002). In addition, Active Learning is identified as a central mechanism by which Joint Productive Activity encourages learning to occur, with Peer Learning and Cooperative Learning in particular forming a key part of this process Dalton, (1998). |
| Language and literacy development | Reflexive approach to teaching and learning (RA) | Within this construct, students were asked about feedback and self-improvement, concepts which feature heavily in the tenet of Reflexive Approach to Teaching and Learning. Hyo-Mi et al., (2018).                                                                                                                                                                                                                                                                                                           |

Again, the review in (Coleman & Money, 2019) suggested a mixed methods evaluation approach was under-utilised despite the valuable information this provides.

### 3.2 Sample

Participants were students studying Computer Science, Business Computing and Multimedia Computing courses at Brunel University (n=32), primarily those in first year. The courses (Computer Science, Business Computing, Multimedia Computing) were selected as they involve the use of Boolean logic, being the core of the learning intentions of the LogicGate System. Participants were recruited through email and through their weekly group tutoring sessions, where they were invited to participate in the study as an additional learning and revision session.

The inclusion criteria for participants were: (1) Participants should be on one of the above courses to ensure their knowledge was comparable. (2) Participants were proficient English speakers to allow all members of a group to contribute to the cooperative, teamwork based learning tasks. No age limits were applied as the courses are designed to be accessible to students from 18+ and it was decided it was appropriate for this to be represented in the study.

### 3.3 Study Design and Procedures

This mixed-methods study utilised a counterbalanced, within-subjects design which allows the effective comparison of the LogicGate System to a traditional student-centred task utilised within the classroom. The study took place at Brunel University of London within regular teaching facilities. A simulated classroom environment was prepared within a computer laboratory, which was reset between each session to ensure the hardware and software required remained functional and students had the same onboarding experience. Upon arrival at a session, participants were randomly assigned to either Group A or Group B using an online coin flip generator. Participants were then asked to log on as normal in a laboratory session and provided with a verbal explanation and an instruction sheet outlining the activities they were to undertake. Participants were divided into groups of three students for the activities and remained in these groups throughout the session.

All participants would take a short knowledge test before joining their groups in using the voice communication software. Those in Group A would first engage with a paper-based classroom task (Traditional task), working in their groups to solve a series of logic puzzles, presented as conventional logic circuits and requiring insertion of various types of logic gates to solve, with complexity of circuits increasing between puzzles, for example, requiring insertion of combinations of gates. Those in Group B would use the LogicGate System, working in groups to complete puzzles in-game. For both tasks, students in their groups were able to freely discuss the puzzles, share information and knowledge with each other and support each other throughout the tasks. Following this all students would fill out the Course Experience Survey (Hyo-Mi et al., 2018) and eGameFlow survey (Chen et al., 2018; Fu et al., 2009), and fill out a knowledge test. Participants would then engage in a second iteration of the trial using the alternative task, followed by filling out the surveys and test again. This counterbalanced design allows the identification of and control for order effects, particularly as relates to learning with both tasks covering the same topic area. The session was one hour in duration, with thirty minutes allotted for each task, including completing tests and surveys.

When both learning experiences had been completed and the surveys filled out, participants were invited to take part in a focus group where the learning experiences, challenges and usage intentions were discussed, along with the possibilities for future improvements and deployment in practice. These focus groups were recorded and transcribed verbatim.

### 3.4 Data Analysis

#### 3.4.1 Quantitative Data Analysis

Analysis of the Course Experience Survey and eGameFlow survey responses along with knowledge test data was performed using IBM SPSS statistics package version 29.0.0. For both surveys, descriptive statistics (mean, standard deviation) and gap scores (difference between post-LogicGate System value and post-traditional value) were calculated per construct. Cronbach alpha for scale reliability was reported for each construct. Two-tailed paired t-tests were used to test for whole-group differences in construct scores between the post-LogicGate System and post-Traditional learning experiences (RQ1, RQ2).

Given that multiple construct-level comparisons were conducted, Bonferroni correction was applied to control for Type I error. Specifically, corrections were applied for five constructs in the Course Experience Survey and eight constructs in the eGameFlow survey.

To assess the degree of knowledge improvement (RQ3) occurring after each learning experience, one-tailed paired t-tests were performed to compare pre-experience and post-experience raw test scores (Udovic et al., 2002). To compare the size of the change in raw test scores between learning experiences, a one-tailed paired t-test was performed on the gap score, calculated as the difference in test scores between pre-experience and post-experience. Mean Inter-Item Correlation was used to check reliability (DeVellis, 2003) with acceptability values between 0.15 and 0.7. Questions with an inter-item correlation below 0.15 were removed to increase reliability and validity. Post hoc, correlational analysis (Pearson) was performed to explore the relationship between baseline raw test scores and gap scores representing knowledge improvement post-experience.

### 3.4.2 Qualitative Data Analysis

For the analysis of the seven focus group sessions that explored the LogicGate System SCDGBL experience and the potential of its use as a vehicle for their learning (RQ4), Reflexive Thematic Analysis (Braun & Clarke, 2006, 2021, 2022) was employed using a hybrid inductive and deductive thematic analysis approach. The student-centred learning tenets were used as initial deductive themes to sensitise the analysis. This initial coding was then expanded upon, by identifying further common topics in the discussions and categorising these. Data familiarisation involved repeated reading of the transcripts and associated qualitative responses to support immersion within the dataset. The initial codes were examined and iteratively refined through continued engagement with the data, allowing themes to be developed through researchers' interpretation and reflection. Using an iterative approach, themes were linked and combined, leading to a categorisation of themes under overarching themes that describe the content. Throughout this process, both researchers engaged closely with the dataset through iterative discussion and critical reflection to refine codes and develop themes. The developing thematic structure was repeatedly reviewed and refined to ensure that it provided a coherent and meaningful representation of the dataset, with both researchers revisiting the data throughout the analysis to challenge and refine emerging interpretations. This analysis was conducted on the transcribed Focus Group transcripts (RQ4), the free text responses to survey questions (RQ1), and the recorded voice and text communications from the gameplay (RQ2) as well as the recorded text/voice chat data that was recorded during the task. All coding activities were performed using NVIVO. Consistent with the principles of Reflexive Thematic Analysis, formal measures of inter-rater reliability were not calculated, as coding was conceptualised as an interpretative and reflexive process rather than one seeking objective coder agreement (Braun & Clarke, 2019, 2022).

## 4 Results

Presented below are the results from the analysis of the Course Experience Survey, eGame-Flow Survey and thematic analysis of the qualitative data. A total of 32 participants took part in the experiment.

### 4.1 Course Experience Survey Evaluation

The Course Experience Survey was used to assess many of the Student-centred Learning elements of the LogicGate System. The findings from the Course Experience Survey, taken both after exposure to the Traditional task and after exposure to the LogicGate System may be found below. Results are presented by construct and by question in Table 4 for all participants. Statistical analysis for each construct is presented including mean and standard deviation for the post-LogicGate System and post-Traditional tasks, comparative statistics are included comprising gap score (calculated as post-LogicGate System value – post-Traditional value),  $t$ ,  $df$ ,  $p$ . In addition, mean values and standard deviation are presented per question.

A visual summary of the Course Experience Survey results and effect sizes for each construct are presented in Fig. 12

Of the five constructs in the Course Experience Survey, four of the five presented positive gap scores within Table 4 indicating participants held positive views on the LogicGate System as compared to the Traditional task. Analysis showed the construct of Joint Productive Activity achieved an improvement over the Traditional task that was statistically significant, demonstrating a gap score of 0.245 ( $p = 0.018$ ); although this did not remain significant after Bonferroni correction ( $p\text{-adj} = 0.090$ ). The constructs of Complex Thinking (*Deep Learning*), Contextualisation (*Deep Learning*), Instructive Conversation (*Teacher and Learner Interdependence*) and Language and Literacy Development (*Reflexive Approach to Teaching and Learning*) did not achieve significance in either direction, presenting respective gap scores of 0.042 ( $p = 0.745$ ), 0.000 ( $p = 1.000$ ), 0.081 ( $p = 0.629$ ) and 0.297 ( $p = 0.119$ ). Mean Inter-Item Correlations were within the acceptable range for all constructs indicating reliability.

Focusing on Joint Productive Activity, a significant difference was observed in the uncorrected analysis,  $t = 2.494$ ,  $p = 0.018$ ,  $d = 0.44$ ; however, this effect did not remain significant after Bonferroni correction for five construct-level comparisons ( $p\text{-adj} = 0.090$ ). This suggests an increasing trend, whereby students may have perceived greater collaboration and Mutual Respect with the LogicGate System, with a small-to-moderate effect size.

## 4.2 eGameFlow Evaluation

The eGameFlow survey was used to assess the effectiveness of the LogicGate System as a Digital Game-Based Learning experience. Participants completed this survey after undertaking both the game-based task and the gamified Traditional task. The results of this survey were analysed at a question and construct level for the entire cohort. Statistical analysis for each construct is presented including mean and standard deviation for the LogicGate System and Traditional tasks, comparative statistics are included comprising gap score (calculated as LogicGate System value – Traditional value),  $t$ ,  $df$ ,  $p$ . In addition to these calculations, in Table 5 mean values are presented per question.

A visual summary of the Course Experience Survey results and effect sizes for each construct are presented in Fig. 13.

Five of the eight constructs in the eGameFlow survey demonstrated positive gap scores, indicating that users perceived the game-based task as an improvement over the traditional task. The constructs of Feedback (*Reflexive Approach to Teaching and Learning*), Autonomy (*Sense of Autonomy*), and Social Interaction (*Mutual Respect*) yielded statistically significant gap scores of 0.641 ( $t = 3.715$ ,  $p = 0.001$ ), 0.375 ( $t = 2.958$ ,  $p = 0.006$ ), and 0.385 ( $t = 2.713$ ,  $p = 0.011$ ), respectively. However, after applying Bonferroni correction, only Feedback ( $p\text{-adj} = 0.008$ ) and Autonomy ( $p\text{-adj} = 0.048$ ) remained statistically significant, while Social Interaction did not ( $p\text{-adj} = 0.088$ ). No constructs demonstrating negative gap scores reached or approached statistical significance. Mean inter-item correlations fell within the acceptable range (0.15–0.70), with most constructs within the 0.30–0.50 range, indicating acceptable internal consistency. Subsequent sections focus on constructs that remained statistically significant after correction.

Participants rated the Feedback (*Reflexive Approach to Teaching and Learning*) construct positively (gap score = 0.641,  $t = 3.715$ ,  $p = 0.001$ ,  $p\text{-adj} = 0.008$ ,  $d = 0.66$ ), with this achieving significance. This demonstrates that the feedback on learning and actions was felt to be a marked improvement over that in the traditional learning task, with a medium-to-large

**Table 4** Course experience survey results by construct and questions, comparing LogicGate system experience and Traditional task experience

| Construct                                  | Course experience survey questions | LogicGate system   |                    | Traditional task   |                    | Com-<br>parison<br>statistics | df | t-value | P-Value | P-<br>adjusted<br>bonferroni | Co-<br>hen's<br>d |
|--------------------------------------------|------------------------------------|--------------------|--------------------|--------------------|--------------------|-------------------------------|----|---------|---------|------------------------------|-------------------|
|                                            |                                    | Standard deviation |                    | Standard deviation |                    |                               |    |         |         |                              |                   |
|                                            |                                    | Mean               | Standard deviation | Mean               | Standard deviation | Gap score                     |    |         |         |                              |                   |
| Complex thinking (Deep Learning)           | Construct                          | 3.89               | 0.68               | 3.84               | 0.67               | 0.042                         | 31 | 0.329   | 0.745   | 1.000                        | 0.06              |
|                                            | Higher order thinking              | 3.91               | 0.93               | 4.03               | 0.93               |                               |    |         |         |                              |                   |
|                                            | Application of concepts            | 4.19               | 0.78               | 3.97               | 0.93               |                               |    |         |         |                              |                   |
|                                            | Instructor helps develop solutions | 3.56               | 0.95               | 3.53               | 0.95               |                               |    |         |         |                              |                   |
| Contextualisation (Deep learning)          | Construct                          | 2.85               | 0.74               | 2.85               | 0.80               | 0.000                         | 31 | 0.000   | 1.000   | 1.000                        | 0.00              |
|                                            | Personal Connections               | 2.50               | 1.05               | 2.39               | 1.02               |                               |    |         |         |                              |                   |
|                                            | Teaching relevant to personal life | 2.94               | 0.95               | 3.00               | 1.00               |                               |    |         |         |                              |                   |
|                                            | Everyday Experiences               | 2.91               | 1.06               | 2.90               | 1.08               |                               |    |         |         |                              |                   |
| Instructive conversation (Interdependence) | Relation to prior experiences      | 3.16               | 1.11               | 3.23               | 1.06               |                               |    |         |         |                              |                   |
|                                            | Construct                          | 3.63               | 0.84               | 3.54               | 0.60               | 0.081                         | 31 | 0.489   | 0.629   | 1.000                        | 0.09              |
|                                            | Instructor works with small groups | 3.88               | 0.91               | 3.66               | 1.07               |                               |    |         |         |                              |                   |
|                                            | Small group discussion             | 3.78               | 1.10               | 3.72               | 1.02               |                               |    |         |         |                              |                   |
|                                            | Planned Discussions                | 3.44               | 1.11               | 3.44               | 0.98               |                               |    |         |         |                              |                   |
|                                            | Students contribute to discussion  | 3.50               | 1.16               | 3.50               | 1.11               |                               |    |         |         |                              |                   |
|                                            | Instructor builds understanding    | 3.53               | 1.05               | 3.41               | 0.98               |                               |    |         |         |                              |                   |

**Table 4** (continued)

| Construct                                              | Course experience survey questions | LogicGate system |                    | Traditional task |                    | Comparison statistics | df | t-value | P-Value | P <sub>adjusted bonferroni</sub> | Cohen's d |
|--------------------------------------------------------|------------------------------------|------------------|--------------------|------------------|--------------------|-----------------------|----|---------|---------|----------------------------------|-----------|
|                                                        |                                    | Mean             | Standard deviation | Mean             | Standard deviation |                       |    |         |         |                                  |           |
| Joint productive activity (Mutual respect)             | Construct                          | 3.74             | 0.53               | 3.48             | 0.68               | 0.245                 | 31 | 2.494   | 0.018*  | 0.090                            | 0.44      |
|                                                        | Regular group discussion           | 3.84             | 0.88               | 3.53             | 0.92               |                       |    |         |         |                                  |           |
|                                                        | Topics have activities             | 3.66             | 0.87               | 3.47             | 0.88               |                       |    |         |         |                                  |           |
|                                                        | Working together on Projects       | 4.13             | 0.75               | 3.91             | 1.00               |                       |    |         |         |                                  |           |
|                                                        | Most activities involve groups     | 3.09             | 1.28               | 3.31             | 1.23               |                       |    |         |         |                                  |           |
| Language and literacy development (Reflexive Attitude) | Engagement with others             | 3.66             | 1.31               | 3.00             | 1.32               |                       |    |         |         |                                  |           |
|                                                        | Collaboration in and out of class  | 3.97             | 0.82               | 3.66             | 0.83               |                       |    |         |         |                                  |           |
|                                                        | Construct                          | 3.59             | 0.72               | 3.30             | 0.87               | 0.297                 | 31 | 1.605   | 0.119   | 0.595                            | 0.28      |
|                                                        | Feedback level                     | 3.34             | 0.97               | 3.25             | 1.24               |                       |    |         |         |                                  |           |
|                                                        | Encouragement and Support          | 3.84             | 0.85               | 3.34             | 1.13               |                       |    |         |         |                                  |           |
|                                                        | Guidance on writing                | 2.78             | 1.24               | 2.94             | 1.32               |                       |    |         |         |                                  |           |

\* Statistically significant at the 0.05 level; Gap score is difference between post-Traditional and post-Game scores for construct—positive gap scores favour LogicGate System

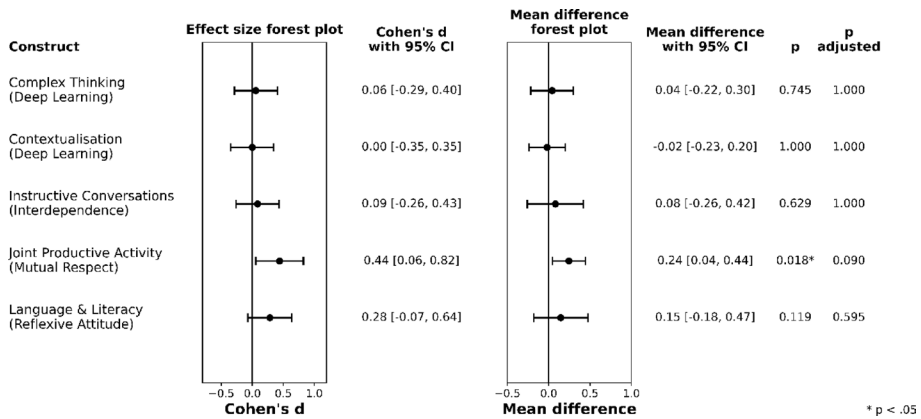


**Fig. 12** Visual summary of course experience survey construct effect sizes and statistical significance

effect size. This positive Feedback result for the LogicGate System shows the implementation of a *Reflexive Approach to Teaching and Learning* is more effective than that within the traditional task.

Autonomy (*Sense of Autonomy*) was also rated as significantly improved in the LogicGate system (gap score = 0.375,  $t = 2.958$ ,  $p = 0.006$ ,  $p\text{-adj} = 0.048$ ,  $d = 0.52$ ), indicating a statistically significant difference after correction. This reflects a moderate effect size, suggesting a meaningful improvement over the gamified traditional task. As both tasks were collaborative, this finding indicates that students perceived greater autonomy within the LogicGate system, feeling more able to act independently and creatively apply solutions to problems.

Social Interaction (Mutual Respect) was rated positively, with a gap score of 0.385 ( $t = 2.713$ ,  $p = 0.011$ ); however, this effect did not remain statistically significant after Bonferroni correction ( $p\text{-adj} = 0.088$ ). This suggests an increasing trend for participants to perceive the LogicGate System as providing enhanced opportunities for social interaction and peer learning compared to the traditional task, although this difference should be interpreted with caution.

Subgroup analysis by task order (see Appendix A) indicated broadly consistent patterns across groups, although some constructs showed stronger effects when the traditional task preceded the LogicGate condition.

### 4.3 Qualitative Analysis of Focus Group and Free Text/Voice Chat Data

Qualitative analysis identified five major themes, these are (1) Social Interaction, (2) Knowledge Improvement, (3) Game Design, (4) Perception and (5) Increased Responsibility. Figure 12 shows these themes and relevant subthemes in a thematic mind map. Emergent themes were added, from inductive analysis, comprising Game Design, Information Provision, Perception, Motivation and Aesthetic (Fig. 14).

**Table 5** eGameFlow survey results by construct and individual questions, comparing LogicGate system experience and traditional task experience

| Construct                       | eGameFlow survey questions      | LogicGate system |                    | Traditional task |                    | Comparison statistics |    |         | P-adjusted bonferroni | Cohen's d |
|---------------------------------|---------------------------------|------------------|--------------------|------------------|--------------------|-----------------------|----|---------|-----------------------|-----------|
|                                 |                                 | Mean             | Standard deviation | Mean             | Standard deviation | Gap score             | df | t-value | P-Value               |           |
| Concentration (Active learning) | Construct                       | 4.08             | 0.83               | 3.93             | 0.70               | 0.156                 | 31 | 1.039   | 0.307                 | 1.000     |
|                                 | Stimulates attention            | 4.03             | 1.03               | 3.81             | 0.78               |                       |    |         |                       | 0.18      |
|                                 | Do not get distracted           | 4.03             | 0.90               | 3.88             | 0.91               |                       |    |         |                       |           |
|                                 | Able to concentrate             | 4.19             | 0.86               | 4.09             | 0.86               |                       |    |         |                       |           |
| Goal clarity (Increased resp.)  | Construct                       | 3.73             | 0.93               | 3.93             | 0.82               | -0.203                | 31 | -1.187  | 0.244                 | 1.000     |
|                                 | Understand goals from the start | 3.66             | 1.26               | 4.00             | 0.98               |                       |    |         |                       | 0.21      |
|                                 | Overall goals clear             | 3.81             | 1.18               | 3.94             | 1.11               |                       |    |         |                       |           |
|                                 | Understand overall progress     | 4.13             | 0.94               | 4.13             | 0.91               |                       |    |         |                       |           |
| Feedback (Reflexive approach)   | Know what will happen next      | 3.31             | 1.18               | 3.66             | 1.04               |                       |    |         |                       |           |
|                                 | Construct                       | 3.78             | 0.81               | 3.14             | 1.12               | 0.641                 | 31 | 3.715   | 0.001*                | 0.008*    |
|                                 | Receive feedback on progress    | 3.84             | 0.99               | 3.16             | 1.17               |                       |    |         |                       | 0.66      |
|                                 | Feedback on actions             | 4.09             | 0.93               | 3.19             | 1.20               |                       |    |         |                       |           |
| Challenge (Active learning)     | Feedback on game performance    | 3.97             | 1.03               | 3.16             | 1.32               |                       |    |         |                       |           |
|                                 | Aware of score in game          | 3.22             | 1.29               | 3.06             | 1.39               |                       |    |         |                       |           |
|                                 | Construct                       | 3.79             | 0.67               | 3.96             | 0.71               | -0.169                | 31 | -1.494  | 0.145                 | 1.000     |
|                                 | Difficulty level suitable       | 4.03             | 1.00               | 4.00             | 1.02               |                       |    |         |                       | 0.26      |
| Autonomy (Sense of autonomy)    | Skills gradually improve        | 3.72             | 1.02               | 3.97             | 0.90               |                       |    |         |                       |           |
|                                 | Motivated by improvement        | 3.69             | 0.86               | 3.94             | 0.84               |                       |    |         |                       |           |
|                                 | Pace of Challenges              | 3.94             | 0.91               | 4.09             | 0.82               |                       |    |         |                       |           |
|                                 | Different levels of challenge   | 3.59             | 0.95               | 3.81             | 0.97               |                       |    |         |                       |           |
| Autonomy (Sense of autonomy)    | Construct                       | 3.83             | 0.80               | 3.46             | 0.95               | 0.375                 | 31 | 2.958   | 0.006*                | 0.048*    |
|                                 | Control over movements          | 3.97             | 0.97               | 3.44             | 1.19               |                       |    |         |                       | 0.52      |
|                                 | Sense of control                | 3.94             | 0.91               | 3.72             | 0.99               |                       |    |         |                       |           |
|                                 | Strategies can be used freely   | 3.59             | 1.04               | 3.22             | 1.13               |                       |    |         |                       |           |

**Table 5** (continued)

| Construct                               | eGameFlow survey questions      | LogicGate system |                    | Traditional task |                    | Comparison statistics |    |         | P-adjusted bonferroni | Co-hen's d |
|-----------------------------------------|---------------------------------|------------------|--------------------|------------------|--------------------|-----------------------|----|---------|-----------------------|------------|
|                                         |                                 | Mean             | Standard deviation | Mean             | Standard deviation | Gap score             | df | t-value | P-Value               |            |
| Immersion                               | Construct                       | 3.23             | 1.11               | 2.93             | 1.08               | 0.297                 | 31 | 1.516   | 0.140                 | 0.27       |
|                                         | Forget about passage of time    | 3.59             | 1.34               | 3.13             | 1.23               |                       |    |         |                       |            |
|                                         | Unaware of surroundings         | 3.13             | 1.21               | 2.77             | 1.31               |                       |    |         |                       |            |
|                                         | Can become deeply involved      | 3.44             | 1.34               | 2.90             | 1.22               |                       |    |         |                       |            |
|                                         | Feel emotionally involved       | 2.75             | 1.37               | 2.77             | 1.38               |                       |    |         |                       |            |
| Social interaction (Mutual respect)     | Construct                       | 4.17             | 0.66               | 3.78             | 0.75               | 0.385                 | 31 | 2.713   | 0.011*                | 0.48       |
|                                         | Social interaction              | 4.44             | 0.67               | 3.94             | 0.84               |                       |    |         |                       |            |
|                                         | Communities supported           | 4.09             | 0.86               | 3.56             | 0.98               |                       |    |         |                       |            |
|                                         | Other players improve my skills | 3.97             | 0.93               | 3.84             | 1.02               |                       |    |         |                       |            |
|                                         | Construct                       | 3.99             | 0.81               | 3.97             | 0.61               | 0.025                 | 31 | 0.222   | 0.826                 | 0.04       |
| Knowledge improvement (Active learning) | Game increases my knowledge     | 3.66             | 1.15               | 3.84             | 0.88               |                       |    |         |                       |            |
|                                         | Caught basic ideas              | 4.13             | 0.91               | 4.03             | 0.65               |                       |    |         |                       |            |
|                                         | Try to apply knowledge in game  | 4.03             | 0.93               | 4.06             | 0.84               |                       |    |         |                       |            |
|                                         | Integrate taught knowledge      | 4.22             | 0.87               | 4.09             | 0.69               |                       |    |         |                       |            |
|                                         | Want to know more               | 3.94             | 0.84               | 3.81             | 0.90               |                       |    |         |                       |            |

\* Statistically significant at the 0.05 level; Gap score is difference between post-traditional and post-game scores for construct—positive gap scores favour LogicGate system

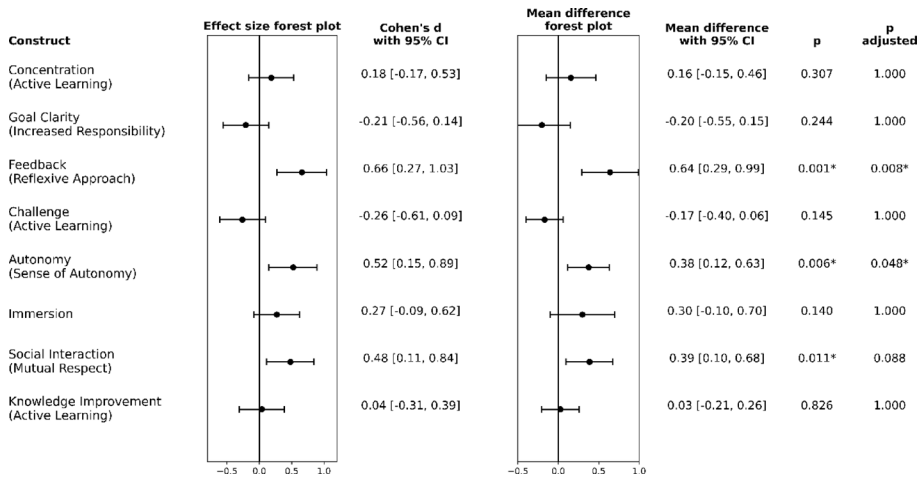


Fig. 13 Visual summary of eGameFlow construct effect sizes and statistical significance

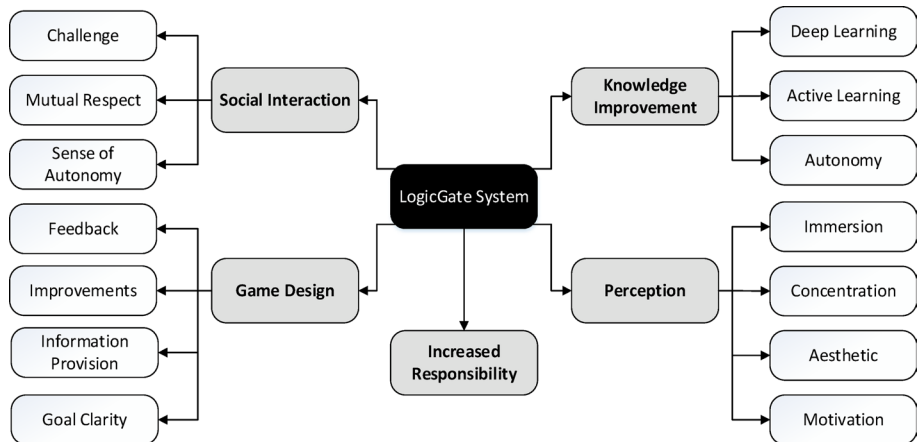


Fig. 14 Thematic mind-map of themes and subthemes

#### 4.3.1 Social Interaction

The Social Interaction theme, derived from the eGameFlow construct, addresses cooperation and community-building. Participants generally favoured collaborative gameplay, with some noting it one of the highlights of the experience.

*“It’s just more engaging when you’re working with other people... so when you apply that to the game, I think it just amplifies that.”*

Participants expressed initial concerns regarding slow startup times and working with unfamiliar peers, although none encountered direct issues. Overall, social interactions were positively received, particularly voice communication, which participants valued for efficiency.

### *Challenge*

The Challenge theme, drawn from the Challenge eGameFlow construct, explores progression or completion difficulties. Participants identified initial orientation toward group tasks as challenging, citing early communication hurdles. Many felt game difficulty escalated rapidly, making team collaboration, with all members, critical to progress and completion.

### *Mutual Respect*

Mutual Respect, aligned with the Student-Centred Learning tenet, emphasises peer respect developed through team-based tasks. Participants often noticed considerable growth in their teammates' confidence and abilities.

*"I just helped him with the first few rooms, and then he just kind of took over."*

While peer learning was positively viewed, some expressed concerns about having to rely on the team's 'weakest link' and the feeling that may generate in a student placed in that role.

### *Sense of Autonomy*

Sense of Autonomy covers a student's belief in their own ability to progress based upon their strength. Discussions emphasised mutual reliance and shared support:

*"It felt like each of us had a different difficulty, at some point... Each one of the others got stuck, so we had to sort of chip in and help. It was very interesting."*

Participants had concerns where sometimes their progression was hindered by something another student had to do, but once effective teamwork was established, individual contributions were seen as valuable.

## **4.3.2 Knowledge Improvement**

Knowledge Improvement addresses perceptions of learning through gameplay, examining different learning types and student engagement. Participants were generally positive and found the game effective for learning, however, expressed reservations about initial knowledge expectations and the time required to adapt to the game mechanics.

*"I think as long as it doesn't hinder what you've learnt otherwise, and it still covers everything, I think it would still be fine even if it took a bit longer."*

Discussion highlighted the importance of orientation to fully benefit from the educational content.

### *Deep Learning*

Deep Learning, aligned with Student-Centred Learning tenets, involves meaningful association of learning with personal experiences. Participants felt the application of their learning in a practical sense was effective and appreciated being able to see the effect.

*"And then, probably trying to apply the circuit logic in real life... When I was first learning about it, I was like: Oh, I will never need it in my life... and it is in video games."*

Participants recognised value both in reinforcing previous knowledge and acquiring new knowledge directly through gameplay.

#### *Active Learning*

Active Learning, a widely covered Student-Centred Learning tenet in video games, covers engaging with educational content through practical activities. Students valued the immediate application and feedback of game-based learning, noting its appeal compared to traditional methods.

*"It's kind of cool, the real-life application. You see that you cannot go if the circuit is open or the circuit is closed... I've never seen these educational games I think, only the children's videos for alphabet."*

Many described the game as an enjoyable learning approach due to active experimentation.

#### *Autonomy*

Autonomy relates to students' control over tasks, strategic use of knowledge, and error correction. Some participants experienced frustration due to dependency on team members but generally appreciated the freedom to progress through tasks independently or collaboratively.

### **4.3.3 Game Design**

Game Design emerged from discussions of the mechanical aspects of gameplay separate from educational content.

#### *Feedback*

Feedback, a theme from the eGameFlow construct, highlights the game's responsiveness to student actions and problem-solving efforts. Students strongly favoured instant, clear feedback and the visual and audio cues offered in response to in-game actions.

*"If there was a group one that we played in class, I would play it definitely because the feedback is instant and as long as there is communication, everything will go well."*

#### *Improvements*

Improvements represent student suggestions for enhancing gameplay effectiveness and enjoyment. Common requests included more detailed initial tutorials, clearer teammate status indicators, and reward or penalty systems based on in-game decisions.

#### *Information Provision*

Information Provision emerged inductively, addressing how information was communicated within the game. Students preferred audio information delivery over written text.

*"I also liked when you can hear the person talking. It's a lot easier to follow than reading it off the screen, I think."*

Participants differed in their awareness and usage of library features, indicated a preference for audio-delivered instructions and narration, and would have appreciated more information presented in this way.

#### *Goal Clarity*

Goal Clarity covers student understanding of immediate and long-term objectives. Participants generally appreciated clear overall goals but requested better orientation in early stages.

*"Actually playing the game wasn't complicated. It was reasonably informative, so you weren't getting confused as to where you were supposed to go, it was more, what do I need to do? Not, where do I need to go to continue?"*

Some discussions were over the later stages, where the goal changed, with students sometimes missing the text cue and looking for a door as in previous sections.

#### 4.3.4 Perception

Perception addresses the participants' overall experience, including immersion, concentration, aesthetic appeal, and motivation.

##### *Immersion*

Immersion covers participants' sense of engagement and emotional involvement. Students often reported losing track of time and deeply enjoying successful gameplay.

*"Maybe, it was really exciting to escape... you just feel this relief and you're like: Oh, yes, finally."*

Immersion occasionally suffered due to level of task difficulty.

##### *Concentration*

Concentration involves sustained participant engagement with the game. Participants described gameplay as enjoyable, aiding sustained concentration compared to traditional learning activities. The team-based aspect further encouraged continued focus.

*"So, if... I'm enjoying it, say, which I probably would a game, I'd be far more willing to spend the extra half hour doing that as opposed to sitting there, pen and paper, working through a sheet."*

##### *Aesthetic*

Aesthetic addresses the visual and sensory aspects of gameplay. Participants generally appreciated environmental features like weather effects and dynamic lighting, though a few noted that simpler visuals sometimes seemed childish.

*"Every room was really mysterious, and the lights were cool and the graphics, like the... the rain falling down."*

##### *Motivation*

Motivation includes game aspects encouraging sustained participation. Participants linked motivation directly to enjoyment, immediate rewards, and a sense of achievement:

*"...every time you have unlocked a door, you feel the progress... you feel more motivated to keep going."*

Periodic checkpoints further reinforced team achievement.

#### 4.3.5 Increased Responsibility

Increased Responsibility reflects student accountability in team success and individual contribution. Participants varied between taking responsibility for guiding their teams and focusing on individual roles:

*"I'm just waiting for everybody else to do it. As long as everybody does their part, the door will open."*

Students agreed they held personal responsibility for their contributions and overall team performance.

#### 4.4 Knowledge Test Performance

All students completed the 5-question knowledge test prior to their learning experiences, and repeated this test following each learning experience. Table 6 presents their mean scores pre-experience and post-experience.

A statistically significant increase in test score was identified after both learning experiences from baseline (post-LogicGate System gap score = 0.38,  $p = 0.036$ , post-Traditional gap score = 0.44,  $p = 0.014$ ), but the level of improvement, identified through the gap score, was not significantly different between the two learning experiences. This demonstrates that both the Traditional learning experience and the LogicGate System improved test scores by similar amounts.

### 5 Discussion

This study deployed the LogicGate System, a Student-centred Digital Game-based Learning experience, in a simulated classroom environment. A total of 32 Brunel University students used the LogicGate System in additional revision sessions to augment the study of the subject matter undertaken during their existing course. Key researchers in the DGBL field have called for more research into multiplayer DGBL experiences where cooperative learning is at the heart of the gameplay experience (Plass et al., 2019). This study directly addresses this gap, presenting a novel multiplayer DGBL experience deployed in a real-world setting, and accompanied by a full mixed methods evaluation.

*RQ1* aimed to determine the extent to which the LogicGate System effectively delivered all seven tenets of Student-centred Learning (SCL) compared to a traditional, paper-based

**Table 6** Statistical analysis of knowledge test scores

|                       | Mean score<br>(SD) | Gap score<br>(Experience—Pre-experience) | t     | p-value |
|-----------------------|--------------------|------------------------------------------|-------|---------|
| Pre-experience        | 3.03 (1.68)        | —                                        | —     | —       |
| Post-LogicGate system | 3.41 (1.27)*       | 0.380                                    | 1.939 | 0.036   |
| Post-traditional      | 3.47 (1.41)*       | 0.440                                    | 2.301 | 0.014   |

\*Statistically significant improvement from baseline at 0.05 level with one-tailed test

classroom task. Statistically significant advantages were identified in tenet-linked constructs including Autonomy (*Sense of Autonomy, Increased Responsibility and Accountability*), and Feedback (*Reflexive Approach*). Thus, compared to a paper-based student-centred learning task, the LogicGate System delivers improved outcomes in multiple key areas of student-centred learning, with at least equivalent performance in all other areas.

Qualitative feedback indicated participants successfully linked in-game experiences to learning, demonstrating effective integration of Deep Learning through active application of knowledge and connections to prior experiences.

The Goal Clarity construct (*Increased Responsibility and Accountability*) showed a minor negative gap, though not statistically significant. Qualitative findings clarified students' perceptions, highlighting difficulties adapting to changing objectives throughout gameplay. Although overarching goals were clear, ambiguity arose regarding specific per-room and per-area objectives, especially when incomplete individual tasks impeded group progress. This revisits a long-standing issue in designing any group educational activity where there is a need to try and ensure the strongest students do not complete the entire activity on their own, leaving other students having not fully engaged and learned (Joyce, 1999; Webb et al., 1995). Limited research has considered this challenge in the context of designing multiplayer DGBL experiences, but one way this can be achieved is by limiting information on what other students are and could be doing in the game to support team progress, encouraging communication and information-sharing (Zea et al., 2009), an approach taken in the LogicGate System. Teamwork and group learning elements are enhanced at a potential cost to goal clarity, as some students who may be technically competent at completing the task can be left unsure as to what needs to be done to progress in other students' areas.

In contrast, the Autonomy construct (*Sense of Autonomy, Increased Responsibility and Accountability*) received higher ratings for the LogicGate System compared to the traditional task. Qualitative themes of Autonomy and Increased Responsibility revealed students appreciated flexible approaches, problem-solving individually or collaboratively, and voluntarily assuming leadership roles. These findings align with existing research identifying that group collaboration can be fostered through shared objectives/goals (Costley, 2021; Wang & Huang, 2023). Some research in multiplayer educational games indicates that having one learner adopting a team leader role can more effectively support team performance (Wendel et al., 2013; Zea et al., 2009), although some students in the current study expressed concerns about reliance on weaker students in the team, and how those students would feel. Similar concerns have been expressed by students in other multiplayer DGBL experiences based on lack of confidence in knowledge or aptitude (Riivari et al., 2021). However, the LogicGate System effectively employed DGBL principles such as control over interactions (*P4: Manipulation*) and strategic flexibility (*P2: Customisation*), enhancing student autonomy and collective responsibility, thereby reducing dependency on team members. Qualitative findings showed that once teamwork practices were established, students valued individual contributions by their teammates and appreciated their growth in knowledge and confidence as gameplay progressed.

RQ2 explored students' gameplay experiences with the LogicGate System compared to a traditional, paper-based student-centred task, specifically regarding engagement. Survey results indicated higher ratings for the LogicGate System in certain areas, notably the Feedback (*Reflexive Approach to Teaching and Learning*) construct. Thus, while the LogicGate System can deliver an engaging experience, quantitative data alone cannot fully determine

its effectiveness across all areas. Additional insights from survey reliability statistics and qualitative data are beneficial.

Reliability statistics for survey constructs suggested some interpretive difficulties among students. Removing two problematic questions from these constructs improved reliability, highlighting the need to complement quantitative findings with qualitative insights.

Qualitative data supported the quantitative findings on Feedback, linking closely with the Motivation theme. Students positively noted feedback elements such as opening doors and checkpoint reunions, enhancing motivation and progression. Existing literature identifies rewarding experiences as a powerful motivator for continued engagement with DGBL experiences by students (Plass et al., 2019), as well as games more generally (Yee, 2006). Comparable motivational mechanisms have also been identified within gamified information systems outside education, where timely feedback, autonomy, and reward structures have been shown to promote sustained engagement with complex digital environments (Binsar et al., 2023). Additionally, the absence rather than presence of scoring feedback mechanisms (*performance tracking*) in-game could explain limited qualitative mentions.

Within the Concentration theme, qualitative data conflicted somewhat with the survey results, potentially due to misinterpretation of questions about maintaining consistent task focus, especially where students paused to support others or encountered rest points. The impact of multiplayer aspects of the experience upon focus is of particular relevance as multiplayer elements are infrequently used within DGBL, with a meta-analysis only identifying four recent examples of multiplayer DGBL experiences in the literature (Barz et al., 2024).

In the Challenge theme, students identified rapid difficulty escalation and team-based coordination challenges as concerns, affecting their perceived game progression and impacting survey ratings negatively. There is an interest within the wider games design literature in dynamic difficulty adjustment as a means to solve, this issue (Guo et al., 2024; Seyderhelm & Blackmore, 2021). However, dynamic difficulty scaling remains unproven in multiplayer educational games which provides an opportunity for further extension and exploration (Seyderhelm & Blackmore, 2021). The difficulty level directly influences the delivery of the Active Learning tenet, and improving pacing could address these challenges in future system updates, for example by incorporating additional tasks to support skill development.

*RQ3* examined student knowledge improvement following exposure to the LogicGate System compared to a traditional learning experience, using pre- and post-test scores. Analysis indicated that both learning methods led to equivalent improvements in test scores. This suggests the LogicGate System provides comparable knowledge gains while more effectively delivering certain tenets of Student-centred Learning. Notably, initial test scores were relatively high (mean of 61%), likely influenced by the LogicGate System's implementation during a revision session. The use of gap scores, measuring improvement from baseline, revealed a strong negative correlation between initial scores and subsequent improvement; students with lower initial scores demonstrated greater improvements. This suggests a potential ceiling effect for higher-achieving students, a recognised issue in educational intervention assessments (Flanagan et al., 2022; Judson, 2012). Overall, findings confirm that the LogicGate System delivers equivalent knowledge improvement compared to traditional methods, effectively addressing *RQ3*.

*RQ4* explored students' views on SCDGBL as a vehicle for their learning, and was answered through the thematic analysis of qualitative data. Overall, students were keen on the use of SCDGBL experiences within their learning, were broadly receptive to the idea of

SCDGBL experiences within future courses, and viewed the LogicGate System as an enjoyable way to learn. They were aware of their learning throughout the game and valued important aspects within the *Game Design* theme that facilitated their learning, such as instant feedback on changes they made within the game and whether they yielded solutions. These findings reinforce an existent body of research that shows DGBL experiences to be particularly effective at providing this kind of immediate feedback, as opposed to traditional experiences where feedback is typically delayed for a period of days or weeks while marking is completed (Vandewaetere et al., 2013; Wong & Yang, 2017). Feedback is also identified as an important aspect of educational game design to foster enjoyment (Ferreira de Almeida & dos Santos Machado, 2021). However, feedback provision has been identified as an area where many educational games could improve (Tonbuloglu, 2024). Further personalisation could strengthen this aspect (Kickmeier-Rust et al., 2008), such as personalised hints at times that are tailored to a specific user (Anderson et al., 2026), taking into account the impact of their help-seeking behaviours and preferences (Norum et al., 2024; O'Rourke et al., 2014). In the LogicGate System, adaptive feedback was provided by the tutor, who had a presence within the game with their own avatar. Some research highlights that the tutor's own feedback style can have an impact on the gameplay experience (Anderson et al., 2026). When deployed more widely, the learning experience with the LogicGate system may vary with skill and experience of the tutors, this highlights the value of a skilled educator even in the deployment of a SCDGBL experience.

The cooperative learning experience at the heart of the LogicGate System was viewed positively by the students, who contrasted it to other group-based exercises that they had done in class. However, they also perceived this to be a core source of much of the challenge of the game. Existing literature on collaborative multiplayer DGBL experiences highlights a strong role of individual personalities in the team upon group dynamics, which in turn impact the overall learning experience either positively or negatively (Plass et al., 2019). In the current study, students were supportive of working with others and felt the SCDGBL experience also changed their view of learning with their peers, through seeing them respond to challenges and taking on increased responsibility to lead or support others in their group. However, the *Perception* theme did raise an issue relating to the perception of learning through games; potentially not being perceived as serious or mature, depending on the aesthetic, which can impact learning as highlighted in other work (Alexiou et al., 2022).

Existing literature has identified that a number of aesthetic factors can affect user engagement with games, and particularly serious games, as if these factors are not addressed it can be a barrier to achieving flow state and subsequently perceived learning. Examples of these factors are narrative elements, emotional connection, game visuals, and design features, encompassing game feedback, goal clarity, challenge, meaningful choices and exploration (Alexiou et al., 2022; Jafarkhani et al., 2024). Addressing these factors alongside creating a multiplayer DGBL experience has been identified as extremely complex (Plass et al., 2019; Zea et al., 2009). Literature in the broader area of instructional design indicates that if students perceive an exercise to be meaningless or that goals are unclear, this can result in a non-aesthetic learning experience (Parrish, 2009). A number of these factors we endeavoured to address in the game ahead of time, such as adding an overarching storyline that is progressed through actions of players in the game, establishing coherent visual patterns within puzzles, and ensuring that all players could make meaningful contributions to progression.

However, particularly relevant in this case, may be the absence of realism within the game's design, as realism has been identified as an influencing factor for motivation in educational gameplay (Belanich et al., 2004). The use of the game's abstracted and cartoon-like graphics may lend an air of childishness which may detract from its perception as a serious learning tool (Risley et al., 2025). This may also be compounded by student familiarity with the base game, Minecraft, as a game more well known for its popularity amongst a younger age group than that targeted with this intervention. It has been suggested that the difference between emotional and cognitive experiences of players can impact serious game experiences, recognising previous gameplay experience as a contributing factor, (Jafarkhani et al., 2024) which may be particularly relevant to this study due to some players' familiarity with Minecraft. It is possible that this may have impacted perception of learning seriousness as the task was closely associated with play (Cheng et al., 2015). However, other work has not found an impact of increased realism on learning outcomes in a DGBL experience (Rojas-Salazar & Haahr, 2024). Such issues may be something future games delivering SCDGBL experiences must work to overcome, to achieve wider acceptance within a variety of learning environments.

Having evaluated the LogicGate System, and its role as an exemplar of SCDGBL experiences within the classroom, a number of more generalisable implications for wider deployment can be proposed. These implications will now be discussed alongside recommendations for the deployment of this and future SCDGBL experiences in teaching and learning practice.

## 5.1 Implications and Recommendations for Design, Development and Deployment in Practice

The deployment of the LogicGate System, including the testing and evaluation performed, gives rise to some implications, and recommendations relevant to educators, students, and developers, that can be offered for the design, development and deployment of games that create SCDGBL experiences in practice. These implications and recommendations are summarised in Table 7 which demonstrates for the findings the two areas of focus, associated qualitative themes and survey constructs, and the linked SCL tenets.

### 5.1.1 Implications and Recommendations for Deployment in Practice

*Emphasise importance of teamwork:* Before beginning an activity with the LogicGate System, teachers or demonstrators should explicitly clarify expectations to students, emphasising collective responsibility for group success. This may include explicit mention of teamwork as a learning outcome. Teachers or demonstrators should reinforce this through their presence in the game world.

*Important social benefits:* Important peer-learning benefits were noted by participants noting increased motivation and concentration due to collaborative interactions, hence, reinforce the positive implications of incorporating multiplayer SCDGBL activities in teaching practice.

*Primary use as reinforcement learning:* Students reported preferring initial instruction via traditional lectures or demonstrations, followed by game-based reinforcement.

**Table 7** Implications and recommendations for deployment in practice

| Area of Focus                                               | Finding                                                                                                                                     | Themes/Constructs                                        | Linked SCL tenets                                                                                                   |
|-------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Implications and recommendations for deployment in practice | Emphasise importance of teamwork to students from the introduction of the exercise to clarify goals and reinforce this from within the game | Goal clarity, challenge, increased responsibility        | Teacher and Learner Interdependence (ID)<br>Increased Responsibility and Accountability (IR)<br>Mutual Respect (MR) |
|                                                             | Important social benefits of multi-player experiences                                                                                       | Social interaction, concentration                        | Active Learning (AL)<br>Mutual Respect (MR)                                                                         |
|                                                             | Primary use as reinforcement learning activities                                                                                            | Deep learning, contextualisation                         | Deep Learning (DL)                                                                                                  |
|                                                             | Continuous student feedback is important in deploying effective experiences                                                                 | improvements                                             | Reflexive Approach to Teaching and Learning (RA)                                                                    |
| Design and functionality recommendations                    | Provide improved orientation and onboarding activities                                                                                      | Social interaction, challenge, joint productive activity | Mutual respect (MR)<br>Active Learning (AL)                                                                         |
|                                                             | Multiple channels to suit individual students                                                                                               | Information provision                                    | Sense of Autonomy (SA)                                                                                              |
|                                                             | Maintain rapid feedback to enhance student attention                                                                                        | Feedback, immersion                                      | Sense of Autonomy (SA)                                                                                              |
|                                                             | Deeper tutorial section to introduce game mechanics and taught concepts at a slower pace                                                    | Knowledge improvement, goal clarity                      | Active Learning (AL)<br>Deep Learning (DL)                                                                          |
|                                                             | Increased awareness of peers' activities may help students direct peer support more effectively                                             | Increased responsibility, immersion, social engagement   | Active Learning (AL)<br>Increased Responsibility and Accountability (IR)                                            |

*Continuous student feedback:* Practitioners are encouraged to continuously gather and utilise student feedback to optimise SCDGBL deployment in their educational contexts, as is the case example of LogicGate, which is grounded in the *Improvements* theme.

*Value for students:* Beyond the immediate learning task, qualitative findings suggest the SCDGBL experience supported students in developing autonomy, peer-support skills, and a sense of shared responsibility for outcomes, competencies with relevance beyond the specific subject area studied here.

### 5.1.2 Design and Functionality Recommendations

*Improved orientation and onboarding:* A key recommendation arising from the qualitative data relates to the orientation and onboarding process within the LogicGate System, this must be a primary focus in future versions of the application.

*Multiple channels:* Future versions should consistently provide all task critical information in both audio and text formats, enhancing accessibility for learners with sensory impairments or specific learning difficulties and preferences.

*Maintain rapid feedback:* Students greatly appreciated the rapid in-game responses to their actions, facilitating quick iteration and problem-solving. Future versions should build on this and include embedding clear and immediate visual and audio cues within puzzles to highlight successful actions, particularly those relating to teamwork.

*Deeper tutorial section:* Future iterations should feature expanded tutorial sections clearly integrating game mechanics and educational content, enabling new learners to develop essential skills gradually. Advanced students could bypass these tutorials, provided alternative engaging tasks maintain their interest.

*Increased awareness of peers' activities:* Recommendations for future iterations include introducing clear indicators, such as traffic-light-style status signals or enhanced positional indicators and mini-maps, to clarify team readiness and location, allowing students to assist effectively without undermining the collaborative learning structure.

*Institutional considerations for deployment:* For institutions considering investment in technology-enhanced learning tools, these findings suggest SCDGBL experiences are best positioned as a supplementary reinforcement resource alongside traditional teaching, rather than a replacement for it, a consideration relevant to curriculum design and resource allocation decisions.

## 5.2 Limitations and Future Research Directions

This study evaluated the LogicGate System within a simulated laboratory setting. Despite demonstrating advantages over the traditional task, several limitations were noted, potentially impacting the generalisability of findings. While the session was presented as a revision session, to minimise the effect of this and retain a connection to the students' course, it was nonetheless notably different due to the presence of research elements such as consent forms and information sheets, and this may colour students' perception, thus a research participation or 'Hawthorne' effect cannot be ruled out, although the degree of impact of such effects is extremely difficult to capture (McCambridge et al., 2014).

It is also possible that the novelty of introducing a game-based learning task may have caused students to focus on the task significantly more, impacting upon focus-related dimensions of outcome measures, such as Concentration and Immersion in eGameFlow, and on topic memorisation for the knowledge test, as novel experiences are linked to the desired learning. The selection of a paper-based task was drawn from the current real-world implementation of teaching in this topic area, utilising a directly comparable analogue to the currently used practical task deployed in the module. While a low-tech digital tool (e.g., a web-based quiz) could provide a more scalable or interactive alternative, the paper-based format was chosen to closely reflect authentic learning scenarios and to maintain consistency with existing pedagogical approaches. Future work could explore the use of digital implementations to assess potential differences in engagement and learning outcomes. There were no statistically significant differences in gap scores favouring the LogicGate System for these dimensions or for knowledge improvement in the outcome measures, suggesting any impact of novelty bias on study findings may be limited. Future work could explore this by comparing to other novel learning activities that are not explicitly game-based.

Lastly, participant self-selection may have biased outcomes towards research-interested students (Ben-Nun, 2008). These limitations could be mitigated in future through deployment within standard classroom environments, improving participant diversity. The modest and relatively homogeneous sample, comprising undergraduate students from closely related computing programmes at a single institution, also limited opportunities to undertake meaningful subgroup analyses beyond the task-order analysis that is included in the present study. Furthermore, variables such as educational sector, teaching experience and geographical

background were not collected as they were not applicable to the study population. These considerations, together with the modest sample size, may limit broader generalisability of the findings. Future research involving larger and more diverse participant cohorts could investigate whether SCDGBL experiences differ across participant groups and educational contexts. The degree of acceptance of games delivering SCDGBL experiences could also be explored in students at different educational levels, potentially utilising established acceptance metrics alongside the qualitative approach adopted in the current study.

Reliability for the Course Experience Survey was inconsistent, suggesting caution in interpreting these results. Complementing these findings with qualitative data can provide a more balanced interpretation. Future iterations may benefit from deploying the survey in conditions more reflective of standard classroom practice. It should also be noted that the study's outcome measures were not limited to self-reported perceptions: an objective knowledge test was administered pre- and post-intervention (RQ3), and survey findings were triangulated against qualitative focus group data collected from participating students (RQ4), providing a more complete picture of learning outcomes than perception-based measures alone.

Although a counterbalanced within-subjects design was used to mitigate order effects, subgroup analysis (see Appendix A) suggests that some outcomes (e.g., Joint Productive Activity, Autonomy, and Immersion) may be partially influenced by task order, with stronger effects observed when the traditional task was completed first. This may be a result of students having had the more effective team bonding experience second, and therefore viewing the experience more positively, but this could be further explored. While overall patterns remained broadly consistent, these findings indicate that some results should be interpreted with caution.

Knowledge improvement measures faced limitations due to high initial student scores and potential ceiling effects. This may have arisen or been exacerbated by the presentation of this experience as a revision session, thus students were already familiar with the concepts. Future studies might include more detailed testing to detect subtle misconceptions, carefully balanced against the risk of respondent fatigue from extensive assessments (Ben-Nun, 2008). Alternatively, future longitudinal studies could clarify whether LogicGate System use impacts long-term knowledge retention, providing deeper insights into the effectiveness of this educational approach and whether such impacts are sustained (Darland & Carmichael, 2012).

Improvements in *Goal Clarity* remain essential, with further developments recommended to clarify student tasks without extending gameplay excessively. Enhancements could involve improved alignment of student progression indicators and clearer user interface prompts for peer status updates, aligning with effective SCDGBL principles (Biggs & Tang, 2015).

## 6 Conclusions

This study evaluated the LogicGate System, a Student-centred Digital Game-Based Learning (SCDGBL) experience, within a simulated classroom setting against a traditional student-centred task. The study assessed its effectiveness in delivering SCDGBL principles and achieving learning outcomes. The LogicGate System delivered a statistically signifi-

cant improvement over a traditional paper-based task in provision of some core aspects of Student-centred Learning (SCL), such as reflexive learning and student autonomy, and a trend towards statistically significant improvements in peer learning, mutual respect and social interaction, with no measurable loss of performance in other aspects. These findings were confirmed by the Course Experience Survey, eGameFlow survey, and focus group discussion. Participants found the game engaging and interactive, valuing its emphasis on peer collaboration. Students were receptive to game-based learning and cooperative experiences. However, improvements are needed in Challenge, Immersion, and Contextualisation, which highlight areas for refinement in future iterations and related games.

Future work on the LogicGate System may seek to establish the long-term effectiveness of the LogicGate System particularly with regard to knowledge retention. Improvements to the game may include extending the game to allow a slower learning curve, and integrating testing into the LogicGate System, to further develop the reflexive learning aspect of the game. The development of additional easy-to-access guidance aimed at educators may help the development and deployment of similar systems in future to spread beyond an academic and technical background. Finally, the improved system may be deployed in a wider context to assess its practicality outside of close support by the researcher and to gather wider participation data. Such improvements may be addressed in a future revision of the LogicGate System and wider deployment evaluated in future studies.

## Appendixes

### Appendix A: Effect Order Analysis

During the testing of the LogicGate system, although a counterbalanced survey design was deployed to account for and control for order, it was considered possible that this could have affected the final result regardless. Order analysis was undertaken to verify if there was any meaningful effect and is presented here. Overall, there was no significant difference between the groups in a majority of areas, however, Joint Productive Activity in the Course Experience Survey as well as Sense of Autonomy and Immersion in eGameFlow showed students who took the traditional task were more likely to rate the LogicGate System higher. This may be due to more significant team bonding and communication through the LogicGate System causing students to reflect more positively on their second experience over the first.

### Data Analysis

In subgroup analysis by which learning experience participants had completed first, the t-tests for differences in construct scores were repeated. Although whole-group analysis controls for order effects in a counterbalanced crossover design, it is important to identify the impact of order of learning experiences upon scoring, hence performing subgroup analysis.

Equivalence of student baseline raw test scores and gap scores for each learning experience between groups (completing Traditional or LogicGate system experience first) was assessed through use of independent t-tests.

## Course Experience Survey Evaluation

Table 8 presents the data separated by the order in which experience participants were first exposed to. It includes the same statistical and comparative data (mean, gap score,  $t$ ,  $df$ ,  $p$ ) and is presented to provide comment on the potential bias and benchmarking effects that may be present in crossover trials.

### Complex Thinking

Within the experimental groups the Traditional first group showed a gap score of 0,  $p = 1.000$ , where the LogicGate system first group showed a gap score of 0.083,  $p = 0.609$ , neither of these results achieving significance. These results indicate a relatively small difference in the perception between the traditional and SCDGBL engagements.

### Contextualisation

Within the experimental groups the Traditional first group demonstrated a gap score of 0.104,  $p = 0.436$  while the LogicGate system first group showed a gap score of  $-0.141$ ,  $p = 0.410$ , neither achieving significance. These results show a small difference in perception between the traditional and SCDGBL engagements with a slightly larger difference in the perception based upon the experience offered first.

### Instructive Conversation

Analysis of the subgroups showed similar results for both groups, with the Traditional first group showing a gap score of 0.146,  $p = 0.606$ , while the LogicGate system first group presented a gap score of 0.075,  $p = 0.802$ , with neither achieving significance. These results identify a similar perception for this construct within both tasks.

### Joint Productive Activity

Subgroup analysis, based on which learning experience was completed first, indicated this effect was primarily driven by the group who completed the Traditional learning experience first with a gap score of 0.417,  $t = 3.76$ ,  $p = 0.002$  compared to the LogicGate system first gap score of 0.073,  $t = 0.48$ ,  $p = 0.642$ .

### Language and Literacy Development

Within the subgroups, both groups showed a similar positive trend that did not achieve significance, Traditional first participants demonstrated a gap score of 0.167,  $p = 0.271$  while the LogicGate system first group showed a gap score of 0.125,  $p = 0.676$ .

**Table 8** Course Experience Survey constructs comparing LogicGate system experience and traditional learning experience, grouped by which experience came first

| Construct                         | Which experience was played first? | Mid-point |                    | Post-game |                    | Post-traditional |                    | Gap score | df    | t-value | P-value |
|-----------------------------------|------------------------------------|-----------|--------------------|-----------|--------------------|------------------|--------------------|-----------|-------|---------|---------|
|                                   |                                    | Mean      | Standard deviation | Mean      | Standard deviation | Mean             | Standard deviation |           |       |         |         |
| Complex thinking                  | Traditional                        | 3.00      | 3.750              | 0.672     | 3.750              | 0.551            | 0.000              | 16        | 0.00  | 1.000   |         |
|                                   | Game                               | 3.00      | 4.021              | 0.672     | 3.938              | 0.781            | 0.083              | 16        | 0.52  | 0.609   |         |
| Contextualisation                 | Traditional                        | 3.00      | 2.859              | 0.408     | 2.755              | 0.561            | 0.104              | 16        | 0.80  | 0.436   |         |
|                                   | Game                               | 3.00      | 2.891              | 0.801     | 3.031              | 0.898            | -0.141             | 16        | -0.85 | 0.410   |         |
| Instructive conversation          | Traditional                        | 3.00      | 3.871              | 0.691     | 3.725              | 0.326            | 0.146              | 16        | 0.53  | 0.606   |         |
|                                   | Game                               | 3.00      | 3.438              | 0.947     | 3.363              | 0.760            | 0.075              | 16        | 0.26  | 0.802   |         |
| Joint productive activity         | Traditional                        | 3.00      | 3.781              | 0.504     | 3.365              | 0.621            | 0.417              | 16        | 3.76  | 0.002*  |         |
|                                   | Game                               | 3.00      | 3.667              | 0.558     | 3.594              | 0.704            | 0.073              | 16        | 0.48  | 0.642   |         |
| Language and literacy development | Traditional                        | 3.00      | 3.167              | 0.471     | 3.000              | 0.710            | 0.167              | 16        | 1.14  | 0.271   |         |
|                                   | Game                               | 3.00      | 3.479              | 0.709     | 3.354              | 0.992            | 0.125              | 16        | 0.43  | 0.676   |         |

\*Statistically significant at the 0.05 level; Gap score is difference between post-traditional and post-game scores for construct—positive gap scores favour LogicGate system

## eGameFlow Evaluation

Table 9 presents the data separated by the experience first exposed to, it includes the same statistical and comparative data (mean, gap score,  $t$ ,  $df$ ,  $p$ ) and is presented to provide comment on the potential bias and benchmarking effects that may be present in crossover trials.

### Concentration

Within the subgroups both the traditional first group (gap score = 0.271,  $p = 0.245$ ) and the game first group (gap score = 0.042,  $p = 0.841$ ) showed a preference for the game-based task that did not reach significance.

### Goal Clarity

Subgroup analysis showed similar responses for both groups, traditional (gap score =  $-0.328$ ,  $p = 0.212$ ) and game first (gap score =  $-0.078$ ,  $p = 0.745$ ), neither group achieved significance.

### Feedback

Analysis of the subgroups showed a significant positive result in both experimental groups, the traditional first (gap score = 0.672,  $p = 0.019$ ) and game first (gap score = 0.609,  $p = 0.023$ ) with both groups offering similar ratings.

### Challenge

Analysis within the subgroups showed this effect was driven primarily by the traditional first group but did not achieve significance when considered alone (gap score =  $-0.325$ ,  $p = 0.057$ ) while the game first group had a lesser effect (gap score =  $-0.013$ ,  $p = 0.937$ ).

### Autonomy

Analysis within subgroups shows this effect to be driven by the traditional first group (gap score = 0.646,  $p = 0.006$ ) while the game first group demonstrated a positive effect that did not reach significance (gap score = 0.104,  $p = 0.429$ ).

### Immersion

Within the subgroup analysis however there was a significant effect for the traditional first group (gap score = 0.719,  $p = 0.003$ ), this was counteracted by the game first group which showed a small negative rating (gap score =  $-0.125$ ,  $p = 0.686$ ).

**Table 9** - eGameFlow survey constructs comparing LogicGate system experience and traditional learning experience, grouped by which experience came first

| Construct             | Which experience was played first | Mid-point | Post-game |                    | Post-traditional |                    | Gap score | df | t-value | P-value |
|-----------------------|-----------------------------------|-----------|-----------|--------------------|------------------|--------------------|-----------|----|---------|---------|
|                       |                                   |           | Mean      | Standard deviation | Mean             | Standard deviation |           |    |         |         |
| Concentration         | Traditional                       | 3.00      | 4.146     | 0.730              | 3.875            | 0.729              | 0.271     | 15 | 1.21    | 0.245   |
|                       | Game                              | 3.00      | 4.021     | 0.931              | 3.979            | 0.694              | 0.042     | 15 | 0.20    | 0.841   |
| Goal clarity          | Traditional                       | 3.00      | 3.688     | 0.854              | 4.016            | 0.629              | -0.328    | 15 | -1.30   | 0.212   |
|                       | Game                              | 3.00      | 3.766     | 1.018              | 3.844            | 0.991              | -0.078    | 15 | -0.33   | 0.745   |
| Feedback              | Traditional                       | 3.00      | 3.797     | 0.786              | 3.125            | 1.125              | 0.672     | 15 | 2.64    | 0.019*  |
|                       | Game                              | 3.00      | 3.766     | 0.849              | 3.156            | 1.143              | 0.609     | 15 | 2.56    | 0.023*  |
| Challenge             | Traditional                       | 3.00      | 3.875     | 0.677              | 4.200            | 0.532              | -0.325    | 15 | -2.06   | 0.057   |
|                       | Game                              | 3.00      | 3.712     | 0.669              | 3.725            | 0.793              | -0.013    | 15 | -0.08   | 0.937   |
| Autonomy              | Traditional                       | 3.00      | 4.063     | 0.743              | 3.417            | 1.029              | 0.646     | 15 | 3.22    | 0.006*  |
|                       | Game                              | 3.00      | 3.604     | 0.818              | 3.500            | 0.894              | 0.104     | 15 | 0.81    | 0.429   |
| Immersion             | Traditional                       | 3.00      | 3.484     | 1.164              | 2.766            | 1.055              | 0.719     | 15 | 3.48    | 0.003*  |
|                       | Game                              | 3.00      | 2.969     | 1.032              | 3.094            | 1.110              | -0.125    | 15 | -0.41   | 0.686   |
| Social interaction    | Traditional                       | 3.00      | 4.271     | 0.561              | 3.813            | 0.789              | 0.458     | 15 | 2.09    | 0.054   |
|                       | Game                              | 3.00      | 4.063     | 0.752              | 3.750            | 0.725              | 0.313     | 15 | 1.68    | 0.114   |
| Knowledge improvement | Traditional                       | 3.00      | 3.925     | 0.906              | 3.963            | 0.571              | -0.038    | 15 | -0.18   | 0.858   |
|                       | Game                              | 3.00      | 4.063     | 0.722              | 3.975            | 0.673              | 0.087     | 15 | 0.91    | 0.379   |

\* Statistically significant at the 0.05 level; Gap score is difference between post-traditional and post-game scores for construct—positive gap scores favour LogicGate system

## Social Interaction

While the total group achieves significance, within the subgroups, the traditional first group (gap score = 0.458,  $p = 0.054$ ) and the game first group (gap score = 0.313,  $p = 0.114$ ) both did not achieve significance.

## Knowledge Improvement

Analysis of the subgroups showed a small negative effect within the traditional first group (gap score = -0.038,  $p = 0.858$ ), while the game first group demonstrated a small positive effect (gap score = 0.087,  $p = 0.379$ ) however neither effect reached significance.

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## Declarations

**Conflict of interest** The authors declare that they have no competing interests.

**Ethical Approval and Consent to Participate** This research was approved by Brunel University of London Research Ethics Committee. Informed consent to participate was obtained from each participant through signing of informed consent forms. Participants were informed of their right to withdraw from the study at their own will without any repercussions at any point during or after the study.

**Consent for Publication** Not applicable.

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