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A Digital Simulation Game for Resource Management in Construction Projects

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Abstract: The construction industry is on the verge of a digital transformation. Consequently, the gap widens between industry demands and fresh graduate capabilities. Therefore, there is a pressing need for a paradigm shift in the teaching approach for construction management education. To meet both industry demands and student expectations, Game-Based Learning (GBL) can substantially enhance both technical and transferable skills for digital-native students who struggle with traditional teaching methods. Although the body of knowledge recognizes GBL in general, their utilization remains limited in construction management. Moreover, there is little discussion on the design process of educational games. To address these gaps, this study adopted a unique approach to educational game design by developing a time-management strategy game about resource management in construction projects with unpredictable events. This paper presents the game design process and evaluation results of a single-player digital game called '*Always Under Stress*' developed using the Godot game engine. The goal of the game is to introduce resource management in construction projects and its associated challenges. The design and development steps, game engine, and workflow are discussed in-depth in relation to the learning objectives. In addition, this study explains how elements of randomness in educational game design can be used to challenge students' planning and adaptability skills. Various stakeholders (n = 31), comprising of students, professors, and industry professionals, were invited to evaluate the game across six dimensions of educational game design. Results revealed positive reception towards the developed prototype regarding educational value and critical comments regarding user experience and onboarding for beginners. The findings of this study provide invaluable guidelines, considerations and lessons learned for prospective educational game designers and researchers.

Keywords: Game-Based learning, Digital simulation game, Construction management, Resource management, Higher education, Experiential learning

1. Introduction

The construction management field is witnessing a digital transformation. In today's fast-paced digital age, there are three key industry demands for construction managers: strong theoretical understanding, adept technical skills, and transferable soft skills. These demands are compounded by the increasing difficulty of continuing professional development after employment due to the intensive work demands of the industry (Wall and Ahmed, 2008). As a result, the gap widens between industry demands and fresh graduate capabilities (Castronovo et al., 2022). In line with changing industry demands, students place more importance on the development of transferable skills and the effective use of virtual learning tools, which they considered more practical and useful for future job prospects (Ojiako et al., 2011). Consequently, the limitations of traditional teaching methods have gained considerable attention and scrutiny in recent years to ascertain the necessary changes for bridging the gap between CM education and industry demands (Pereira and Thom, 2022). Hence, there is a pressing need for a paradigm shift in the teaching approach for CM education.

In the past two decades, research in experiential game-based learning has risen in popularity to address those limitations. Game-Based Learning (GBL) refers to a pedagogical approach using a serious game or simulation model that emulates a system or process to better recognise its underlying principles and mechanisms (Kriz, 2017). Serious games vary in complexity and realism, and they have supported educators, policymakers, and researchers for several decades (Kriz, 2017). This approach is especially important for seizing the attention of the *digital natives* who were raised in the digital age (Lee, Samad and Miang Goh, 2020). Thus, this study argues that GBL offers a highly compatible method of experiential learning in the classroom for CM education. The aim of this paper is to present the design process and evaluation of a digital simulation game called *Always Under Stress*. A relatively new software called the *Godot* game engine was chosen to develop the game, and it is explained in great detail in this paper. The findings of this study provide invaluable guidelines for prospective educational game designers and researchers.

2. Simulation Games for Construction Management Education

The advantages of simulation games were discussed extensively in the literature. They provide a risk-free environment for experimentation (Dib and Adamo-Villani, 2014; Miettinen et al., 2016). Moreover, they promote experiential learning by allowing learners to engage with the subject matter directly (Oo and Lim, 2016). Reflection serves a major role in experiential learning, and digital games offer immediate, real-time feedback for learners (Miettinen et al., 2016; Perini et al., 2018). Hence, this study argues that construction management education can greatly benefit from adopting this strategy as a complementary learning tool.

Previous digital educational games in this field were mostly singleplayer experiences. In Dib and Adamo-Villani (2014), the player was a sustainability consultant who helped designers improve their buildings' environmental and economic performance. In Miettinen et al. (2016), the player was a project manager in charge of labor and change order management. In Perini et al. (2018), the player was a sustainability manager evaluating the environmental performance of a virtual company. In Kandi et al. (2020), the player was an engineer identifying design errors by walking around a virtual building. In Castronovo et al. (2022), the player was responsible for building a structure from start to finish under certain constraints. In all studies, the common thread was the kind of experience they offered learners: Linear, narrative-driven gameplay. For a breakdown of the general design parameters in digital games, see Table 1. Overall, GBL was met with positive reception as a complementary learning tool across all prior studies. Thus, further exploration in this research field is encouraged to build upon these findings.

Table 1: Design parameters of Digital Games, adapted from (Elenany and Ahmed, 2023)

Design parameter	Description
Learning Objectives	Introduction to technical skills, problem-solving, decision-making
Number of Players	1-2 players per game
Duration per level	Less than 1 hour
Strengths of Medium	Visual, interactive, adaptive, information-intensive
Limitations of Medium	Requires coding knowledge, visual-audio assets

To expand on prior efforts in this field, three new aspects of GBL are explored in this study. The first aspect is diversity in educational game design. Currently, most games relied on linear, narrative-driven gameplay with an immersion focus. This type of gameplay does not encourage replay, and students may not absorb all the information from one playthrough. On the other hand, strategy games are inherently repetitive and iterative, revisiting a concept multiple times in different variations to fully explore its boundaries and applications. One subgenre of strategy games is the time-management simulation game, which relies on strategic planning and quick decision-making to achieve the game objectives. Thus, it can be a suitable genre for simulating construction management scenarios.

Elements of randomness can emulate the risky nature of construction projects, enhancing the learning experience where risk and strategy are involved. Moreover, they would discourage memorization or following a fixed strategy. Burgun (2018) defined two types of randomness in games. The author defined input randomness as a randomized piece of information determined before the player acts. Input randomness creates unpredictable events. Thus, it can provide an opportunity for players to learn from their mistakes and increase the replay value of a game. However, the author cautioned that misuse or over-reliance on input randomness can also lead to player frustration. On the other hand, he defined output randomness as a randomized piece of information determined as a result of a player decision. For example, a player rolling a die can result in any value between 1 to 6. Based on these definitions, neither form of randomness was found in previous GBL interventions.

In prior literature, the focus was on assessing students' technical skills or factual knowledge more often than their transferable skills. Transferable skills are competencies that are not subject-specific and can be applied to a wider range of activities, such as communication and decision-making (Ojiako et al., 2011). These skills are crucial for the professional development of CM students, whose future responsibilities entail managing dynamic, unique, and complex construction projects. Thus, linear gameplay would not suffice to represent the complexity of the manager's role. On the other hand, the time-management strategy genre may be more compatible with the goal of enhancing both technical and transferable skills simultaneously. To address these gaps, this study

adopted a unique approach to educational game design and developed a strategy game about resource management in construction projects with unpredictable events.

3. Game Design Framework

Creating a game is both an artistic and methodical endeavor. Previous educational games found in the literature used different design methods, as there is currently no single agreed-upon approach (Fumarola, van Staaldin and Verbraeck, 2012). There are limited studies on the design process of educational games from pre-development to validation, which greatly inhibits the dissemination of GBL in higher education. Thus, this study explains the pre-development, development and evaluation methodology for the developed game as guidelines for future game developers and researchers. Game design can be broken down into three general phases: Pre-development, development, and evaluation. The first two phases followed the Ten-Step Design Method developed by Fumarola, van Staaldin and Verbraeck (2012) for simulation games. Lastly, the game evaluation strategy adopted the LEAGUE framework presented by Tahir and Wang (2020) as a guide to breaking down the game design into separate dimensions. This process is visualized in Figure 1. The rest of this section explains what each phase entails.

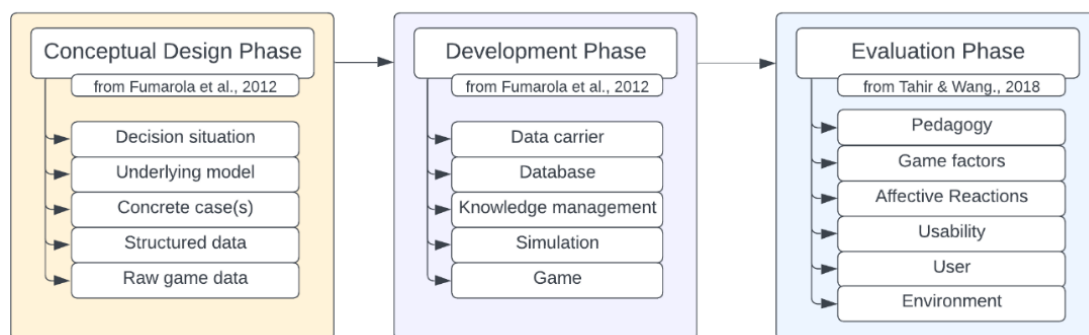


Figure 1: Visual summary of the game design process for this study

According to Fumarola, van Staaldin and Verbraeck (2012), the goal of the conceptual design phase is to prepare the blueprint for a game concept. In modern game development, the blueprint is referred to as a Game Design Document. It is recommended to develop a concise document, as details can and will change during the course of development. This document outlines all of the necessary components for developing the game. The five steps are defined in Table 2.

Table 2: Descriptions of design steps, adapted from Fumarola, van Staaldin and Verbraeck (2012)

Design steps	Description
<i>Decision situation</i>	Describe the player's role and decisions, and the game's general features.
<i>Underlying model</i>	Outline the rules and relationships in the game in relation to learning objectives.
<i>Concrete case(s)</i>	Identify the type of project(s), scope, and character(s) involved in the game.
<i>Structured data</i>	Collect and analyze real project data to form the basis for the game scenario(s).
<i>Raw game data</i>	Define in-game variables to represent the structured data.

Next, Fumarola, van Staaldin and Verbraeck (2012) state that the development phase entails creating the simulation game. This phase involves coding, storyboarding, preparing aesthetics (i.e., audio-visual feedback), and designing the user interface. There are five recursive steps involved in development (see Table 3). In other words, external feedback from play-testers during development is a valuable tool for improving clarity and usability of the game for the target audience. Thus, this framework was adopted for this study's pre-development and development phases.

Table 3: Descriptions of development steps, adapted from Fumarola, van Staalduinen and Verbraeck (2012)

Development steps	Description
<i>Data carrier</i>	Select a platform to develop and run the simulation game.
<i>Database</i>	Store and organize game data in an entity relationship model.
<i>Knowledge management</i>	Design how information is presented to the player (i.e., user interface).
<i>Simulation</i>	Create a core gameplay loop and secondary systems.
<i>Game</i>	Test and balance game flow, adding audio-visual feedback (e.g., images, sound effects).

Next, the LEAGUE framework codified six dimensions for the evaluation of any game's design: Pedagogy, game factors, affective/cognitive reactions, usability, user, and environment (Tahir and Wang, 2020). Within each dimension were factors and metrics to measure objective data (e.g., scores and time) and subjective data (e.g., ratings and reviews). Hence, this framework forms the basis for this study's game design evaluation.

4. Selecting a Game Engine

The next preparation step is to select a game development platform, known as a game engine. This engine can then export the game file as a computer application. On itch.io, a widely recognized online marketplace for independent game developers, there are over 40 game engines listed. In the literature, there was minimal research comparing game engines. In a study by Dobroskok et al. (2020), five free game engines were reviewed for use in higher education. These engines were Unity, Unreal Engine 4, Construct 3, GameMaker Studio 2, and Godot, which corresponded to the top 5 most versatile game engines (Itch.io, 2023). Thus, these options were adapted for this study's objectives. In this study, the game engine selection consisted of three criteria: scripting flexibility, accessibility, and user experience. Table 4 summarizes the main features of each engine, followed by an explanation of the elimination process to reach the most suitable option.

Table 4: Game engine comparison

Game engine	Scripting language	Availability in the market	Engine capabilities
<i>Godot 3.5</i>	GDScript (primary), C# (alternative)	Free	Downloadable software, supports 2D (primary) and 3D games
<i>Unity</i>	C#	Free (with fees for commercial games)	Downloadable software, supports 2D/3D/AR/VR games
<i>Unreal Engine</i>	C++	Free (with royalty fees for commercial games)	Downloadable software, support 3D games
<i>GameMaker Studio 2</i>	GML and Visual scripting	Free (to learn), Paid (to publish)	Runs in browser, supports 2D games
<i>Construct 3</i>	JavaScript and Visual scripting	Limited free version, Subscription-based	Runs in browser, supports 2D/3D games

First, scripting flexibility determines the engine's learning curve and complexity (Dobroskok et al., 2020). There are two types of scripting methods in game engines: Visual scripting and coding. Visual scripting uses a drag-and-drop system without writing any code (Bay, 2023). Although visual scripting is beginner-friendly, coding allows for more complex design, which is desirable for a simulation game. Thus, code-based game engines (i.e., Unity, Unreal Engine 4, and Godot) were more favored for this study over visual scripting game engines (i.e., Construct 3 and GameMaker Studio 2). Moreover, the visual script-based engines offer restricted free versions, limiting the development capacity. The second consideration is engine accessibility. Unreal Engine 4 is eliminated due to its high hardware requirement and steep learning curve; moreover, this engine is more suited for 3D game development (Wilson, 2019). Lastly, the decision between Godot and Unity is decided by personal experience. After learning the basics of each engine, Godot is favored for its intuitive user interface, beginner-friendly scripting language and organized workflow. Godot also has built-in user interface tools that streamline the prototyping process, which are not available in Unity. Thus, Godot is chosen as the game engine of choice for this study.

5. Game Design Methodology

This section describes the methodology of this study, following a three-phase process: Pre-development, development, and evaluation. The first two phases are adapted from the 10-step design framework, and the evaluation phase follows the LEAGUE framework (as in Section 3).

5.1 Pre-Development Phase

The goal of the pre-development phase is to define the game's learning objectives, then represent them in a game environment. The developed game is titled, *Always Under Stress*, reflecting the pressure of a construction manager on the job. The rest of this section explains the thought process within each step.

5.1.1 Decision situation

The first step of the pre-development phase is to define the general parameters of the game. These parameters are determined from the simulation game classification framework. Table 5 summarizes the general parameters of the game developed in this study, henceforth called the developed game. The decision situation places players in charge of procuring, monitoring, and allocating resources for a construction project.

Table 5: General parameters of the developed game, titled "Always Under Stress"

Design parameter	Description
Target Audience	Undergraduate and graduate engineering students
Genre	Single-player, time and resource management, simulation, scenario-based levels
Duration	10 to 15 minutes per level
Subject	• Introduction to procurement management • Time-cost trade-off
Learning objectives	• Factual knowledge: Resources involved in construction projects • Technical skills: Time and cost management, Risk response • Transferable skills: Planning, Decision-making, Adaptability, Handling uncertainty
Game objectives	Complete the project with three objectives: • Before the deadline • Within budget • Reach a target profit margin
Decision situations	• Choose from a set of suppliers with different prices and lead times • Plan ahead to avoid delays • React to randomized risk events

The gameplay loop is the recurring decision pattern of the player towards achieving a certain goal. In this game, the player's recurring decision is to choose from a set of suppliers with different prices and lead times, then initiate construction work until all activities are completed. The core gameplay loop is illustrated in Figure 2. Similar games in the management genre include *Virtual City* (2009), *Royal Envoy* (2010), and the *Build-a-Lot* series (2007-2020).

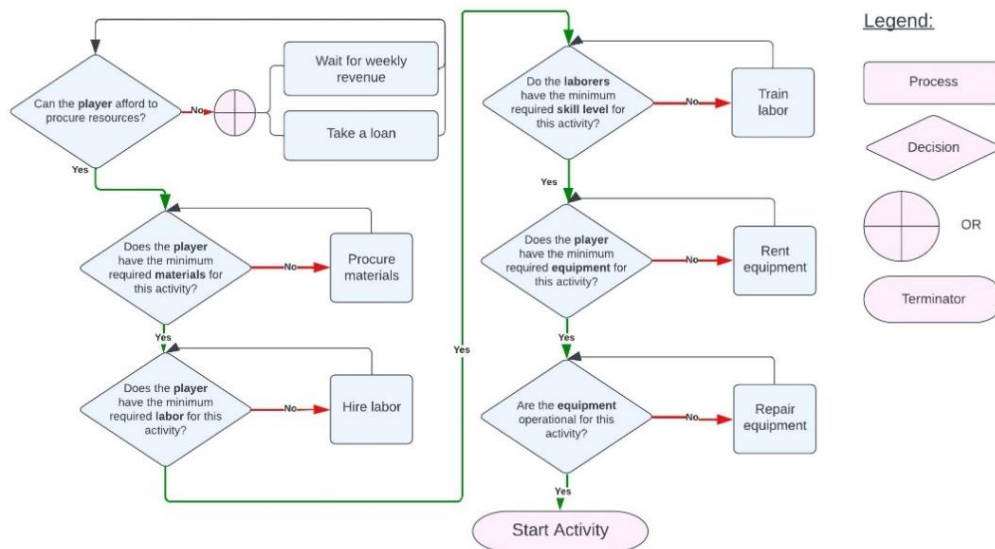


Figure 2: The core gameplay loop of the developed game (starts at the top left)

Furthermore, secondary gameplay elements are systems added to enhance the gameplay loop. The player must plan ahead to avoid delays, consider taking out a bank loan, and react to random risk events. The idea of random risk events draws inspiration from real-time strategy game, *Plague Inc.* (2021). With these parameters established and similar games available to draw inspiration from, the next step is to develop the underlying model of the simulation.

5.1.2 Underlying model

The underlying model is the second step in the pre-development phase where learning objectives are translated into game objectives. Moreover, this step is concerned with establishing the rules and relationships of the simulation game. Figure 3 illustrates the relationship between the variables in the developed game. A top-down approach is adopted for developing this relationship chart, starting from the game objectives (i.e., schedule and budget). Then, decisions are linked to each objective.

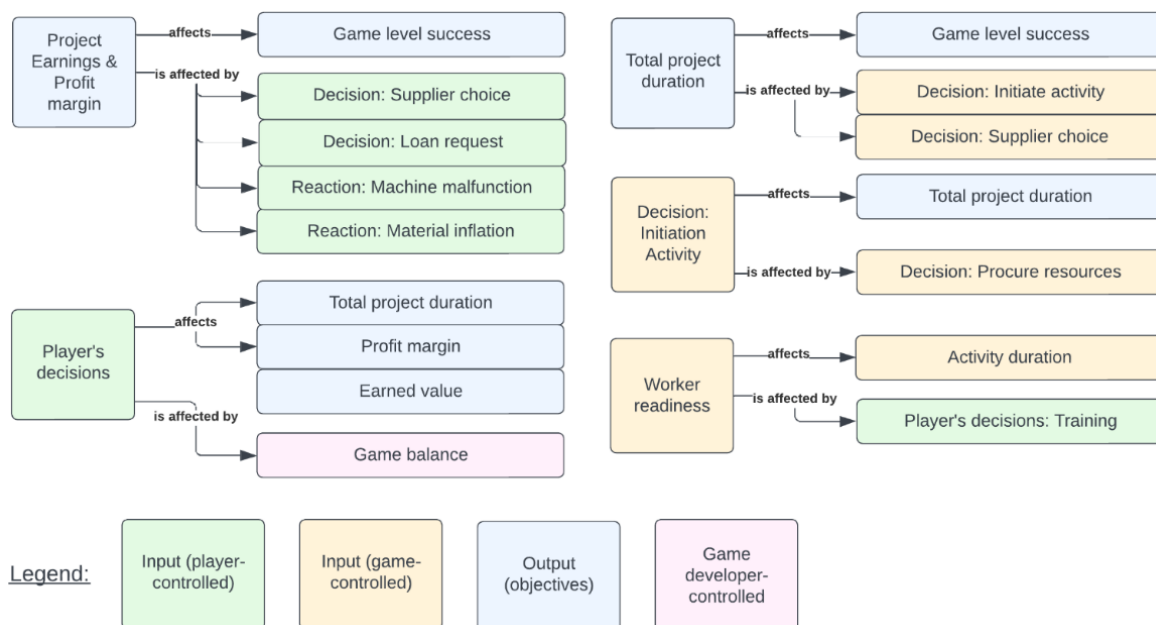


Figure 3: Illustration of the relationship chart for the developed game

By defining the relationship chart, game mechanics from established titles can be adapted. To avoid scope creep, game elements are sorted into a priority list under one of three categories: Educational, Motivational, or

Accessibility features. Narrowing down the most important variables is necessary to establish a core gameplay loop. Next, concrete cases are needed to create each level.

5.1.3 Concrete cases

The concrete cases step involves gathering data from real-life projects to define game scenarios. For this game, a simplified linear construction schedule is chosen. Second-hand information is collected from YouTube videos (see Table 6) to determine the general order of activities involved in different infrastructure projects, namely bridge and highway construction.

Table 6: Some construction-scenario videos found on YouTube

Title	Notes	URL
<i>"How Modern Roads Are Built? Highway Construction Process"</i>	General highway construction activities + associated resources	https://youtu.be/juWc-DpFolY?si=QH4j-TYWXfWrR6lB
<i>"Building Construction Process step by step with Rebar placement"</i>	Activities related to building foundation	https://youtu.be/vkew-1KK3Sc?si=obBNuVOLT3zRou4l
<i>"12 Steps of Construction"</i>	General site preparation activities + associated resources	https://youtu.be/mbwuj58UEPg?si=m6K47uhLI5p5cD1V
<i>"Every Bridge For Every Situation, Explained By an Engineer A World of Difference WIRED"</i>	Introduction to bridges, helped with finding the simplest bridge type for a beginner scenario	https://youtu.be/1bUnFjMOrPs?si=Mxs7Jpo7HAPgE-3e

The benefit of this approach is to simplify design while representing the general work involved in real construction projects. For a prototype, this method accelerates the design process without compromising validation of the game concept. With content established, the final step in the pre-development phase is to define variables in the simulation model.

5.1.4 Structured and raw game data

The structured data are the simulation components while raw game data refer to the variables being manipulated by the player. For this prototype, the project objectives are tied to two constraints: Time and Cost. Thus, the player's input is the decision to procure resources required for construction projects within time-cost limits. Four types of resources are selected for the developed game: money, materials, equipment, and labor, as described in Table 7.

Table 7: Description of in-game resources and their characteristics

Variable / Resource	Characteristics	
Money	- Small starting amount is given to the player - Earned from completing construction activities - Can be loaned from the bank with a high interest rate	
	Unique characteristics	Shared characteristics
Materials	- Risk of faster decay - Risk of inflated prices	- Has a time limit until it expires and cannot be used anymore - Risk of supplier delay
Equipment	Risk of malfunction	
Labor	Each labor type has different training requirements: - Foreman, Driver (no additional training) - General workers (1 training cycle) - Tradesmen (2 training cycles) - Equipment operators (3 training cycles)	

Hence, these resources become in-game variables that the player manipulates to achieve the game objectives. Thus, the player gain contextual understanding of these terms. With all the design elements established, the development phase can begin.

5.2 Development Phase

The second phase of the game design process is the development phase. This study argues that development should focus on building a prototype to validate the game concept before committing more resources for polish. This section explains the development steps of the prototype.

5.2.1 Data carrier

The Godot game engine is the chosen data carrier (as explained in Section 4). The engine runs on GDScript, a Python-like custom coding language. It is suitable for beginner programmers due to its intuitive workflow and built-in features for full stack development (i.e., user interface and system code). To share the game with participants, the game is hosted on itch.io, and it can be accessed with a private link. Thus, participants can access the game from their own devices.

5.2.2 Database

For a simulation game, the Entity-Component-System (ECS) design pattern is implemented. This design pattern determines how game elements are created, organized, and linked to each other. A *component* is an object with a singular purpose; an *entity* is an object comprised of components; and a *system* runs code that manipulates entities and components during the course of the game. This approach is greatly complemented by Godot's *Scene-Node-Script* structure (see Figure 4).

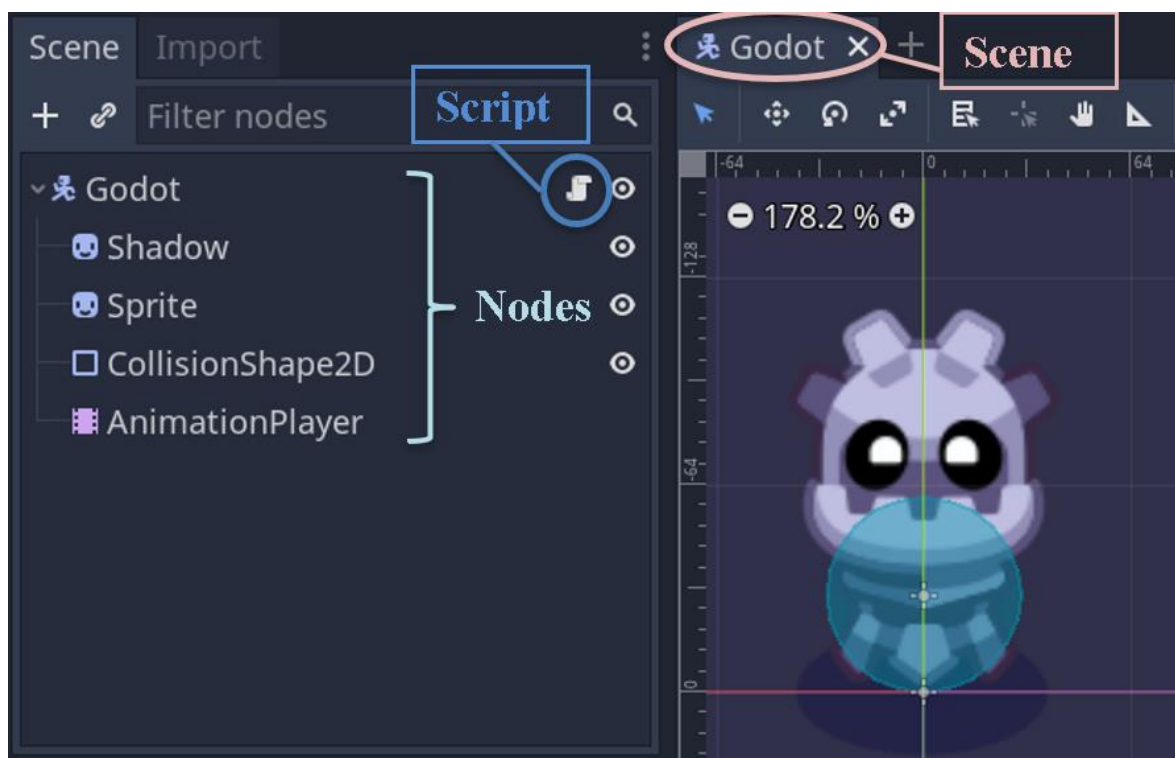


Figure 4: Object-oriented programming in Godot

In the Godot engine, every object is a *node*, and every node has a unique purpose (e.g., button, panel, character). Moreover, a *scene* is a collection of nodes organized in a parent-child hierarchy, and a *script* is attached to a node to run code. In most scenes, the scene's parent node is attached to a script that handles all children nodes' functions. This workflow allows for modular development. Each system can be edited or removed with little to no effect on other systems. The Godot engine also supports global scripts, which store information shared across all levels, such as audio-visual files and constant variables. Lastly, signals in Godot allow nodes, scenes, and scripts to react to player input. The full stack development process is described in the next step.

5.2.3 Simulation

The goal of this step is to establish the core gameplay loop. Using Godot, the following work pattern is adopted:

- **Step 1:** Construct a scene out of nodes
- **Step 2:** Write the system script that manipulates the constructed objects

- **Step 3:** Write the UI script to reflect system information to the player
- **Step 4:** Connect the scenes, systems, and UI scripts using signals.

All of the code is developed in a test environment, then duplicated to create individual levels. Thus, any changes to the code in the test scene would automatically apply to the individual levels because they share the same attached script.

5.2.4 Knowledge management

Development is inherently a recursive process, and it requires continuous testing and external feedback to improve, as seen in Figure 5. For this study, the game is treated as a standalone learning tool to identify its strengths and weaknesses outside of a classroom setting. Hence, any pre-requisite information that the player needs is presented in the game.

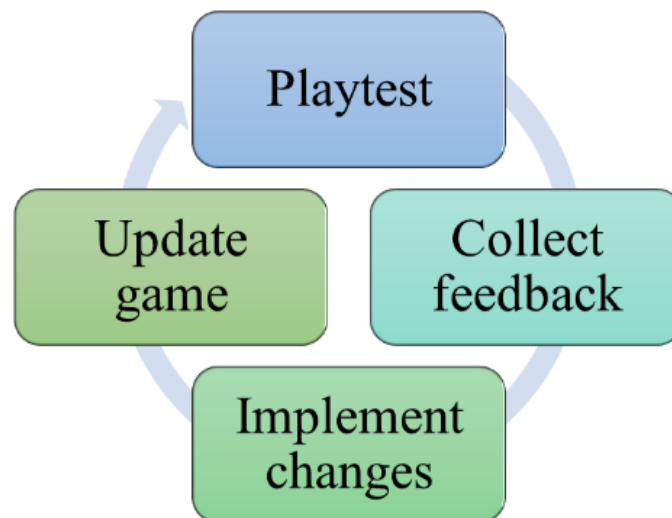


Figure 5: The cyclic workflow of the development step

The user interface consists of different systems to convey information to the player. It is responsible for signaling the players in the right direction when they are lost. To support this need, a short tutorial level is added to acquaint the player with the rules and controls of the game.

5.2.5 Game

To ensure balanced gameplay, debugging is needed, which refers to testing the game for unexpected or undesirable outcomes. Game elements are adjusted often to achieve a balance of fairness and challenge for players. Play-testers are encouraged at this step to gain feedback from the target audience and improve accessibility. The user interface is expected to undergo the most changes throughout the course of development.

5.3 Evaluation Phase

For this study, evaluation is carried out in three different forms: A pilot study, a quasi-experiment for students, and semi-structured interviews with other stakeholders. All participants will be referred to using unique identifiers where needed. The rest of this section describes the methodological steps involved in each step of the evaluation phase.

5.3.1 Pilot study

The goal of the pilot study is to play-test the game for accessibility, information clarity, and immersion. Thus, participants with little to no background in construction management are selected to identify areas of improvement in those aspects. A convenience sampling strategy is adopted to gather feedback quickly and efficiently. Based on the most recurring comments, changes may be needed to improve the usability. Specifically, concerns related to the core gameplay loop are prioritized while suggestions that expand on existing game mechanics are noted for future work.

5.3.2 Students' quasi-experiment

A quasi-experiment is designed to determine the educational value of the game, based on how well the game objectives translated into understanding factual and conceptual knowledge of construction management concepts. A systematic sampling strategy is used for the quasi-experiment, specifically targeting undergraduate and graduate students currently enrolled in an engineering program.

The student survey consists of six sections. The first section is about demographic information. The second to fourth sections ask about gameplay experience. The last two sections are identical knowledge tests, presented before and after playing the game. Table 8 lists the knowledge test questions from the survey. Comparing these two tests sheds light on how well the game improved students' understanding of resource management.

The questions are categorized according to Bloom's taxonomy. The first two questions check students' attentiveness to construction-related keywords found in the game. The third question assesses students ability to describe a term not directly defined in the game based on context. Specifically, words like *contract*, *supplier*, *quantity*, and *price* are expected in the answers, as these are the keywords used directly in the game. The fourth and fifth questions require attention to details as another indicator of students' active learning. The last question asks players about their risk response strategy, both hypothetically (in the pre-game test) and during the simulation (in the post-game test).

Table 8: Knowledge Test Questions

No.	Test Question	Bloom's Taxonomy Level
1	What is/are the core objective(s) of any construction project from the contractor's point of view? (Note: a contractor is a company in charge of building structures, e.g., buildings, bridge, road)	Remember (1)
2	What are the types of resources needed for any construction work?	Remember (1)
3	What is a purchase order?	Understand (2)
4	What are some criteria for choosing the best resource suppliers?	Remember (1)
5	What are some risks that could negatively impact reaching the construction project's objectives?	Remember (1)
6	How would you respond to the risks mentioned in the answer to the previous question?	Apply (3)

A point system is used to determine the extent of the students' improvement in understanding new concepts. If the response was *I don't know* or incorrect, it was awarded 0 points. If the response was partially correct, or lacked keywords mentioned in the game, then it was awarded 1 point. When a students' response was descriptive with in-game keywords or was improved from their pre-game test response, it was awarded 2 points.

5.3.3 Interviews with other stakeholders

Semi-structured interviews are conducted to collect qualitative feedback from non-student perspectives. The stakeholders include professors, industry professionals, and engineering alumni, selected using purposive sampling strategy. The shared trait among all selected participants is having prior work experience in the construction industry. The participants are invited to either play the game or watch a demonstration, then share their thoughts on the game's educational value and implementation in higher education.

6. Results and Analysis

Various stakeholders were invited to share their opinions on the developed game with respect to the six dimensions of game design evaluation: User, Affective/Cognitive Reactions, Learning, Game Factors, Usability, and Environment, as per the LEAGUE framework. The following sections discuss the strengths and weaknesses under each dimension, supported by feedback from the respondents.

6.1 Profile of the Participants

In total, 31 participants were involved in the study at different steps. The distribution of participants are illustrated in Figure 6. Moreover, Figure 7 provides more information on the distribution of participants' gender and prior game exposure. The majority of participants have played games for entertainment in the past three months, but less than half played a simulation game in particular.

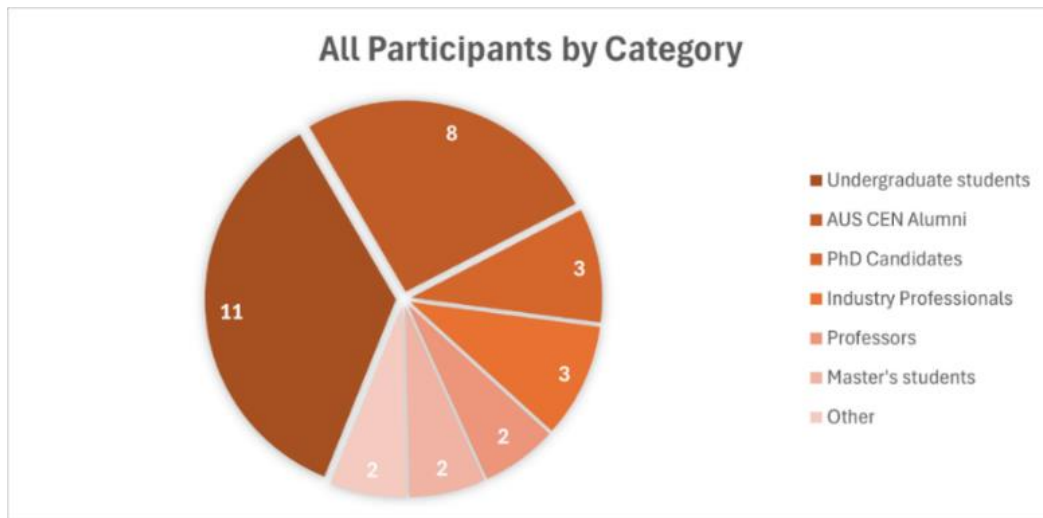


Figure 6: Distribution of all participants by category

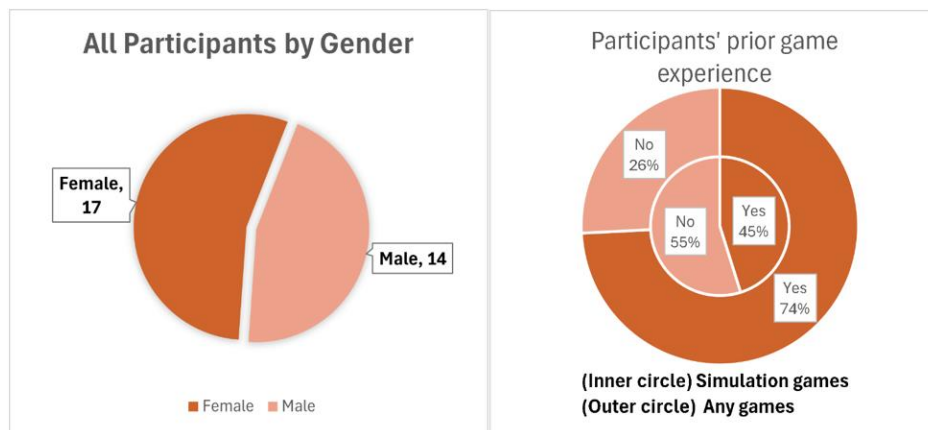


Figure 7: Demographic information. (a) Gender, (b) Prior game experience

12 students in the quasi-experiment portion of the study, whose demographic information is presented in Figure 8. The majority of students did not have prior exposure to CM concepts, either from an internship or from a university course. Therefore, this study assumes that the difference in knowledge before and after playing the game is mainly derived from the gameplay experience.

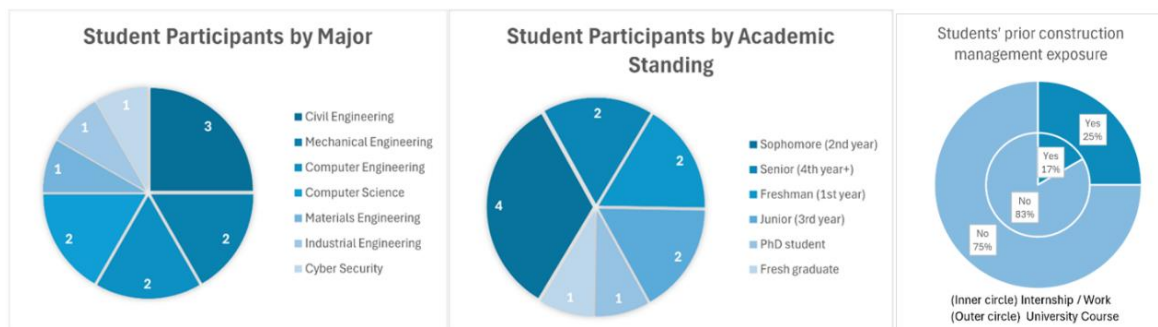


Figure 8: (left) Major, (middle) Academic standing, (right) Prior exposure to CM

The wide range of perspectives led to a well-rounded evaluation of the current prototype. The goal of this evaluation is to highlight the strengths and areas of improvement of the developed game as well as shed light on educational game design advice for future researchers.

6.2 Evaluating the User Dimension

In the LEAGUE framework, the User dimension assesses the extent to which the cognitive and psychological needs of the user are considered in the game. The intended target audience for the game is undergraduate

students new to construction management. Regarding cognitive needs, the user should be gradually introduced to the game rules. Hence, a tutorial level is created to guide the player on a small scale. Second, there should be adequate visuals attached to new keywords. For the developed game, one participant said the use of unique images to represent each material, equipment, and laborer is *visually appealing* and *aids in understanding*. Regarding the psychological needs, participants may feel stressed at certain points of the game, especially players who are new to time-sensitive games. To accommodate for this, the player is able to pause or restart the level if the current run feels hopeless.

6.3 Evaluating the Affective/Cognitive Dimension

Open-ended survey questions served to gain insight into the players' gameplay behavior and experience from both cognitive (learning) and affective (feeling) lenses. These questions were shared among both students (labelled S) and interviewees (labelled I) who opted to play the game. These insights inform better game design practices in the future for simulation games that are minimally discussed in the literature.

When asked about their feelings towards the game (see Figure 9), most participants agreed that it was challenging but useful. Moreover, most players put considerable effort, though not all of them felt confident in their abilities. These reactions are expected, as the game was designed to challenge the players in an area they are unfamiliar with. In addition, this distribution of feelings indicates that the difficulty of the game did not impair the players' perception of its usefulness as a learning tool.

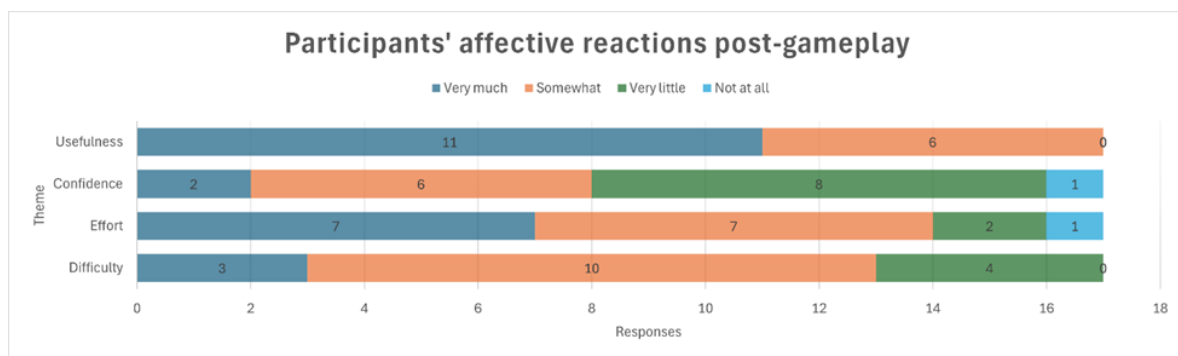


Figure 9: Affective reactions post-gameplay

When asked to describe what players liked, 9 participants praised the developed game's ability to simulate resource management of construction projects in a *fun yet challenging* manner suitable for undergraduate students. Specifically, one student called it a *fun brain exercise* (S8), and another said it was *both educational and enjoyable* (I2). Furthermore, 8 participants applauded the level scenarios for being realistic or reflective of a real-life experience. This realism also enhanced the immersion of the game, as one student admitted, *at some point I forgot I was playing it for reviewing it* (S6). Some students highlighted specific in-game tasks that supported this view, as follows:

"Even the tiniest detail of training labor or having them get injured or not having enough space on site was amazing." (S6)

"There were day-to-day issues and management that surprised me to see in a game but would not have surprised me to see in real life." (S7)

"I liked the random events that can occur to ruin your run, they're not intrusive enough to be annoying but just enough so it can add to the challenge. it was pretty exciting to try and work under a time limit." (S8)

"included most of the details that are usually involved in construction projects, such as unexpected delays, storage space issues, etc." (I3)

In the next section of the survey, student participants were asked about their cognitive reactions towards the game (see Figure 10). Regarding their feelings towards the time spent in the game, they were split on whether it was worth it or not. This was the only statement with the most diverse opinions. Conversely, there was a majority agreement about the game being thought-provoking, enjoyable, and aligned with its learning objectives. In addition, most students agreed that they played an active role in their learning during the game.

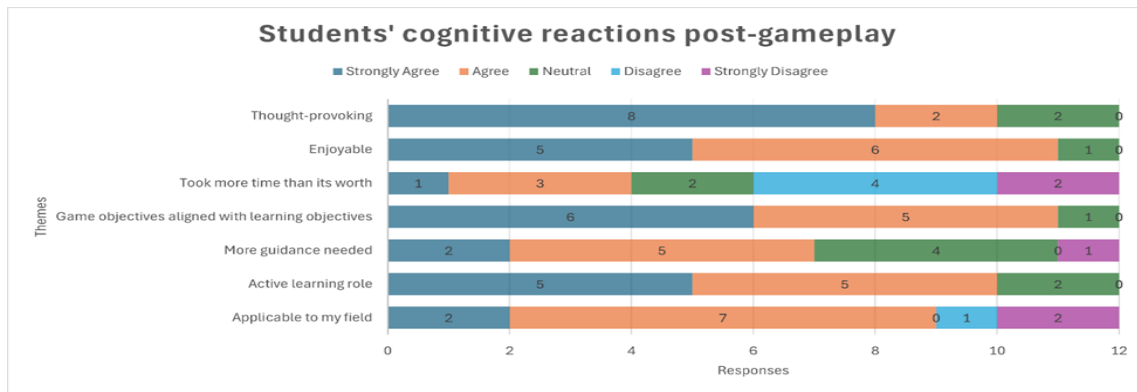


Figure 10: Students' cognitive reactions post-gameplay

Based on these results, the students' perception of the game was mostly positive and aligned with the objectives. The next section will discuss how these feelings translate into knowledge gained according to the results of the pre-game and post-game tests as well as participants' reflections.

6.4 Evaluating the Learning Dimension

The learning dimension is concerned with evaluating the educational value of the developed game. Generally, the majority of players agreed or strongly agreed with the statement of gaining a better understanding of several learning objectives, technical and transferable skills, as seen in Figure 11.

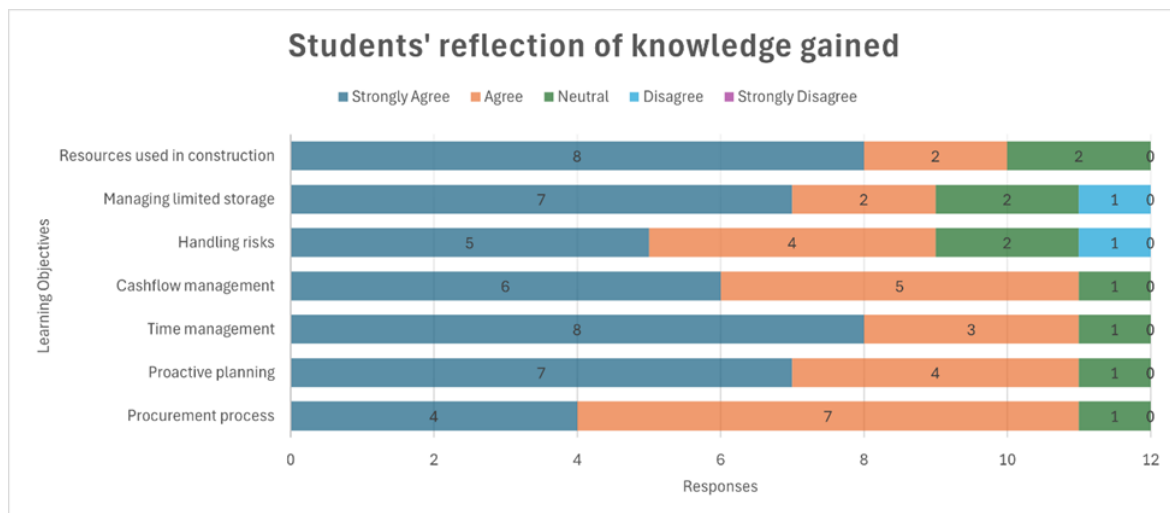


Figure 11: Students' reflection of knowledge gained

When asked to describe their most important takeaways from the gameplay experience, the participants recognized the value of *planning ahead* (S2, S6, S8, I4), *adapting to change* (S2, S6), *strategic thinking* (S6, S8), and *decision making* (I5). In addition, one computer engineering student (S9) found the game approachable and relevant for their career development despite construction not being their major. Regarding specific moments during the game, some participants shared their observations:

"now i know the importance of keeping track of time and money in a construction project and there were several factors that i didnt think of such as material getting expired or machines breaking down and need fixing." (S3)

"Buying cheap material is not always the best solution." (I1)

Furthermore, a couple of AUS alumni praised game-based learning as a novel approach that they had not encountered before. They reflected on the usefulness of the developed game as a learning tool for undergraduate students, describing their views as follows:

"I really like the idea of having a simulation game being introduced for undergraduate students, as it allows them to step into the shoes of a manager and make important decisions and then face the

consequences of those decisions. It gives you a new perspective and prepares you for managerial roles.”
(I2)

“This kind of simulation games is a very useful idea to help students understand how construction project management works and to give them a close resemblance of real-life project management experiences.”
(I3)

For the knowledge test component of the survey, the student participants were given six questions. Figure 12 present the results of the pre-game and post-game tests, respectively. Overall, there was 115% improvement across all questions (from 19 to 41 total 2-point answers), mostly shifting from 1-point to 2-points, with the exception of questions 3 and 6. For question 3, three students did not change their answers, two students improved significantly (from 0 to 2 points), and one student did worse (1 to 0 points). 5 participants recognized that the role of a manager was *important* (S4, S7, S12), *difficult* (S1, S11), and even *risky* (S1). As one student wrote, *management has a major responsibility to be as focused as possible to keep track of everything for the sake of the health of the project* (S7).

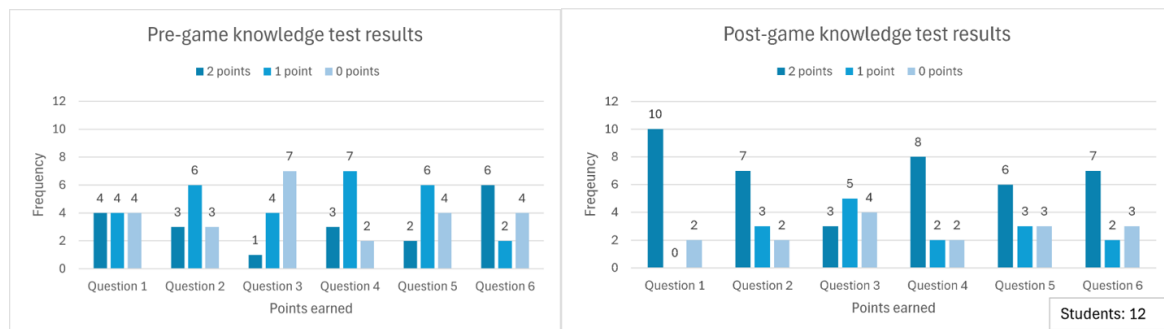


Figure 12: Pre-game (left) and post-game (right) knowledge test results

The students’ recognition can be attributed to the inherent difficulty in the game. The next section will discuss the players’ reactions to the game factors.

6.5 Evaluating the Game Factors Dimension

Assessing the replay value of the game was one of the goals of the study. Previous studies mostly focused on evaluating the extent of learning through playing a game once. However, this study argues that there is added value in learning gained from repetition, and there must be some variety and challenge to the gameplay to incentivize replaying the same level as a means to learn from past mistakes. Figure 13 shows how often each level was attempted. All participants attempted Level 1 while fewer continued to Level 2. Moreover, most players played each level once or twice at most, and 5 players repeated the same level 4 or more times with the highest repeat count at 10 times. This number may include restarts in the middle of the level. In the survey, the participants were invited to play for as long or as little as they wished.

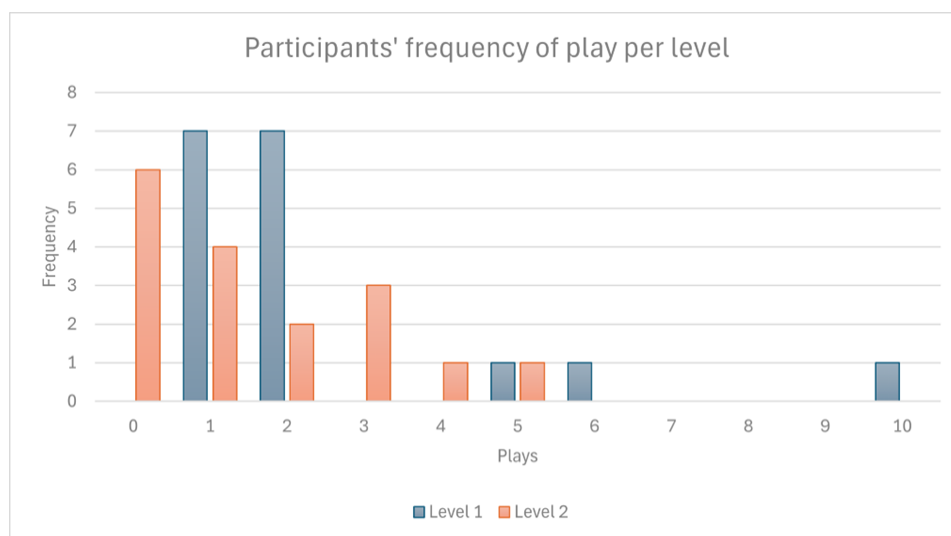


Figure 13: Frequency of play per level

Figure 14 presents the distribution of time spent in the game. 10 out of 17 players spent between 10 to 40 minutes on the game, and two people spent up to 90 minutes. Regarding gameplay, the participants rated each task based on how easy or difficult it was to execute (see Figure 15). According to these results, the core gameplay loop was considered mostly very easy or somewhat easy (e.g., starting activities, selecting suppliers) while the most difficult tasks were the secondary game mechanics (e.g., responding to risks). Monitoring and tracking tasks were also deemed mostly somewhat difficult. Thus, adding the option for an auto-tracking system in the game may be helpful for players. When asked about personal factors that may influence their game performance, the players were given several options to consider (see Figure 16). Most respondents stated that they were not familiar with the subject and yet found it interesting and pleasant. Most notably, the game was not considered easy or luck-based by at least half of the participants. These results suggest that those players perceived their success or failure as a consequence of their own decisions rather than a system-influenced outcome.

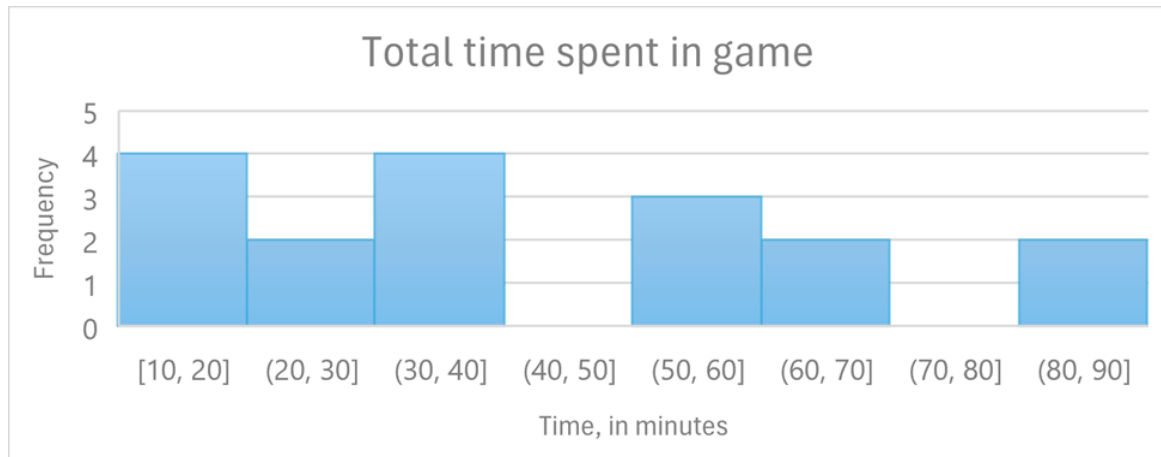


Figure 14: Total time spent in game

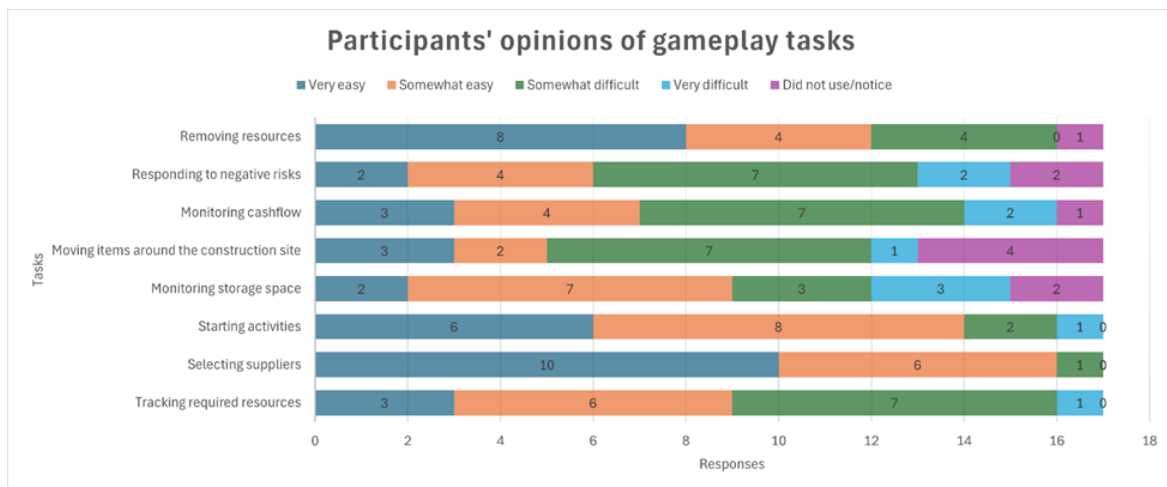


Figure 15: Participants' opinions of gameplay tasks

Time management was one of the intended challenges in the game. 7 players (S1, S3, S5, S7, S9, I1, I2) mentioned struggling with the time scale in the game. This issue impacted the core gameplay loop, as it conflicted with the goal of careful decision-making. To address this concern, a few suggestions were provided. One alumnus (I1) recommended presenting time in the game in terms of minutes and seconds, rather than days and weeks. Three participants (S6, S12, I2) offered a different solution: *Customizable pacing*. This option would allow the player to slow down or speed up time to fit their own pace. This suggestion is commonly found in contemporary simulation games and was noted down for future development.

Most students mentioned focusing on the time objective over the cost objectives. In fact, 66% of students described actively changing their strategy to be within schedule. Some students planned each task at a time (S6, S7, S9) or prioritized the cheapest supplier (S8), leading to delays and missing the schedule objective. Upon

repeating the level, they realized the importance of planning ahead and adopted that strategy moving forward, as described in their own words:

“after noticing that I am late on schedule I decided to risk it by managing tasks and ordering resources beforehand while the previous task is being done, which was kind of confusing at first, but saved alot of time eventually” (S6)

“eventually i started hovering over the future steps and ordering materials in bulk so i have them on hand even if they were not needed immediately. i had to think of future plans to cut down on lead time” (S7)

“the more I played and understood the mechanics, I changed my strategy to thinking ahead and making using of resources efficiently” (S9)

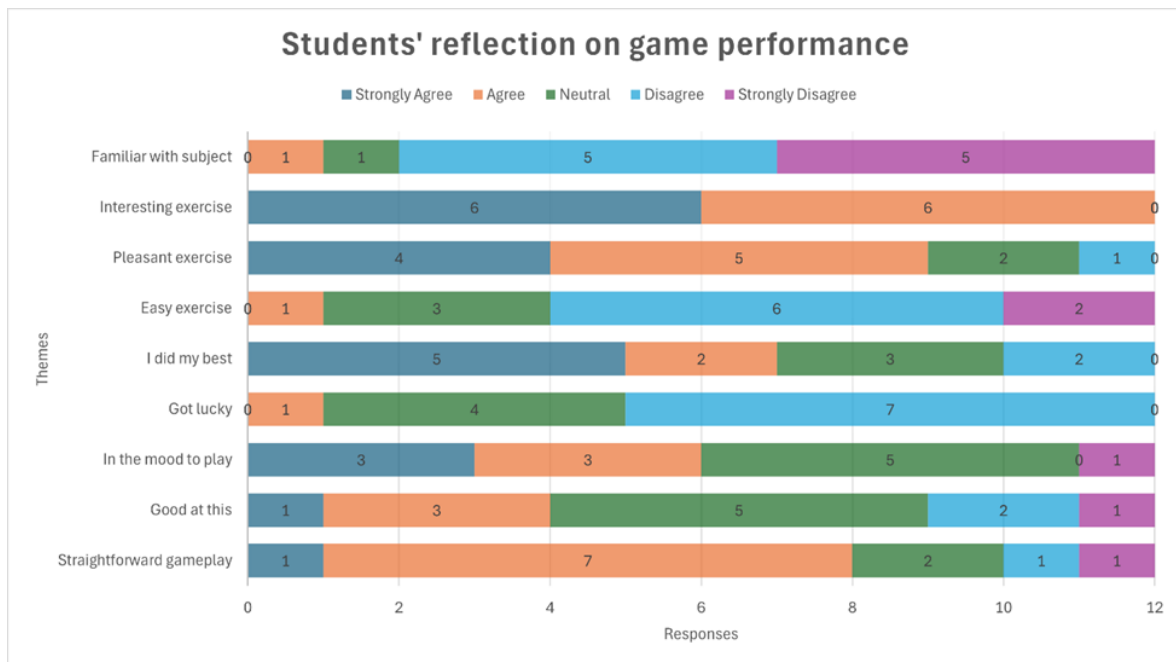


Figure 16: Students' reflection on game performance

Regarding the limited storage space, some students observed patterns that helped them play more efficiently. When asked about their strategy, their accounts were as follows:

“making sure I manage my limited resource space and knowing what to keep because I might need it for the future while removing other resources I don't need to make room for the ones I do need” (S8)

“Procure from standard supplier at first. Buy stuff for later stages from the economic supplier. Buy labor last since their contracts expire faster than the equipments'/materials decay” (S12).

In sum, students' reflections share crucial insights into how players think and consequently how learners approach a new subject. The core gameplay loop was deemed simple yet challenging, striking a balance that is often difficult to achieve. However, there were some aspects of the game that needed more revision, specifically within the usability dimension.

6.6 Evaluating the Usability Dimension

The user interface received mixed comments from the respondents. On the surface level, professors (I6, I7), industry professionals (I8, I9, I11), and some students (S10, S11) commended the *overall look* or called it *impressive* for a first-time developer. On user interface, they rated each UI element for how clear or confusing it was to interact with (see Figure 17). Most UI elements were considered *very clear* or *somewhat clear*. *Error Messages* and the *Manager's Manual* went unnoticed by a handful of players, suggesting that the game may have lacked proper signals to alert the player. Some participants mentioned that the error messages did not remain on the screen long enough to be read fully. In addition, the lack of sound effects could be part of the issue as well.

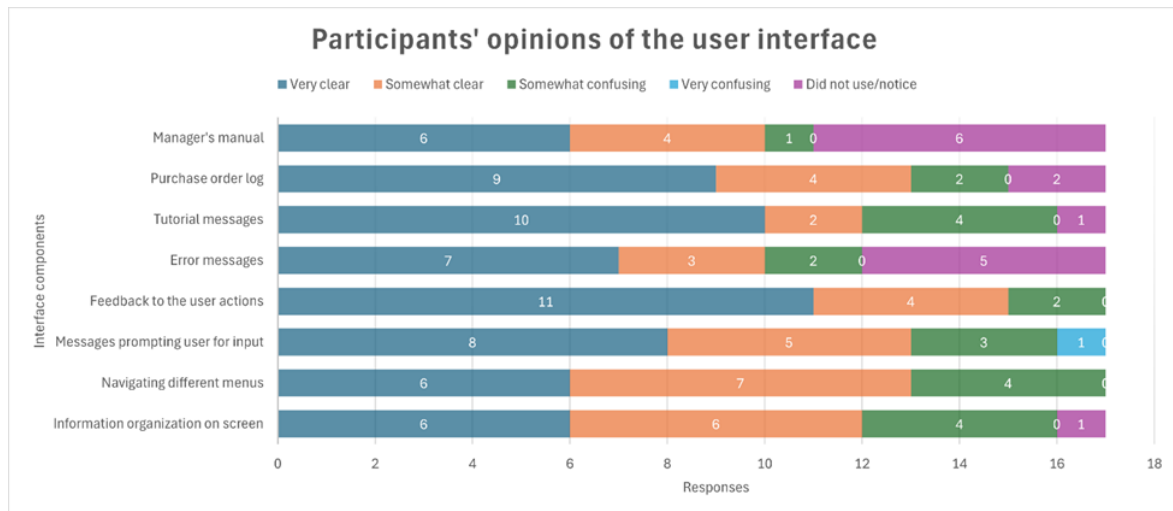


Figure 17: Participants' opinions of user interface

Although the content and gameplay met the learning objectives of the game, several players struggled at the start to get acquainted with the simulation. 5 students suggested having a more interactive tutorial, and this statement was also common among the play-testers from the pilot study. The current tutorial is a text-based set of instructions with screenshots of the user interface. A fellow game developer [S9] commented:

"[it is] generally a bad practice to have essay blocks as tutorials, a better approach would be a "guide step-by-step" tutorial where the tutorial teaches the player as he's playing the game."

6.7 Evaluating the Environment Dimension

The environment dimension is concerned with the technical requirements to run the game as well as the context for playing the game. In this study, all players accessed the game in-browser on their own devices. When asked about classroom implementation, one professor suggested three different scenarios: as a group in-class activity for first-year students, as an individual assignment for second-year students, and as a formal assessment tool for final year students. Many respondents considered the game suitable for the university level. Five respondents mentioned that the game shows promise as a commercial product. One respondent suggested adding complexity tailored to the specific needs of contractors. Likewise, another respondent suggested that companies with graduate programs may be interested in particular.

7. Summary, Conclusion and Future Work

The aim of this study was to discuss the design method and evaluation results of a single-player digital game called *Always Under Stress* developed with the Godot game engine. The goal of the game was to teach resource management in construction projects. The design development steps, game engine, and workflow were discussed in-depth. Moreover, this study showcased how elements of randomness can be used in an educational game to challenge students' strategic planning and adaptability skills.

Participants generally agreed that their learning experience was positive and enjoyable. The elements of randomness in the game proved to be a formidable challenge, particularly reacting to random risk events. The students' self-reflection mirrored their improvement between pre-test and post-test scores. The core gameplay loop was considered engaging and interesting though the tutorial should be revamped to facilitate onboarding new players. Similarly, the user interface can be made more intuitive. Overall, this outcome places the game prototype in a positive position to move forward with further development.

The goal of every GBL study is to get one step closer to implementation. For digital games, some useful applications would be in online or blended learning classrooms, where the students need more interactive activities to engage with the subject material. For future work recommendations, there is a need for more longitudinal studies to assess the impact of game-based learning in the long term.

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Ethics and AI Statement: The authors state that no Artificial Intelligence tool was used in any part of this study. Ethical approvals have been obtained with precautions taken to ensure participants' informed consent and confidentiality.

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Implementation of Game-Based Learning in Educational Contexts: Challenges and Intervention Strategies

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Abstract: In addition to being a fundamental part of human culture, games are also important for social interaction, personal growth, and development. These premises have led to a growing body of research on game-based learning (GBL) as a pedagogical advance in both formal and informal education. Even though GBL has many potential benefits, some challenges need to be taken into account while developing and implementing GBL. In this context, the goal of this study is to accomplish two goals: (a) map the primary barriers encountered when applying GBL approaches in educational settings; and (b) provide an intervention diagram that links each kind of barrier with potential strategies to overcome it. To achieve these aims, a Systematic Literature Review (SLR) was carried out using the PRISMA criteria and methodology. This includes procedures for eligibility and screening that were based on inclusion criteria that were established with the goals of the research. The analysis of the articles obtained for the systematic review reveals four different types of barriers to more regular GBL implementations. These barriers include (1) behavioural and attitudinal barriers; (2) school policy barriers; (3) material and technology barriers; and (4) barriers related to game literacy. Based on these barriers, we propose certain methodological strategies that might help practitioners get beyond the identified barriers. The strategies include: (a) adopting a participatory-driven and co-creation approach; (b) carefully considering whether to use digital, analogue, or hybrid games; (c) using a range of educational actors in the process; and (d) pushing for GBL training in projects. It is possible to argue that attitudinal barriers are related to the other barriers that have been discussed. For example, material barriers affect teachers' belief that there are currently not enough suitable educational games. Although policy makers' attitudes can be examined as a part of the macro-level attitudinal barriers, the effectiveness of their measures in the daily educational context is influenced by a separate set of barriers, which will now be investigated. Assessment literacy in GBL refers to teachers' beliefs about adopting games and how these affect students' motivation and cognitive development and is similar to an attitudinal aspect. In line with this result, it can be stated the potential strategies are also interrelated. Co-creative processes can be enhanced by integrating a multi-stakeholder approach to GBL, where finalized entertainment works successfully reflect the experiences of all participants. This article corroborates, evaluates, and groups the intervention streams as the basis of a comprehensive program of intervention where existing scientific literature on studies of GBL interventions naturally suggests the solutions.

Keywords: Game-Based Learning, Education, Games, Barriers, Systematic literature review

1. Introduction

The benefits of using gamified concepts in education have been extensively studied. However, previous research has primarily focused on the potential advantages of Game-Based Learning (GBL); comparatively little has been written regarding the difficulties and obstacles associated with using GBL methods. Even though GBL has many potential benefits, there are also challenges as well as drawbacks that need to be taken into account while developing and implementing GBL. The purpose of this article is to examine and comprehend the barriers and hindrances to the efficient implementation of GBL in educational contexts. It's challenging to include games in course designs. This research consolidates the most commonly encountered challenges in GBL and presents an intervention scheme tailored to those challenges. This goal elicited the following research questions:

- What are the main obstacles experienced in the implementation of GBL approaches in educational contexts?
- How can we offer an intervention diagram that connects potential strategies to overcoming these obstacles?

1.1 The Role of GBL in Education

Games have been an integral component of human culture for thousands of years, fulfilling diverse functions ranging from amusement to fostering social connections and enhancing cognitive abilities. The advantages and uses of games are wide-ranging. By connecting imagination and reality, games that support children's social development allow them to expand their horizons (Vygotsky, 1978). Games are fundamental to children's cognitive development and evolve with it (Piaget, 1962). Games enable the integration of extrinsic and intrinsic motivational elements, fostering an environment where players are more inclined to engage in the desired behaviours (Hartt et al., 2020). Games intrinsically stimulate and maintain players' attention, drawing them in. In the past decades, advances in digital technology have facilitated the emergence of GBL as a form of pedagogical innovation in formal and non-formal education. GBL is generally characterized as "the application of game design features in a non-game situation" (Deterding et al., 2011, p. 10). In order to cover the subject in depth, it is necessary to explain what GBL is. In order to engage students in learning success, GBL incorporates certain gaming elements into real-life scenarios (Liu, Shaikh, and Gazizova, 2020). In general, the term "game-based learning" describes an educational approach that uses a game or game-like components to motivate students (Van Eck, 2006). Another relevant definition in an educational context is that GBL is the act of solving issues and engaging people by employing game thinking and game mechanics (Zichermann and Cunningham, 2011). GBL encourages students to learn via experience. Since GBL exercises differ from those in the usual curriculum, they could be seen as a way to break up the routine and get students more interested in learning new material. The learning experience in GBL is created by the game itself. Teachers can model complicated systems and reproduce phenomena in an environment that is provided by GBL techniques. Students may apply and test what they have learnt from lectures and study materials in a gamified learning environment. In order to comprehend the underlying impacts and find effective designs, researchers have studied and created different kinds of GBL structures over the past decade (Ke, 2016; Linehan et al., 2011). To encourage students to engage in activities that support computational thinking, game elements—specifically, clear goals and rules, progressive difficulties, instant feedback, story, avatar, social engagement, and varied reward systems—were employed (Wang, Cheng, and Li, 2023). There is a clear consensus that games should be useful teaching tools and some studies have found that games have positive effects on educational outcomes.

Studies have found that GBL enhances students' understanding and improves the achievement of learning objectives for a given course or class (Barzilai and Blau, 2014; Liu, Shaikh, and Gazizova, 2020; Karakoç et al., 2022; Riopel et al., 2019; Sung et al., 2017) and computer educational games positively impact students' academic achievement motivation (Partovi and Razavi, 2019). One of the main advantages of GBL is its ability to engage students, which can help them stay motivated and focused on learning (Balaskas et al., 2023; Hartt et al., 2020; Liu, Shaikh, and Gazizova, 2020; Liu, Wang, and Lee, 2021). It is believed that educational games will inspire students extrinsically—for rewards from outside sources—as well as intrinsically—for enjoyment or challenge. In addition to motivating for students to participate in class, games can generate positive psychological responses, improve concentration, and strengthen memory (Zeng, Parks, and Shang, 2020). Because of their engaging nature, gamified methods of instruction are frequently favoured by both teachers and students. Generally, student motivation appears to be positively impacted by gaming in a learning environment (Balaskas et al., 2023; Liu, Wang, and Lee, 2021; Subhash and Cundey, 2018). Students are motivated by cooperation and competitiveness, which are made possible by the use of gamified techniques and games. Additionally, games encourage active learning and can be personalized to fit the needs of individual students (Orji, Mandryk, and Vassileva, 2017). Students' engagement and learning efficiency are increased by the GBL approach, which is seen to be enjoyable, stimulating, and demanding (Mathrani, Christian, and Ponder-Sutton, 2016). Through GBL, students can manage their learning, gain the knowledge they require, and apply general skills like self-control and self-management (Chen and Law, 2016). Games also provide immediate feedback, which can help students learn more quickly and understand their mistakes (Liu, Wang, and Lee, 2021; Plass, Homer, and Kinzer, 2015). A GBL environment can allow the freedom to fail without worrying about unpleasant consequences. With GBL, students may experiment with various techniques and ways of making decisions as they move toward the objectives of the game. GBL allows students to apply theory to simulated real-world scenarios. They also learn how to use information and procedures based on theory in a simulative setting. Students learn how to manage relationships between people and activities in game contexts by integrating uncertainty and integration (Jääskä, Aaltonen, and Kujala, 2021). Collaboration is another benefit of GBL, as it promotes social skills and teamwork (Chen and Law, 2016). GBL may also help students develop skills like teamwork (Hartt Hosseini and Mostafapour, 2020), decision-making, and problem-solving (Qian and Clark, 2016)—all of which are competencies that require practice and mastery. Studying GBL must, therefore, represent "the integrated viewpoints of cognitive, motivational, affective, and sociocultural perspectives",

including both game design and game research as complementary aspects of the learning process (Plass, Homer, and Kinzer, 2015, p. 278).

1.2 Challenges and Strategies in Implementing GBL in Educational Settings

Researchers have warned that the success of GBL depends on the use of suitable and theoretically effective learning mechanisms (Chang & Hwang, 2019). Both the design and implementation of Game-Based (GB) activities may be guided by one or more theoretical foundations, such as experiential learning theory and constructivist learning theory (Wang, Cheng, and Li, 2023). Scaffolding strategies in teacher-student interactions can help students face challenges and make GBL more structured (Sun et al., 2023). Additionally, adding extra scaffolding to the game enhances students' engagement and interest in the educational process (Taub et al., 2020). A collaborative GBL environment offers enduring learning and is appropriate as a teaching and assessment tool for computational thinking skills in primary school (Zapata-Caceres et al., 2021). The simplest method is using game content as a multiple-choice test, with the game serving as a learning reward for primary school students (Park et al., 2019). A GBL system that integrated a "Prediction-Observation-Explanation" learning strategy can significantly improve students' learning achievement and learning retention (Yang and Chen, 2023). Students' learning effectiveness and intention to continue with digital GBL systems are strongly impacted by information feedback, game quality, and autonomous motivation (Liu, Wang, and Lee, 2021). Although GBL has great potential, its implementation in actual educational settings has encountered numerous obstacles and limitations that restrict its potential impact. Reported problems might include issues with game complexity (Lomas et al., 2017), technological unreliability (Marklund and Taylor, 2016) or instabilities and imbalances. Furthermore, in GBL, students could experience discomfort regarding competitiveness and outcomes comparison (Šćepanović, Žarić, and Matijević, 2015). Students may consider gamified classrooms as hard and may choose more traditional methods of learning (Šćepanović, Žarić, and Matijević, 2015). GBL might be laborious for students and the time the game needs to be played for meaningful effects to occur can be highly variable and unpredictable. Putting the GBL approach into practice can be extremely challenging and expensive because it frequently calls for customizing a freely available game to meet the needs of the specific course and making additional investments in the right equipment (Al-Azawi, Al-Faliti, and Al-Blushi, 2016). Students typically encounter unfavourable effects when teachers face challenges. Educators frequently lack the time and resources necessary to put in extra effort to find, study, and instruct educational games (Jääskä and Aaltonen, 2022). Although most teachers say they use learning games, many are unsure of how to include games in their lessons and wish it were simpler to find games that match their curricula (Takeuchi and Vaala, 2014). According to Molin (2017), there are several obstacles to implementing and embracing GBL, including instructors' lack of availability to plan gameplay periods (Jääskä, 2023), their lack of technical proficiency, their sense of alienation (Steiler-Hunt and Jones, 2017), and their inability to select and include appropriate games. While most teachers are aware of their necessity and efficacy, they do not have the skills and knowledge needed to implement them in the classroom (Hamari and Nousiainen, 2015; Lindgren, 2018). Constraints associated with the adoption of games in education include the financial barriers related to equipment costs (Al-Azawi, Al-Faliti, and Al-Blushi, 2016; Moizer, et al., 2009), disparities in access to technology (Hsu, et al., 2011), potential distractions from educational activities due to entertainment risks (Rowan, 2016), the time constraints of implementing games within a single day's lesson (Justice and Ritzhaupt, 2015; Baek, 2008), the influence of teachers' gender-related self-perception and their motivation and proficiency in handling technology (Hamlen, 2010; Justice and Ritzhaupt, 2015), the lack of customisation options for games (Al-Azawi, Al-Faliti, and Al-Blushi, 2016; Embi, 2008; Javora et al., 2021), challenges in obtaining game analytics and analysing student progress (Hauge et al., 2014), and concerns from educators and parents regarding the use of games in education (Barko and Sadler, 2013; Koh et al., 2011). To fully optimise the potential of GBL, it is imperative to identify and overcome these obstacles and create efficient intervention strategies. To present these strategies, we performed a Systematic Literature Review (SLR) following the PRISMA methodology and guidelines (Page et al., 2021).

1.3 Previous GBL Studies and the Present Study

A number of literature review studies have attempted to analyse GBL from diverse focuses in recent years (e.g. Chang & Hwang, 2019; Guan et al., 2024; Noroozi, Dehghanzadeh, Talaee, 2020; Qian & Clark, 2016; Tokac, Novak, and Thompson, 2019). Some reviews (e.g., Chang & Hwang, 2019) concentrated on a specific type of technology supporting games; others (e.g., Gomez, Ruipérez-Valiente, and Clemente, 2023; Guan et al., 2024; Lester et al., 2023; Sun et al., 2023; Tokac, Novak, and Thompson, 2019; Videnovik, Bogdanova, and Trajkovic, 2024; Zainuddin et al., 2020) reported findings on a specific topic; still others (e.g., Chen et al., 2021; Noroozi, Dehghanzadeh, Talaee, 2020; Qian and Clark, 2016) emphasized the results of GBL. For example, in order to find empirical data about the impact of GBL on 21st-century abilities, Qian and Clark (2016), examined 137 studies.

They found features of good game design that were in line with well-established learning theories. Ekin, Polat, and Hopcan (2023) analysed all studies on games in education conducted between 1968 and 2021. The primary goal of the study was to guide researchers and to identify trends and changes in GB research in education. Of all the research, almost 70% were carried out within the previous ten years. The primary focus of one-third of the research is GBL. In terms of topic usage acceleration, GBL, serious games, and student science games had the greatest values, in that order. Furthermore, Gomez, Ruipérez-Valiente, and Clemente (2023) conducted a systematic literature review of trends and challenges in GB assessment studies. The results indicate that GB assessments are primarily employed in K–16 education and for assessment, with the majority of GB assessments concentrating on assessing STEM content as well as soft and cognitive skills. In addition, the six areas into which the challenges faced by the researchers were classified were game design, data sample, methodological, technical, integration, and validation. They also offered suggestions for the GB assessments' future research goals. For instance, given the size of the data sample gathered was one of the primary limitations of the current research, the future research of GBA studies should make sure that enough data is collected to provide significant and reliable findings. Additionally, they should discuss the game design that will be utilized for the assessment, as many studies involve games designed for other goals (like enjoyment) and fail to consider the crucial connection between game design and gathering the data needed for the assessments. Lester et al. (2023) systematically examined the drivers and barriers to the use of gamification and GBL in universities from the perspectives of educators. According to the educators at universities, the main factors that positively impacted their use of gamification and GBL were their beliefs that it promotes student interactions and collaborative learning, is enjoyable and increases engagement, and is simple for students to use. On the other hand, the primary barriers faced by educators were a lack of time to create gamification strategies, the absence of evidence of their advantages, and problems with the classroom environment. The study classified drivers and barriers as attitudinal, design-related or administrative and suggested that future research and practice could benefit from collaboration among university educators, instructional support staff, and administrators to develop strategies that address these three categories of drivers and barriers to improve student learning outcomes. One may argue that while a suggestion has been made to address these drivers, it has not been thoroughly explained. Another study provided a comprehensive explanation of the procedures and stages involved in a comprehensive implementation of GBL for lecturers in higher education. Fernández-Raga et al., (2023), specifically outlined the procedures and stages of a comprehensive GBL implementation that is appropriate for lecturers. The thirteen phases in this paper's complete introduction to GBL in higher education were designed to assist lecturers in incorporating GBL into their teaching methods. Further, three subsequent phases consisted of the order of the process: preparation, game design, and practicing and evaluation. Dimitra et al. (2020) identified seven key GBL types (flashcard type games/memory games, simulation games, interactives, quiz games, puzzles, strategy games, reality testing games) that are used in education across all levels and situations and talked about the primary benefits and drawbacks in educational circumstances in order to provide an overall evaluation. They stated games can be used to assess several learning-related cognitive or emotional aspects, including individual differences, self-efficacy, and self-concept. However, they said that games have drawbacks in education, such as impacting students' performance, mental conditions, or attitude toward learning. Despite stating both the advantages and disadvantages of GBL in education, these studies either conclude that only the barriers are identified or that, even if implementation ways are proposed, they are restricted to a certain field (e.g., higher education). By identifying challenges with GBL in the field of education and suggesting intervention strategies in parallel with these challenges, our study differs from the current literature.

2. Method

To determine eligibility requirements, the primary research aim was utilised: for studies to be considered for inclusion, they needed to approach GBL interventions, with a particular emphasis on the challenges that were encountered during its implementation in educational settings. Within the scope of this study, empirical research that had been reviewed by peers was included in the sample. Book reviews, systematic reviews, and theoretical articles of any kind were among the types of research that were not considered for inclusion in the study. In addition, studies that concentrated on Gamification rather than GBL were not considered.

2.1 Information Sources and Search Strategy

The electronic search was carried out across various databases, namely All Collections in Web of Science, EBSCO, ERIC, IEEE Xplore, Elsevier, and Springer, through the subsequent survey of the equations:

- “game-based learning” AND barriers;

- “game-based learning” AND challenges;
- “game-based learning” AND obstacles;
- games AND education AND barriers;
- games AND education AND challenges.

The definitive search for retrieving all relevant results from the databases was performed on November 14, 2022.

2.2 Selection Process

Following the transfer of the search results, Endnote X9 was utilised to perform an automatic removal of duplicate entries. After that, the results were transferred to an Excel sheet, where they were subsequently screened in two stages. Study titles and abstracts were reviewed and "included" or "excluded" were assigned based on the previously defined inclusion and exclusion criteria. All of the studies that were deemed eligible during the first phase were subjected to a comprehensive full-text screening during the second phase. This procedure led to the collection of a total of eleven studies, which are presented in a standardised format in Figure 1.

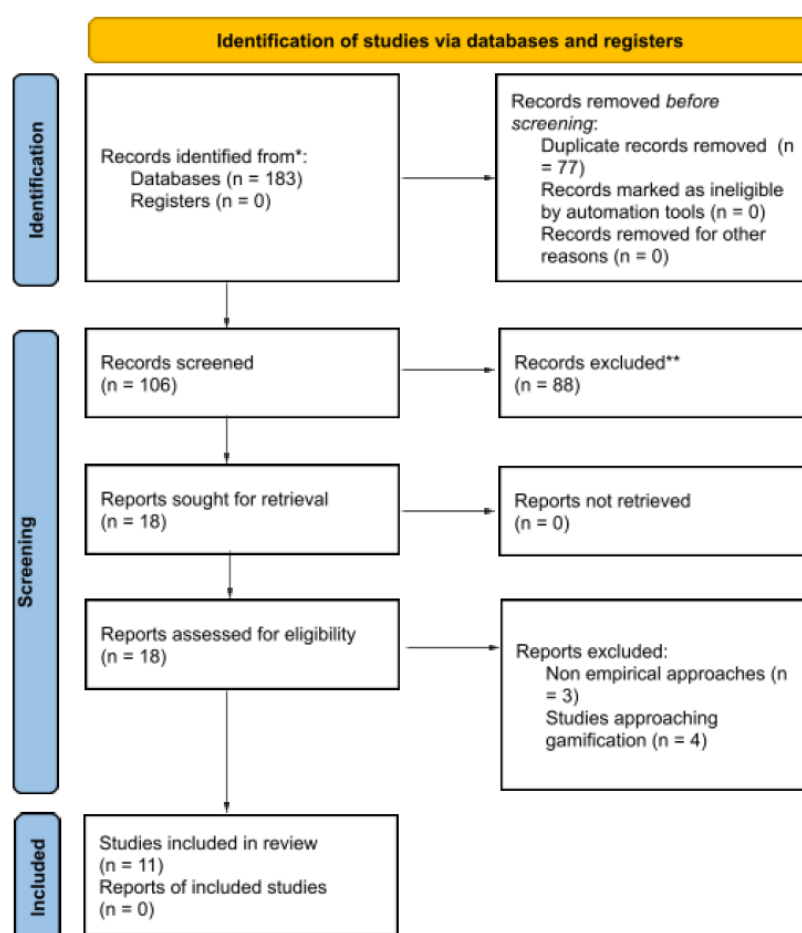


Figure 1: Flow diagram showing the identification process for studies to include in the review

2.3 Data Extraction and Analysis

The sample was coded to determine the most common obstacles and challenges that stand in the way of the more regular and ordinary (through better feasibility) application of games in educational settings. This was done to analyse the articles that were chosen. Following that, a more qualitative lens was utilised to investigate each barrier and the contextual factors that were associated with it, as stated by the authors. The development of a proposal for an intervention diagram was made possible through critical reflection and triangulation with the conceptual models that were already in existence. In addition, statistical analysis methods, specifically descriptive statistics, were utilised to analyse the data about sample characterization.

3. Overview of the Results

The sample description is schematized in Table 1. Of the 11 studies, four were based on a mixed-methods approach (Arnab, Clarke, and Morini, 2019; Chen et al., 2020; Hu and Sperling, 2022; Kaimara et al. 2021), five using a quantitative method of evaluation (Alqurashi and Alqurashi, 2017; Khodabandeh, 2022; Manesis, 2020; Martins and Oliveira, 2019; Sousa, Henriques, and Costa, 2017), and two using a qualitative approach (Jääskä and Aaltonen, 2022; Marklund and Taylor, 2016). It is important to note that five articles had teachers as participants, three had education students/pre-service teachers, one had students as participants, and another one adopted a multistakeholder approach to include the views of parents, youth, and teachers. The study conducted by Marklund and Taylor (2016) only mentioned the inclusion of 17 classrooms in the study without mentioning the number of individuals included. Two studies combined instruments with one or more data-gathering techniques. These included interviews and surveys (Chen et al., 2020), questionnaires and the final reflection pieces (Arnab, Clarke, and Morini, 2019). Two studies utilized questionnaires (Alqurashi and Alqurashi, 2017; Manesis, 2020), four used surveys (Hu and Sperling, 2022; Kaimara et al. 2021; Martins and Oliveira, 2019; Sousa, Henriques, and Costa, 2017), one used interview (Jääskä and Aaltonen, 2022), one study used tests (Khodabandeh, 2022) and one study used recordings (Marklund and Taylor, 2016). Quantitative (Alqurashi and Alqurashi, 2017; Khodabandeh, 2022; Manesis, 2020; Sousa, Henriques, and Costa, 2017) and qualitative (Arnab, Clarke, and Morini, 2019; Jääskä and Aaltonen, 2022) approaches were used to analyse the data that had been gathered. Chen et al. (2020) employed quantitative, qualitative analysis, "Analytic Hierarchy Process", and systematic review analysis. Hu and Sperling, (2022) and Kaimara et al., (2021) preferred both quantitative and qualitative analysis methods. Table 1 summarises all 11 studies.

Table 1: Characteristics of the studies (N = 11)

Author(s), Year	Methodological approach, Sample, Instruments and Assessment	Main objective and Main outcome(s)
Alqurashi and Alqurashi, 2017	<i>Methodological approach:</i> Quantitative <i>Sample:</i> 930 teachers <i>Instruments:</i> Questionnaire <i>Assessment:</i> Quantitative analyses	<i>Main objective:</i> "The purpose of this quantitative study was to identify significant factors that prevented teachers in Saudi Arabia from using video games in their classroom (...)"
Arnab, Clarke, and Morini, 2019	<i>Methodological approach:</i> Mixed-methods <i>Sample:</i> 122 undergraduate students <i>Instruments:</i> The Module Evaluation Questionnaire (MEQ), The final reflection pieces <i>Assessment:</i> Qualitative analyses	<i>Main objective:</i> "This article discusses the application of game design thinking as a learning process for scaffolding co-creativity in Higher Education (...)"
Chen et al., 2020	<i>Methodological approach:</i> Mixed-methods <i>Sample:</i> 231 teachers <i>Instruments:</i> Interviews and Surveys <i>Assessment(s):</i> A systematic review analysis, Qualitative analysis, Quantitative analysis, and Analytic Hierarchy Process (AHP)	<i>Main objective:</i> "The present research aims to explore what GBL informed games literacy for teachers is and what teachers think about their needed capabilities in games literacy for the implementation of GBL in the classroom."
Hu and Sperling, 2022	<i>Methodological approach:</i> Mixed-methods <i>Sample:</i> 130 pre-service teachers <i>Instruments:</i> Survey <i>Assessment(s):</i> Quantitative analysis, and Qualitative analysis	<i>Main objective:</i> "This study investigates pre-service teachers' perceptions of adopting games in education (...)"
Jääskä and Aaltonen, 2022	<i>Methodological approach:</i> Qualitative <i>Sample:</i> 22 project management teachers <i>Instruments:</i> Interviews <i>Assessment(s):</i> Qualitative analysis	<i>Main objective:</i> "(...) to gain an in-depth understanding of teachers' perceptions of applying game concepts in the project management education context."

Author(s), Year	Methodological approach, Sample, Instruments and Assessment	Main objective and Main outcome(s)
Kaimara et al. 2021	<i>Methodological approach:</i> Mixed-methods <i>Sample:</i> 170 pre-service teachers <i>Instruments:</i> Survey <i>Assessment(s):</i> Quantitative and Qualitative data analysis	<i>Main objective:</i> "The purpose of this study was to examine pre-service teachers' views on DGBL [Digital game-based learning], and the possible obstacles that they consider to hinder its implementation in primary and secondary schools in Greece."
Khodabandeh, 2022	<i>Methodological approach:</i> Quantitative <i>Sample:</i> 75 English foreign language students <i>Instruments:</i> Oxford Quick Placement Tests, Multiple-choice test, <i>Assessment(s):</i> Quantitative analysis	<i>Main objective:</i> "The purpose of the study was to compare the effects of flipped and blended classes on students' learning of how to give and ask for directions through the use of ARG [augmented reality game]-based enhanced education."
Manesis, 2020	<i>Methodological approach:</i> Quantitative <i>Sample:</i> 148 early childhood teachers <i>Instruments:</i> Questionnaire <i>Assessment(s):</i> Quantitative analysis	<i>Main objective:</i> "The main aim of this research is to investigate teachers' perceptions of barriers to accepting and integrating GBL in Cyprus pre-school settings."
Marklund and Taylor, 2016	<i>Methodological approach:</i> Qualitative <i>Sample:</i> 17 classrooms (participants not specified) <i>Instruments:</i> Recordings <i>Assessment:</i> Qualitative data analysis	<i>Main objective:</i> "This paper aims to highlight the demands that the implementation and use of an educational game in formal educational settings puts on teachers' working processes and skill sets."
Martins and Oliveira, 2019	<i>Methodological approach:</i> Quantitative <i>Sample:</i> 18 elementary and middle school teachers <i>Instruments:</i> Survey <i>Assessment:</i> No information	<i>Main objective:</i> "This research examines teachers' perceptions about educational games and the use of video games in their teaching practice."
Sousa, Henriques, and Costa, 2017	<i>Methodological approach:</i> Quantitative <i>Sample:</i> 106 teachers, parents, and youth <i>Instruments:</i> Survey <i>Assessment:</i> Quantitative analyses	<i>Main objective:</i> "(...) the present study aims to explore the main attitudes, motivations, perceptions and barriers to the adoption of digital games as a pedagogical tool, mainly in formal educational contexts."

4. Barriers to the Effective Use of Games in Education

To analyse the selected articles, the sample underwent coding to identify the most common obstacles and impediments to the successful utilisation of games in education. Subsequently, the authors employed a qualitative approach to examine each barrier and its contextual factors. By critically reflecting on and triangulating with the existing conceptual models, a proposal for an intervention diagram was developed. Sample characterization data was analysed using descriptive statistics, which are statistical analysis techniques. The analysis of the articles gathered through the systematic review suggests four types of barriers to more regular implementations of GBL. These are Attitudinal and Behavioural, School Policy, Technology and Material, and Game Literacy barriers.

4.1 Attitudinal and Behavioural Barriers

While the majority of data supports the idea that the school community acknowledges the benefits of using and developing educational games, such as their impact on communication, transferable knowledge, problem-solving skills, and self-expression (Sousa, Henriques, and Costa, 2017), there are noticeable barriers in attitudes and behaviour within the analysed sample. These attitudinal barriers can be classified into various categories and subcategories, as depicted in Figure 2.

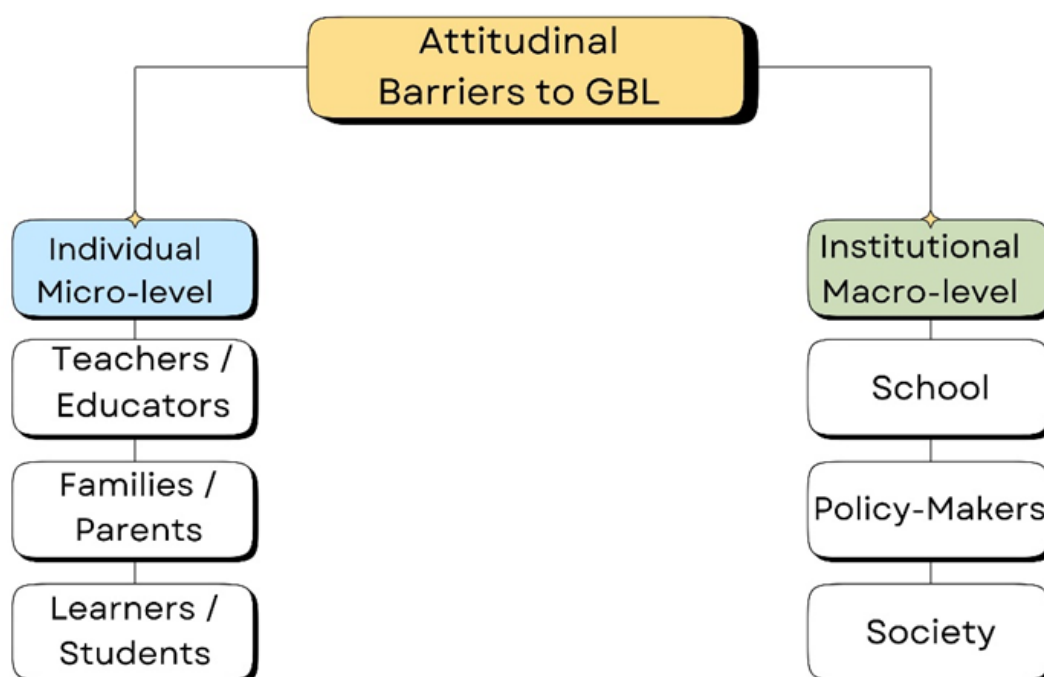


Figure 2: Attitudinal barriers to GBL interventions, according to the sample

The sample revealed that there are two categories of attitudinal barriers to GBL interventions: individual micro-level and institutional macro-level. The micro-level of attitudinal barriers can be understood as the different ways in which beliefs or behaviours of different individual stakeholders can work as drivers or hindrances in the implementation of GBL interventions. According to Martins and Oliveira (2019), teachers and educators tend to rate their technological knowledge as low, which extends to their lack of experience in incorporating games into their teaching practice. Teachers may be discouraged from implementing GBL due to uncertainty about how to incorporate the method into their teaching practice and the relatively novel nature of GBL teaching techniques. Although this can be better explained by the game literacy dimension that we will later approach, it can also be examined as an attitudinal issue, since it stems from a structural disbelief in one's ability to support their pupils to thrive in innovative pedagogical approaches. Teachers who have high levels of self-efficacy will find it easier to push themselves to meet a range of expectations in their professional lives (Manesis, 2020), where this extends to making the most of employing games in the classroom.

Regarding students, analysis of the sample showed some unexpected results regarding their negative attitudes towards GBL. Students may experience additional stress as a result of scoring and competitiveness under pressure among peers or feel uncomfortable with competitiveness, or the comparison of game results (Jääskä and Aaltonen, 2022). Students may prefer more conventional teaching methods, including lectures, written assignments, and exams, that allow them to play a more passive role in the learning process over GBL implementations, depending on the students' profiles as learners (Jääskä and Aaltonen, 2022). This aspect was also found in data from Sousa, Henriques, and Costa (2017), which showed that students have much more positive attitudes toward the recreational role of games than towards their pedagogical role.

We advance potential reasons for a possible disconnect between some learners and the GBL approaches. One potential reason is student frustration with cases of lack of clear instructions in GBL which are often related to the issue of instructors' low game literacy, which will be addressed below. Students become frustrated if they are not given enough or clear instructions on how to take part or play the game. Failure to develop a sense of confidence between instructors and students before properly implementing GBL makes the learning environment look unpleasant, resulting in negative feedback (Jääskä and Aaltonen, 2022). This can also be motivated by an apparent disconnect between an educational game and the educational objectives that were initially proposed to the student. Students may view gamified instruction as irrelevant or as being separated from the learning objectives if they are unable to see how the game relates to and connects to the objectives. For this aspect, the promotion of reflection in debriefing processes becomes an important protective factor against loss of interest as well as a promoter of meaningful learning (Jääskä and Aaltonen, 2022; Marklund and Taylor, 2016).

The negative connotation attributed to games as being exclusively a form of entertainment is common among educators, families, and students. There is a clear distinction between "serious games" which are seen as having educational value, and commercial games which are seen as being a waste of time (Sousa, Henriques, and Costa, 2017). It is important to acknowledge that, based on current knowledge and research, this viewpoint can be considered incorrect. Studies have demonstrated the educational value of both digital and analogue games, ranging from teaching probabilities through games like Settlers of Catan (Austin and Molitoris-Miller, 2015) to developing advanced decision-making skills in games like Counter-Strike: Global Offensive (Kiourti, 2022).

When considering the broader perspective of attitudinal barriers concerning GBL, it is crucial to acknowledge the presence of negative attitudes held by both schools and policy-makers. These attitudes have a detrimental effect on the successful implementation of GBL (Kaimara et al., 2021).

The sample of articles reviewed sheds light on policy-makers unfavourable perceptions of games as instructional tools and disapproval of educational games on the part of ministries of education in different countries are regarded as significant barriers (Kaimara et al., 2021). Education policy-makers have operated on the basis that technology is better suited for leisure activities rather than as a tool to improve teaching and learning (Manesis, 2020). At a societal level, a significant obstacle in terms of attitudes is the widely recognised "digital natives" narrative. Many pre-service or younger teachers believe that they are well-versed in implementing innovation-driven pedagogical strategies, such as GBL, because of the environment they have been raised in. This discourse can be interpreted as an obstacle because it reinforces preconceived ideas about people's backgrounds, socioeconomic situations, technological opportunities, and literacy levels. This goes against the inclusive possibilities that games offer (Hu and Sperling, 2022; Marklund and Taylor, 2016). While Kaimara et al. (2021) examined policy-makers' attitudes as part of the macro-level attitudinal barriers, the effectiveness of their measures in the daily educational context is influenced by a separate set of barriers, which will now be investigated.

4.2 School Policy Barriers

While research can reinforce the pedagogical benefits of GB approaches, they often come up against institutional issues faced by schools and higher education institutions. The process of integrating games into formal educational environments is laborious and complicated, requiring significant time and resource commitments to be accepted as a practical component of the process. This is caused in part by the fact that schools are not set up for GBL (Marklund and Taylor, 2016). These issues can even extend to non-formal education contexts. The analysed sample of articles highlights issues related to limited instructional time available to educators for including innovative pedagogical practices in their work. Teachers are far more likely to discontinue the educational use of games if they have little teaching time or if the content is not appropriate (Hu and Sperling, 2022). Policy and curriculum were two examples of the barriers that affected the perceptions of educators. Teachers have identified that the people who create curriculum, set educational policies, and organize the educational system are the drivers of these barriers (Kaimara et al., 2021). Another problem is that the games aren't aligned with the national curriculum or academic expectations. These studies consistently show that incorporating games into existing curricula is difficult in the absence of appropriate resources. This is exacerbated by difficulties in aligning games with learning goals as stated by a national curriculum (Alqurashi and Alqurashi, 2017; Hu and Sperling, 2022; Marklund and Taylor, 2016). The lack of policies and frameworks for supporting this task makes it more challenging to ensure the desires of all stakeholders – students, teachers, schools, and education ministry – are met (Kaimara et al., 2021).

4.3 Technological and Material Barriers

Access is a necessary precursor to participation in media, as well as participation in democratic civic structures (Carpentier, 2011). From the standpoint of this premise, the thematic analysis of our sample showed a set of technological and material barriers that impact GBL interventions in the educational context, including funding constraints. One fundamental issue with GBL in formal education is that, in their current form, games are not highly trustworthy as instructional tools. It takes a significant amount of time and resources to set up the technological framework necessary for games to run smoothly and consistently, as well as to maintain them during every lesson (Marklund and Taylor, 2016).

For technological barriers, several studies in the sample emphasized the negative impact of infrastructure issues in GBL interventions, such as inadequate internet network service, outdated computers, or a lack of technical staff and software (Alqurashi and Alqurashi, 2017; Jääskä and Aaltonen, 2022; Kaimara et al., 2021; Manesis, 2020; Marklund and Taylor, 2016). This combined with the literacy phenomenon and the inability of teachers to

solve technical issues that may emerge during interventions contribute to a sense of frustration and negative game experiences both for teachers and students (Jääskä and Aaltonen, 2022). Particularly when it comes to computer games, technical issues brought on by a lack of technical expertise, a lack of assistance, a lack of instructions, device incompatibility, or just plain poor luck can cause disruptions in the classroom (Jääskä and Aaltonen, 2022). To effectively implement the approach, the instructor must get familiar with the logic and game mechanics. Because of the technology involved, the use of digital educational games requires teachers to have more technical abilities compared to traditional approaches (Jääskä and Aaltonen, 2022). A wide range of skill sets are needed to complete tasks successfully, including subject-matter knowledge, game literacy and technological proficiency.

Material barriers are associated with the lack of games *per se*, or the lack of funding to acquire them. This is made apparent by the fact that teachers believe that there aren't enough appropriate educational games available currently (Jääskä and Aaltonen, 2022). Lack of games – more specifically educational games in schools – is a salient aspect of this study, as well as their high cost (Alqurashi and Alqurashi, 2017; Jääskä and Aaltonen, 2022; Manesis, 2020). Educational game fees also vary significantly. The game may be too expensive to use. Besides games, a more general issue of lack of funding for educational activities is also noted as a fundamental hurdle to the implementation of GBL in these contexts (Kaimara et al., 2021). In the case that a course lacks funding, teachers will need to defend their game purchases to the university's administration (Jääskä and Aaltonen, 2022). It takes more work on the part of the teacher to provide a framework appropriate for the usage of educational games. Another obstacle is the idea that there aren't enough tools to help teachers use games. Lesson plans that include games, techniques for evaluating students' comprehension of academic information, and extra materials or activities centred around the GBL sessions are examples of supporting resources (Hu and Sperling, 2022).

As stated above, there are effective technological barriers, but there are also skill gaps and low awareness of one's skills (Martins and Oliveira, 2019). This brings us to the issue of game literacy.

4.4 Game Literacy Barriers

Chen et al. (2020) conducted a study to investigate how teachers' lack of knowledge and understanding about games affects the effectiveness of GBL interventions. They utilised a framework that clearly defined different dimensions of literacy, including:

- The literacy of instructional design in GBL refers to the proficiency of teachers in aligning game design with desired learning outcomes before applying these strategies in their classrooms.
- The evaluation literacy in GBL refers to teachers' beliefs about adopting games and how they impact students' motivation and cognitive development, similar to an attitudinal aspect.
- Proficiency in organisational and managerial aspects of GBL, encompassing the aptitude to overcome obstacles related to technology and resources.
- Fundamental understanding of games, which is connected to the choice of games and the overall grasp of concepts, impacts the teachers' ability to actively involve students in the educational process.
- Proficiency in understanding complex game systems and applying strategic thinking.

Hu and Sperling (2022) highlighted the insufficient game literacy among teachers, emphasising their inclination to perceive games solely as supplementary activities rather than as pedagogical tools. This perception may be associated with other recognised obstacles, such as the necessity for heightened awareness regarding the correlation between game mechanics and learning (Jääskä and Aaltonen, 2022), or difficulties in identifying students' concerns with the game interface (Marklund and Taylor, 2016). It is important to understand that game literacy is necessary not only for monitoring gaming sessions but also for the success of contextualising activities, especially critical reflections and debriefings (Marklund and Taylor, 2016).

Game literacy can be fostered through specialised training programmes that aim to empower educators in effectively assisting their students within the framework of GB interventions. An examination of existing teacher-preparation programmes shows them to have insufficient exposure to GB instruction (Hu and Sperling, 2022), along with a general lack of training in Information and Communications Technology (ICT) while failing to recognise the importance of playfulness in education (Kaimara et al., 2021). This matter begs for consideration, as the dissemination of information regarding the educational significance of games is regarded as crucial for their widespread use in education. Martins and Oliveira (2019) suggest improving the accessibility and attractiveness of training by integrating it with pre-service teacher education.

5. Potential Strategies for Dealing with the Identified Barriers

We suggest some methodological approaches that might support practitioners in overcoming the recognised barriers, as indicated by our critical analysis of these barriers. The strategies consist of: (a) employing a co-creation and participatory-driven strategy; (b) making a deliberate choice between using analogue, digital, or hybrid games; (c) involving various educational actors in the process; and (d) advocating for GBL training in projects.

5.1 Co-creation

Co-creation is an intellectual perspective that emerges from the constructivist scientific paradigm, embracing a relativist stance and asserting that reality is a product of human cognition. Concerning the specific matters of GBL and gaming as a whole, the constructivist paradigm is applicable as it centres on how individuals create significance from their experiences, highlighting the diversity and multitude of interpretations (Guba and Lincoln, 1994).

Specifically, in this context, co-creation refers to the inclusion of the player's voice in the creative processes, whereby the audience transitions from a relatively passive position to a more engaged position in shaping the game itself (Kafai, 2006; Rüller et al., 2022). Regarding the process of acquiring knowledge, it pertains to person-centred learning or personalised learning environments (Zhang et al., 2020).

Co-creation implies a certain willingness to engage with participants and incorporate their ideas into a project through different participatory approaches, for instance, design thinking (Ind and Coates, 2013). By including students as a critical part of the teaching process, co-creation increases student involvement and engagement in the learning process (Blau and Shamir-Inbal, 2017). The co-creative process is regarded as an effective way to foster communication, student creativity, and positive group dynamics (Zarandi et al., 2022). Student success, retention and persistence all increase with co-creation. When users participate in the co-creation process, gamification's advantages usually increase as well (Lopes et al., 2022). Creativity and co-creativity developed through play-inspired design thinking have the potential to sustain students' practices and mindset long term, which will impact their engagement with the community (Arnab, Clarke, and Morini, 2019).

5.2 Analogue Games VS Digital Games

In the initial stages of academic discourse on GBL, Gee (2005, p. 34) advocated for the conceptual definition of this field by establishing the learning principles inherent in "good games". According to Gee (2005), a "good" game needed to inherently embody the latest scientific principles of skill acquisition in cognitive science within its gameplay, including identity, interaction, production, risk-taking, customization, agency, well-ordered problems, challenge and consolidation, "just-in-time" and "on-demand" situated meanings, pleasantly frustrating experiences, system thinking, exploration, lateral thinking, goal reconsideration, cross-functional teams, and performance before competence.

While initially framed within a digital context, these principles apply to board games as well. The literature now strongly supports the learning potential of board games, emphasizing the role of play in human development (Gobet et al., 2004) and how these artefacts reflect the culture of each society (Booth, 2021).

Although empirical research has supported the learning potential of digital games, particularly in terms of motivation, engagement, and confidence levels (Abdul Jabbar and Felicia, 2015), recent approaches underscore specific advantages of analogue games for both educators and students. These advantages include the development of skills such as collaboration, communication, creativity, problem-solving, and decision-making (Sousa et al., 2023). Analogue games are characterized by their flexibility and are easily adaptable to the specific requirements of any classroom or group of players (Maratou et al., 2023).

The ability to make an informed choice between digital, analogue, or hybrid games is pivotal for the sustainability of an intervention, considering issues like technological barriers or micro-level and school policy barriers to GBL adoption. No option is inherently superior or more pedagogical than another; their contextual feasibility relies on a detailed assessment of the target audience, available funding, existing technology, the literacy of trainers and trainees, and potential accessibility needs, among other factors.

5.3 Multistakeholder Approach

The concept of stakeholder is used broadly to define all those who affect or are affected by the achievement of an organization's purpose (Freeman, 2010), often characterizing a systemic focus on the relationships between them. The label "multistakeholder approach" intends to emphasize interventions where different voices are

heard and included in the process of educational change through play, regardless of their inherent power relations. This horizontality means that the perspective of a teacher or a pedagogical director cannot be more highly valued than that of a student.

The methodological proposal in this paper aims to address school policy barriers, based on the notion that including different voices in educational decision-making enhances satisfaction, trust, and a sense of belonging, for educators (Rosales, 2019), families (Gülcan and Duran, 2018), and students (Mitra, 2018). It can also help circumvent other individual or institutional barriers, considering that higher levels of participation tend to promote a higher engagement in educational change processes (Cook-Sather, 2018). Considering that parents' views on games in the classroom appear to have an impact on educators, students, and policy-makers (Bourgonjon et al., 2011), integrating innovative strategies through stakeholders may be possible with strong reactions from scholars, teachers, practitioners, policy-makers, families, students or others. Therefore, the successful adaptation of educational change processes related to GBL requires the participation of all stakeholders, from student needs to teacher preparation programs, as well as from the gaming industry to policymakers. For example, teacher preparation programs should offer greater opportunities to explore and closely examine GB educational practices while resources should be made available for the purchase of modern hardware, software, and equipment as well as for the training of administrators and educational officials and teachers. Operationalizing a multistakeholder approach for GBL might be enhanced through co-creative processes, where the final playful artefacts effectively represent the experiences of all the participants.

5.4 Training

According to the empirical approach of García et al. (2022), teachers perceive that their training must be pragmatic and empower them with skills that enable their adaptation to diverse educational contexts, keeping them up to date with the most recent pedagogical interventions. According to Marklund and Taylor (2015), for teachers to acquire game literacy they require opportunities to play a broad range of games regularly. Pre-service and in-service teachers need to be knowledgeable both practically and pedagogically to select and apply the most effective uses of games in their lessons. This will support teachers in developing adaptable, innovative, and flexible educational techniques that effectively integrate game-playing sessions into non-game elements of the course (Hu and Sperling, 2022). These authors also acknowledge the relevance of teachers in the promotion of digital competencies, since training teachers in these competencies contributes, in an indirect manner, to the development of these competencies in students. Furthermore, teachers who possess a reasonable level of technical proficiency will be better equipped to choose a game that matches learning objectives, have access to the resources needed to continue using the game, and put the best integration strategies into practice (Hu and Sperling, 2022). Professional training in digital GBL implementation might facilitate and encourage the use of GBL approaches, particularly if more and more digitized learning settings are employed in the future.

Sousa and Costa (2019) propose the application of GBL to teacher training, namely in the areas of digital competence and media literacy. The pedagogical premises in GBL of using failure as a motivational strategy or learning by doing can be effectively implemented to promote educators' media and information literacy skills. This is a less direct and possibly more cross-cutting impact for training than what the authors and studies in the SLR in this paper seemed to anticipate. Nevertheless, more informed and empowered teachers, families, educators, and other stakeholders for GB pedagogical innovation could work as an important factor in promoting successful GBL interventions.

6. Proposing an Intervention Diagram

By reflecting on the different barriers and strategies presented above, the diagram presented in Figure 3 was created to support the development of GBL interventions.

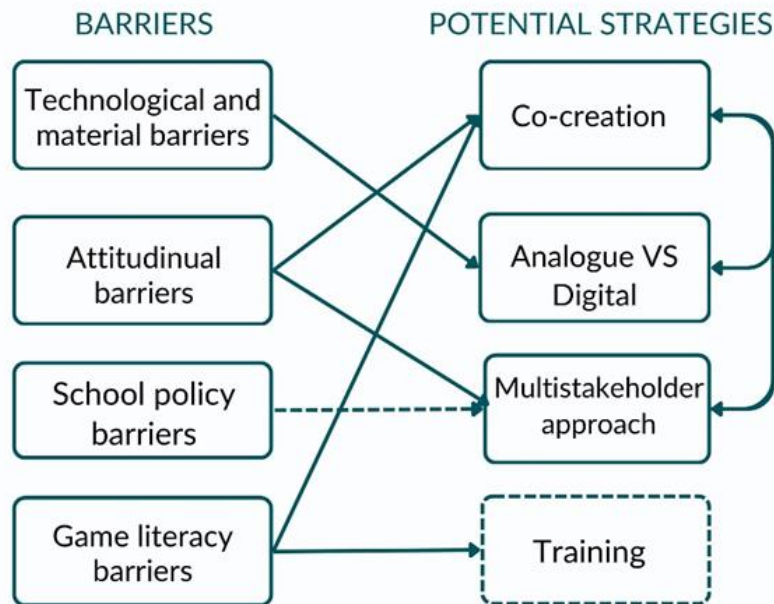


Figure 3: Proposed intervention model based on the barriers and strategies explored

Figure 3 offers concrete guidance to teachers, educators, practitioners, and others on how to connect various concepts when implementing GBL interventions.

- By conducting a thorough and timely examination of potential technological and material obstacles within the given context, certain issues can be preemptively circumvented. Specifically, by selecting either analogue, digital, or hybrid games based on the available technology, expertise, and financial resources.
- Co-creation aims to engage players as essential participants in the creative process of games, with a deeper understanding and a positive impact on player attitudes and literacy. It is thought that one of the effective ways to enhance players' attitudes and literacy is to involve them in the co-creation of the game.
- Successfully designing and implementing GBL applications involving multiple stakeholders will also have a favourable impact on their attitudes towards GBL. Ensuring that GBL interventions are multistakeholder fosters multilevel changes that bridge the attitudinal gap between educators, learners, and families, facilitating the implementation of innovative pedagogies.
- Including policy-makers in these multistakeholder approaches can indirectly support change and help bridge the gap between them and the obtained results.
- While we lack control over the pre-training of participants in a GB intervention, it is crucial to raise awareness among institutions about its significance and, whenever feasible, incorporate it into the projects. Once institutions create programs that teach and train professionals with broad abilities and literacy, then they will also be prepared to encounter, adjust to, and take management responsibilities of gaming intervention.
- Co-creative strategies are contingent upon conducting a thorough analysis of the preferred technology for the game being implemented, whether it be analogue or digital. This choice will influence both the material circumstances and the capacity of individuals to participate on an equitable basis.
- Co-creation is aligned with the multistakeholder approach due to its participatory and horizontal nature, which enables the involvement of multiple actors at an equal level.

7. Conclusion

For all the potential in GBL, instructors and students still find it difficult to fit it into everyday educational activities compared to other educational technologies where this is not restricted to digital games and can include tabletop or other forms of analogue games. This is discussed and cited in the introduction to this article: the costs and risks in employing GBL seem to offset its benefits, but these costs and risks are not seemingly for

the most part inherent to GBL and thus avoidable. The costs and risks waste the potential of GBL by preventing a more consistent application of GBL to fully deliver on its potential.

The main contribution of this article is the mapping between potential strategies for driving more ubiquitous use of GBL. More than simply finding the most cited barriers and hindrances for GBL and more than simply proposing remedies, this article relates the nature of each type of barrier to associated solutions, namely (per Figure 3):

- technological and material barriers to making informed choices about using analogue games (or making more informed choices about using digital games);
- attitudinal barriers to co-creation and multistakeholder approaches;
- policy barriers linked to multistakeholder approaches;
- game literacy barriers to co-creation and training;
- co-creation, demystified analogue and digital, and multistakeholder approaches linked together as a mutually reinforcing intervention approach.

Future research and practice may benefit from university educators, teaching support staff, and administrators collaborating to develop strategies across attitudinal and school policy barriers. Analog games and digital games are not pedagogically superior to each other. Therefore, the contextual appropriateness of each choice must be carefully determined against the target audience's possible accessibility demands, available funding, available technology, instructors' and trainees' literacy, and other considerations. For games and learning to be deeply and meaningfully integrated, teachers must be specialists in both areas. Teachers should be trained and reminded that integrating gaming elements, technology choices, and instructional methodologies requires an awareness of learning theories. This could enable educators to come up with new pedagogical uses for educational games. Finally, we can suggest that answering the following questions during the design thinking process can facilitate both the co-creation process and overcoming barriers: What is important to us? Can we do anything? How can we accomplish that? How do we resolve this? Now where are we going?

The prescriptive power of these mappings comes from the Systematic Literature review enabling the issues with GBL to be triangulated, organised into categories, and handled together with solutions of countermeasures also found in literature, which are grouped into main intervention streams to enable mappings with the barrier categories. The literature provides the solutions and problems, but not in a consolidated, mutually reinforcing approach needed to fully contend with the underutilization of GBL. Where existing scientific literature on studies of GBL interventions naturally suggests the solutions; this article corroborates, evaluates, and groups the intervention streams as the basis of a comprehensive program of intervention. Where the literature overlooks possible solutions, for instance, literacy and training being a more cross-cutting approach than anticipated by the analysed GBL literature, this article argues for these solutions, rounding out the intervention program. Future work includes further consolidation of the program, including for instance analysis of teacher training and policy-making using the intervention diagram in Figure 3 as a lens. For now, this article is launching the consolidated intervention as an avenue of research.

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Number Express: A Digital Game to Improve Early Numeracy

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Abstract: Early numeracy has repeatedly been observed to predict more advanced mathematical skills and vocational prospects. Accordingly, there is increasing interest in interventions using games and game-based activities to foster basic numerical skills. In the current study, we describe how we sought initial feedback on the game Number Express following a design-based research method and a study piloting the game with a group of four to six-year-old children to evaluate its usability and likability. The game consists of a train with six carriages for the player to fill in with numbers in the correct order. The game progresses in difficulty across several levels, moving from smaller to larger numbers and sequences in steps of 2, 5, and 10. Informative feedback is provided to assist players when they make incorrect responses. Associating numbers to carriages in the correct order earns the player points, with which they can buy items in a virtual shop, providing additional experience with calculating with money. During the design phase, we sought feedback from researchers, teachers, and an education consultant specialising in the learning and teaching of primary mathematics. We modified the game based on their suggestions. In addition, we ran a pilot study to test the game on a small group of preschool children (N = 45) evaluating its playability and user experience to allow for further development of the game. Overall, the results of the pilot study indicated that Number Express is straightforward to engage with, features easily memorable instructions, and incorporates an effective number line tool that supports number ordering skills. As a next step, we plan to use Number Express in a larger-scale intervention study to determine its effectiveness in improving children's early numeracy skills. In case the game proves to be effective, it has the potential to be a valuable tool for educators and parents in supporting their children's early numerical development.

Keywords: Digital game, Number ordering, Preschool and primary children, Early numeracy, Piloting

1. Background

Basic numerical skills are the foundation of more advanced mathematical skills (Watts et al., 2014) and significantly predict future mathematical learning and academic achievement (e.g., Atkinson et al., 2022; Duncan et al., 2020; Davis-Kean et al., 2022; Jordan, Hanich and Kaplan, 2003; Duncan et al., 2006). Around the age of two years, children typically start implementing counting routines to learn the cardinal meaning of number words, this means that “one” describes a set with one item, “two” a set with two items, etc. (Gelman and Gallistel, 1978; Sarnecka, 2015; Sarnecka, Goldman and Slusser, 2015). From there on, children progressively associate specific number words with specific numerosities in terms of symbol-magnitude associations. In this context, children also learn that number words reflect ordinal relations depending on their position within the counting sequence and children need to understand the ordinal relations among the corresponding digits, for instance, that 5 comes after 4 but before 6 (Sasanguie and Vos, 2018). The fact that numbers can be spatially represented in order on a number line (i.e., the position of a number provides information about its magnitude and ordinal relation as argued for cartesian axes, Sella et al., 2017) is another important characteristic of early numerical representations.

Not surprisingly, numerous interventions draw on games and activities to facilitate understanding of ordinal relations between numbers, but also cardinal number magnitude understanding by fostering children's skills in correctly locating numbers on a number line (e.g., Siegler and Ramani, 2008).

With the increasing availability of touch-screen devices such as smartphones and tablets, specific games and apps have been developed to support children's early numerical learning (Klawe, 1999; Annetta et al., 2009; Sella et al., 2016; Sella et al., 2021; Benavides-Varela et al., 2020).

Besides acquiring subject-specific mathematical skills and knowledge, such digital games also seem to increase students' motivation and promote positive attitudes towards learning (e.g., Ke, 2009; Pareto et al., 2011; Crittenden, Biel, and Lovely, 2019). For instance, The Number Race (<http://www.thenumberrace.com/nr/home.php>) is an example of a research-informed digital game (Wilson et al. 2006;) that has been evaluated in both typically and atypically developing children (Sella et al. 2016; Rasanen et al., 2009; Sella et al., 2021, Sella et al., 2016). The game presents numbers in various forms: as digits, spoken number words, and visualized quantities through sets of objects. The player is tasked with selecting the larger of two numbers, beginning with concrete sets and gradually advancing through spoken and written forms until only written numbers are used. Moreover, the tokens earned by the player are moved to a racetrack, illustrating how numbers are mapped to a number line. The game supports multiple numerical skills, such as comparing symbolic and non-symbolic numerical quantities, counting, and simple arithmetic. During the game, children are also asked to move their game character along a line, therefore reinforcing the ordinal components. Other digital games have directly used the concepts of the number line, where players are required to place numbers along a visual number line (for example Rescue calculatoris, a mental number line training for children with developmental dyscalculia, Kaser et al. 2013; Semideus, a game on fraction processing, Ninaus et al. 2017). Even though these games support different basic numerical skills, including the use of a number line, they do not specifically target number-ordering skills.

This seems surprising as there is accumulating evidence that number-ordering skills are crucial for the development of early numerical skills (Devlin et al. 2024; Morsanyi, O'Mahony and McCormack, 2017). Additionally, in a recent review by Balladares and colleagues (2023), the authors selected nineteen articles exploring the relationship between board games and mathematical skills. Interestingly, only one game was reported to focus on number ordering.

Conversely, there are plenty of apps and online games designed to help children learn numbers by focusing on their order, such as Bud's Number Garden (BITESIZE, 2024) or Jumpy: Counting by Ones From 1 to 100 (education.com, 2024). However, for most of these apps, the research underlying the game is not clear, and many are freely accessible only for a limited number of trials.

Therefore, we decided to create a freely available game facilitating number order processing.

Against this background, the current article describes the development of the app Number Express which is intended to facilitate early learning about numerical order by requiring children to place numbers in the correct order on a number line. In this study, we describe how we gathered initial feedback on the game using a design-based research method. Moreover, considering that the use of digital games with kindergarten children could present challenges—such as understanding the rules and instructions—we also conducted a pilot study with a group of four- to six-year-old children to evaluate the game's usability and likability.

In the following, we will first introduce the main conceptual characteristics of the game and initial feedback on its usability by numerical cognition researchers and educational practitioners before we report the results of a pilot intervention study. Finally, we discuss next steps to further develop the app and evaluate its effectiveness in a larger-scale intervention study.

2. Conceptual Characteristics of the Game

2.1 The Theme and the Game's Main aim

The narrative of *Number Express* is situated at a train station where the train conductor has to renumber carriages of an incoming train because some carriage numbers have fallen off. The train has six carriages, some of which still have their number label on (serving as reference points for numbering the other carriages), while others do not (reflecting target numbers to be allocated by players).

When starting the game, children first choose between different animal characters representing the train conductor they want to play with and type in their name (see Figure 1).

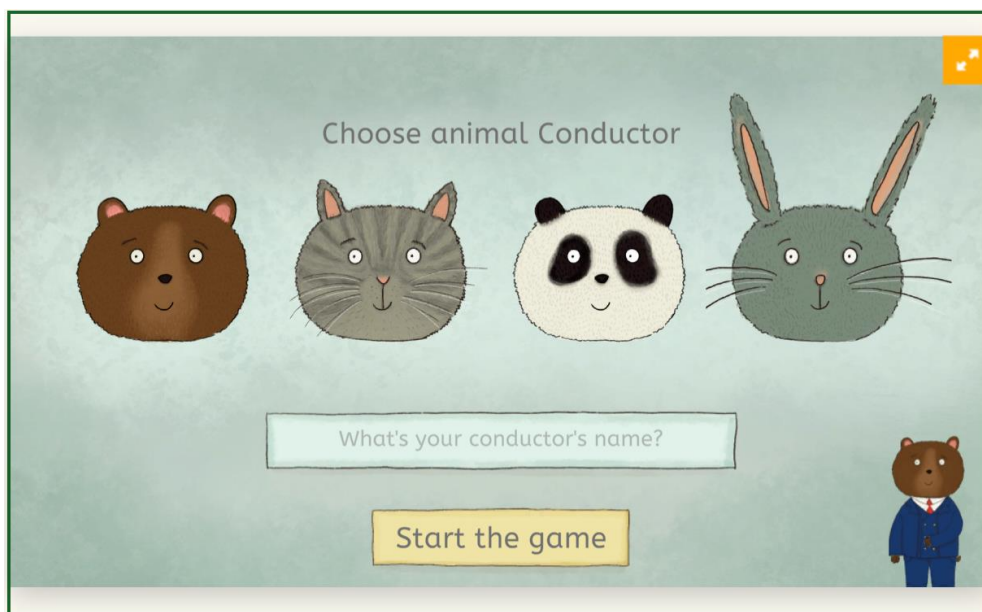


Figure 1: Starting screen to choose the character of the train conductor

Then, children have to select the level they want to start playing from (see Figure 2).

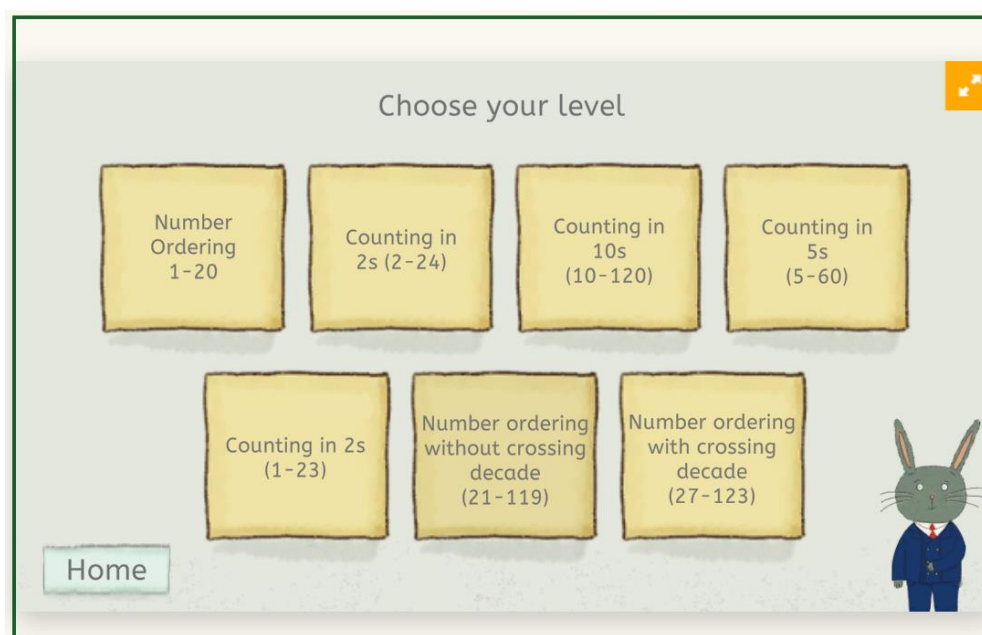


Figure 2: Starting screen to choose the level the player wants to play in

Then, a train arrives on the screen, and a target number (to be associated with one of the unlabelled carriages) is shown at the top-left of the screen together with the sound of the respective number word emphasizing the association between visual and verbal representations of the respective number (e.g., “four”; and 4, cf. Figure 3). The player then has to drag the presented target number to the respective carriage, considering the given numbering on the other carriages as references or simply click on the chosen carriage.

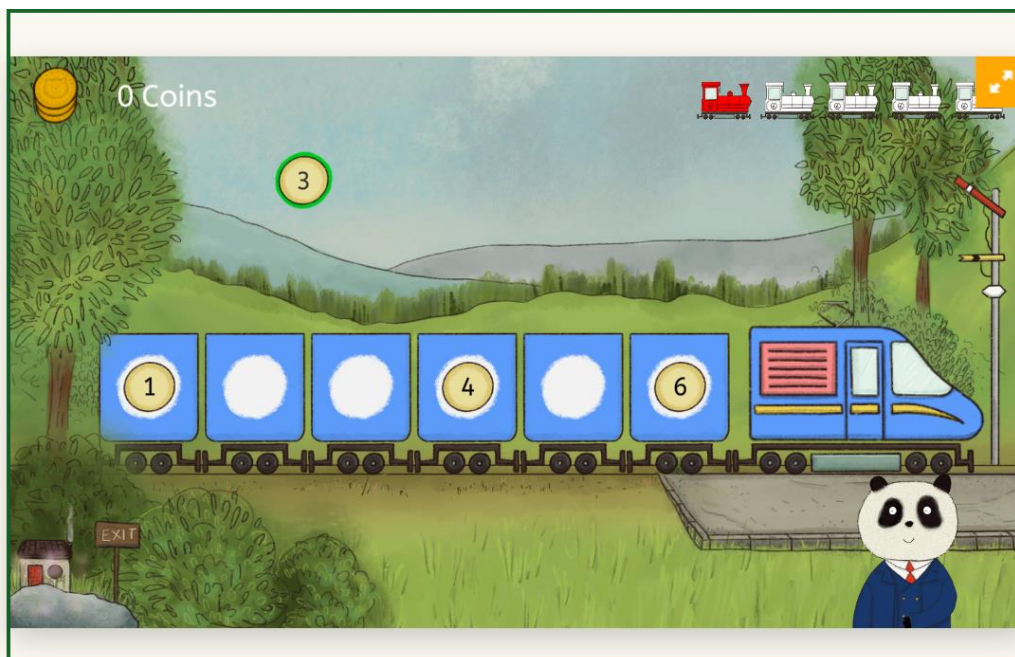


Figure 3: Main gameplay screen showing the train with already numbered carriages. The number 4 with a green circle around it is the number that the player has to put on the right carriage. At the top of the screen, the number of coins earned by the player is given (the number next to the coin's image) as well as the number of rounds a player has already completed within a level (the coloured train indicates that this is the first round played. When the player plays the second round the second train will turn orange and so on). Each level has five trains. The button *exits* (the sign on the bottom left of the screen) leads the player to exit the game. The button *home* (the little house depicted on the bottom left of the screen) leads the player to the game's homepage

After associating the first target number with a respective carriage, the next one will appear until all carriages are numbered. At that point, the locomotive shines, and children can click on it to make the train leave the station. In case target numbers were associated with carriages to reflect a correct order (e.g., 1, 2, 3, 4, 5, 6 in Figure 3), the train leaves the station, and another train appears on the screen. When some of the numbers are not put on the carriages in correct order, the train does not leave the station and the numbers which are on the wrong carriages will be moved to the top of the screen with informative feedback appearing on the screen. In case the player puts the numbers on the wrong carriages the first feedback that they receive is a visual and verbal message (Good try! But some of the numbers are not at the right place). Then they can try again to put the target numbers onto the right carriages. When they put the numbers in the wrong order again, they receive the same message as for the first reply. In addition, a number line appears right under the train so that the player can use the number line to copy the position of some numbers (See paragraph 2.4 and Figure 5 for more information on this game's informative feedback). For every train the player makes leave, they are awarded one coin as a virtual incentive. After five trains successfully leave the station, the player will have earned five coins to spend in a virtual shop (Figure 4) allowing them to buy accessories for the train (e.g., stickers to decorate the train or the possibility to change the shape of the train) and clothes or accessories for the train conductor (e.g., a new outfit, a hat, or a toy). To pay in the shop the player can only use the virtual coins earned playing the game. They can also change the train conductor character for free (e.g., panda, bear, cat, and rabbit). Once they are done with their shopping, they can return to playing the game.

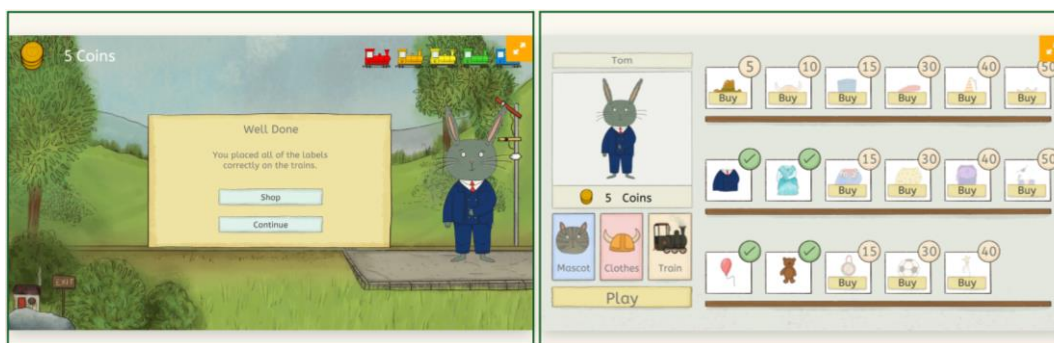


Figure 4: The shop. On the left panel, the screen is displayed on which the player can choose to go to the shop or continue playing after five rounds of playing. In the latter scenario, the player will continue accumulating the coins earned during the game. The right panel shows the screen of the shop. The player can see their train conductor with their name and the amount of virtual coins they can spend in the shop. Once they have completed their shopping the amount of coins will change accordingly. Clicking on the button with the label Clothes allows the player to see all the goods they can buy for the train conductor. Clicking the button with the mascot on allows the player to change the train conductor for free. Finally, clicking on the button with the train on allows the players to see all the accessories they can buy for the train

2.2 The Levels

The game comes with 118 levels of difficulty, which mainly vary depending on the number range and the respective number of reference numbers already on the carriages. For instance, level 1 only involves numbers between 1 and 6 with three reference numbers given, whereas level 60 involves numbers between 71 and 76 with only one reference number depicted on one of the carriages. Each level involves 5 rounds (5 trains with all the carriages labelled).

It is possible to start the game at seven different starting points (Table 1) for levels operating on the same numerical content (i.e., number range, counting in 1s, 2s, decade crossings, etc.) and thus difficulty. The starting points align with the UK Curriculum (Department for Education, 2021) reflecting that during the Early Years Foundation Stage, children up to 5 years (Reception year) should learn to verbally count beyond 20 (reflected by starting point 1), and recognise the pattern of the counting system (e.g., even numbers patterns: 2, 4, 6,...; odd number patterns: 3, 5, 7,...reflected by starting point 2). Children in Year 1 should learn to count, read, and write numbers up to 100 in numerals, count in multiples of 2s, 5s and 10s, as well as identify and represent numbers using pictorial representations, including the number line (Department for Education, 2021). This is reflected in starting points 2 to 7, in which children have to count in multiples of 2s, 5s, and 10s within the number range of up to 119 involving or not involving decade crossings. This way, the game facilitates children's understanding of the ordinal and spatial relations between numbers by working with number lines while also strengthening the association between Arabic numbers and the corresponding number word (e.g., 10 = "Ten"). Children can learn to count in 2s, 5s, and 10s, while exploring the number range from 1 to 120, including trials involving decade crossings. Additionally, children practise some arithmetic when buying items in the shop although this is not the primary learning opportunity of the game. All these features make the game align well with the aims of the UK curriculum for Early Years Foundation Stage and Year 1.

Table 1: Starting points of the game.

Starting points	Levels	Numerical Content
starting point 1	1-10	Counting in 1s between 1 and 20
starting point 2	11-17	Counting in 2s between 2 and 24
starting point 3	18-24	Counting in 10s between 10 and 120
starting point 4	25-31	Counting in 5s between 5 and 60
starting point 5	32-38	Counting in 2s odd numbers between 1 and 23
starting point 6	39-78	Counting in 1s between 21 and 119 not crossing tens
starting point 7	79-118	Counting in 1s between 27 and 123 crossing tens

2.3 Adapting the Difficulty of Levels According to Players' Performance

Irrespective of the starting point chosen, we implemented an adaptive algorithm to determine the player's progression through the game. The algorithm keeps the player in a zone of optimal challenge by presenting more difficult levels in case of a given number of correct responses and easier levels in case of incorrect responses (see Table 2a and Table 2b for details). An incorrect response is when the player puts the number on the wrong carriage. The train will not leave the station unless all the numbers are on the right carriages. There is no time limit for the player to correct their responses. For players that commit two or fewer errors, there is a 10% chance they play rounds on the same level, a 60% chance they go to the very next more difficult level, a 10% chance they go to two levels up and a 5% chance they go three levels up. For players who give two or more incorrect responses, there is a 60% chance they play rounds on the same level, a 25% chance they go to the previous level, a 10% chance they go two levels down and a 5% chance they go three levels down.

Table 2a: The adaptation algorithm in case of ≤ 2 incorrect responses in a round (each level has 5 rounds). The algorithm determines the difficulty of the next round based on the present round player performance

In case the player had ≤ 2 incorrect responses (i.e., clicking on the locomotive to leave the station, but numbers were not in the correct order) in the current round, the algorithm will direct the player to a specific level for the next round with the following probabilities.					
Next Level	L-1	L	L+1	L+2	L+3
Percentage of next-level selection	0%	10%	60%	25%	5%

Table 2b: The adaptation algorithm, in case of > 2 incorrect responses in a round (each level has 5 rounds. The algorithm decides the difficulty of the next round based on the present round player performance.)

In case, the player had > 2 incorrect responses in the current round, the algorithm would direct them to a specific level for the next round with the following probabilities.					
Next Level	L-3	L-2	L-1	L	L+1
Percentage of next-level selection	5%	10%	25%	60%	0%

2.4 Game Elements for Motivation

Malone (1980) described three elements that can make a game fun, and increase intrinsic motivation: *challenge*, *fantasy*, and *curiosity* (Malone, 1980). To be motivating, a game needs to present a challenge to the player with goals and uncertain outcomes, that can engage a player's self-esteem. Moreover, fantasy (i.e., a game can stimulate a player's imagination with its story) can make a game more interesting because the game can evoke images of scenarios, situations or objects that can engage players. Lastly, a game is more engaging when it stimulates players' sensory and cognitive curiosity with novel and surprising content. According to Malone's taxonomy, we considered some of these elements when designing the game.

The adaptive algorithm manipulates the difficulty level to keep the player in a zone of optimal challenge. Moreover, the algorithm adds a surprise element as children who correctly responded in a round may suddenly face much more difficult levels. It is important to notice that this surprise of being presented with much more difficult levels does not apply to children who are already struggling with the current level to avoid any frustration. Another element that makes *Number Express* challenging is its *goal*. The *goal* of *Number Express* is to number the carriages correctly to allow the train to leave the station. When players do this correctly, they earn virtual coins to spend in the *shop*, which could be considered an additional goal itself. Children's desire to personalize their character and thus buy items in the shop may further motivate them to play the game for longer. Moreover, buying items in the shop offers more opportunities for learning mathematics, such as comparing the cost of an item to the coins a player has and calculating how many more coins are needed to buy a specific item.

For designing this game, we hired a professional graphic designer to create illustrations that stimulate children's fantasy. We also chose to present shop items that are frequently liked by both boys and girls. The detailed background and the possibility of choosing and naming their character to play the game should also further stimulate children's fantasy and immerse them in the game's narrative.

To stimulate cognitive curiosity, we implemented a *two-stage informative feedback system*. In particular, when the player puts the numbers on carriages in the wrong order, the wrongly ordered number labels move to the top of the screen again, and a visual and vocal message appears to inform the player that the indicated order was not correct (i.e., stage 1, see Figure 5, left chart). At this point, the player can associate the numbers with the respective carriages again. In case, the player gets the order wrong again, a number line will appear under the train so they can use it to order the numbers correctly (i.e., stage 2, see Figure 5, right chart). Stage 2 shall guarantee that all children can place the numbers in the correct order by matching the numbers on the carriages to those on the number line. This feedback provides players, including those struggling with number ordering, with enough information to order the numbers accurately (Figure 5).

Overall, the game's goal and the adaptative algorithm make the game *challenging* for children. The visual aesthetics and the narrative stimulate children's *fantasy* of being the train conductor who needs to make the train leave the station. Finally, the two-step informative feedback system ensures that children get enough information to complete the task at hand.

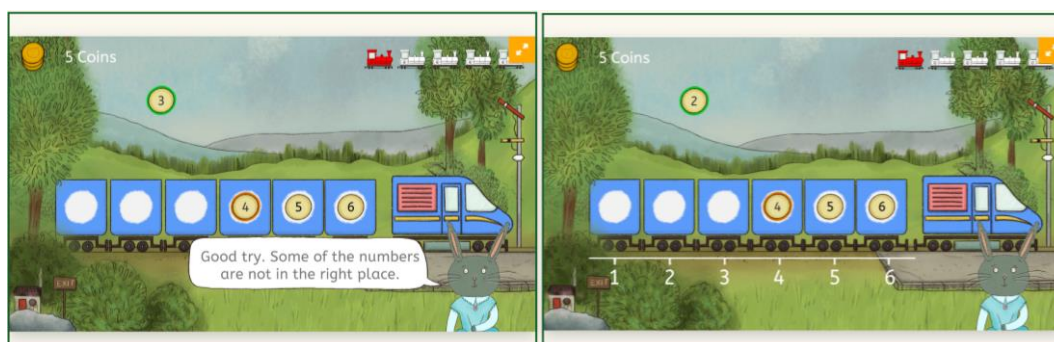


Figure 5: The two-level informative feedback system

3. The Design of the Game

To design *Number Express*, we reviewed the literature on number ordering skills (Devlin et al., 2022; Sasanguie & Vos, 2018; Sella et al., 2020) and on what makes a digital game engaging for children (Malone, 1980; 1981). We considered studies on the importance of the number line as a tool to spatially represent numbers in number games (e.g., Siegler & Ramani, 2008). This evidence guided the design of the game. Accordingly, the numbers on the screen are presented in linear order and equidistantly to each other with numerical magnitude increasing from left to right (i.e., 1-2-3-4...). Moreover, we set the levels of difficulty according to the national math curriculum for the Early Years Foundation Stage and Year 1 in the UK. Furthermore, we had a professional graphic designer create the game scenarios and characters mimicking the style of popular books in nurseries and primary Schools in the UK to make sure the illustrations were familiar to the children and suitable for their age. Finally, the first version of the game was modified according to the received feedback from researchers, teachers, and an education consultant specialising in the learning and teaching of primary mathematics to further improve the game based on their feedback. Then we run a pilot study, which is described in the next section.

4. Initial Incremental Changes of the Game

After preparing the first version of the game, we followed a design-based research method to gather initial feedback. We sought input from academic colleagues with cognitive and pedagogical backgrounds, a primary school teacher, and an educational consultant specializing in Early Years mathematics education. We initially presented the game to a group of colleagues in a mathematics pedagogy seminar at the Department of Mathematics Education, Loughborough University. Their primary suggestion was to implement an option for players to choose the level of difficulty and number range at the start of the game. This feature prevents players from getting bored by playing through the easier levels before reaching more challenging ones.

In the second step, we consulted additional colleagues from the Department of Mathematics Education for further feedback. They recommended introducing larger number intervals, ranging from 20 to 120, without crossing a decade before introducing intervals that do.

In the third step, we shared the game with a primary school teacher. He found the game engaging, noting that the learning goals were clear and aligned with the UK curriculum. His suggestion was to group the game levels

in a way that prevents children, parents, or teachers from feeling confused by too many choices when selecting them.

As the fourth step, we presented the game to an Early Years consultant. She advised us on how to improve the game's graphics, making them less distracting and more meaningful for children. In particular, she suggested we use an image of a stack of coins to mark the points earned instead of a single coin, to be mathematically coherent. Indeed, having a number greater than 1 next to an image of a single coin could confuse children. Additionally, she recommended adjusting some levels to focus more on number ordering (we initially included levels with addition and subtraction). Finally, she suggested a slight modification to how numbers reappear on the screen after a wrong response from the children. Initially, when children placed the numbers in the wrong order, all the numbers in incorrect positions appeared at the top of the screen to be re-ordered by the children. That could be confusing. Therefore, she suggested making the numbers in the wrong positions reappear one at a time. This way, children can focus on positioning one number at a time.

Following this initial phase, we felt the game was ready for piloting it with children.

5. Evaluation of the Game's Playability and User Experience

5.1 Method

5.1.1 Participants

Forty-five preschool children (from 4 to 6 years of age; 26 boys) participated in the study during their last kindergarten year. Children were randomly separated into two groups one playing *Number Express* on a desktop PC (18 children) and one playing the game on a tablet (27 children).

5.1.2 Design

Children played four 15-minute sessions in small groups in a separate room supervised by a trained research assistant. At the beginning of the first session, children watched a video tutorial to understand how to play the game. During the other three sessions, they watched the video tutorial or had some help remembering how to play the game, but only when they asked for it. Trained research assistants supported the children in playing, filled in the observation checklist (see Table 3) during each play session, and, at the end of the last play session, asked children a few questions about their user experience (see Table 4). Research assistants kept their interaction with children to a minimum, resembling future user contexts in which teachers would set up play sessions for multiple children without the necessity of constantly supervising them.

5.1.3 Materials

We aimed to evaluate the game's playability and user experience as "a quality attribute that assesses how easy user interfaces are to use" (Nielsen, 2012, paragraph 1) across five components (Nielsen, 2012): i) *learnability* (e.g., how easy it is for users to accomplish basic tasks the first time they encounter the game), ii) *memorability* (e.g., when users return to the design after a period of not using it, how easily they re-establish proficiency), iii) *errors* (e.g., how many errors users make, how severe these errors are, and how easily they recover from the errors), iv) *efficiency* (e.g., once users have learned the game, how quickly can they perform tasks), and v) *satisfaction* (e.g., how pleasant it is to use the game). In this vein, we developed an observation checklist and an interview-based questionnaire, which were adapted from Ismail and colleagues (2011).

The observation checklist assessed *Learnability*, *Memorability*, *Effectiveness*, *Errors*, *Self-corrections*, and *Efficiency* (Table 3). The *Learnability* item captures the number of times children requested to watch the video tutorial. During the first session, all children watched the video tutorial once. From the second session onwards, the research assistants recorded the number of times a child asked to watch the video tutorial.

In the *Memorability* item, children were awarded a score between 1 and 10 based on how well they remembered how to play the game (1= "the child did not remember how to play the game"; 10= "the child remembered well how to play the game with no need to watch the video tutorial").

The *Effectiveness* subscale entailed eight items to investigate whether children were confident in using some technical features of the game (e.g., how to start playing, and how to choose the train conductor). All items were scored from 1 to 10 based on how well children used the game's features (see Table 3) where 1 indicates poor use and 10 indicates excellent use. We removed Item 3 ("The child did not need help to write the train conductor's name.") from the analysis because some tablets failed to display the keyboard to type the name of

the conductor, and some children just skipped this step and went directly to play the game. For each child in each session, we calculated the average across the seven items as an overall effectiveness index.

The *Error* item assessed how frequently children committed errors during the play sessions, where 10 was the best score (“the child did not commit any error while playing the game”) and 1 was the worst score (“the child committed many errors while playing the game”).

In the *Self-correction* item, children were awarded a score between 1 and 10 based on how confident they were in correcting their errors, where 10 was the best score (“The child is confident in correcting their errors”) and 1 was the worst score (“The child did not know how to correct their errors”).

The *Efficacy* item assessed whether the number line, which appeared in the case of two consecutive errors in numbering carriages, was an effective scaffolding tool to prompt children to order numbers correctly. No scores were assigned in case the number line did not appear on the screen, meaning the children did not commit two consecutive errors. A score of 10 was the maximum score (“The child was able to put the numbers in order using the number line”) and 1 was the minimum score (“The child was not able to put the numbers in order even using the number line”).

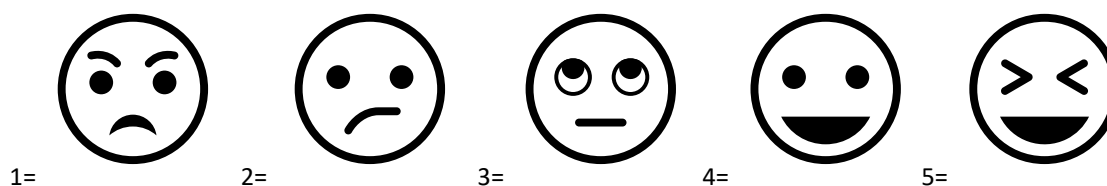
Table 3: The Usability Observation Checklist

Component	Item
Learnability	The number of times a child requested to see the video tutorial.
Memorability	The child remembered how to play without asking to watch the video tutorial or seeking support from the adult.
Effectiveness	The child understood how to start the game.
	The child could select the train conductor.
	The child did not need help to write the train conductor's name.
	The child knew how to move the number tag through the screen.
	The child understood how to make the train leave.
	The child understood how to enter the shop.
	The child could buy items in the shop.
	The child could come back to the game after having been in the shop.
Errors	Errors.
Self-correction	The child knows how to correct themselves.
Efficacy	The number line helps the child to put the number in the right order.

Finally, we evaluated the children's *User experience* using an interview-based questionnaire at the end of the fourth play session. Children had to point to emoji faces corresponding to values from 1 to 5 to assess their response agreement with 5 statements (see Table 4).

Table 4: The Interview-based Questionnaire

Statements
1. The game was fun.
2. The game was easy to play.
3. I like the game characters.
4. I want to play this game again.
5. I would like to play this game at home.



5.1.4 Data analysis

Data analysis was performed using the statistical software JASP (JASP Team, 2023), and plots were created using R (R Core Team, 2023). We mainly analysed changes in scores between the two groups [PC, Tablet] across the four play sessions by running mixed ANOVAs. We applied the Greenhouse-Geisser correction for p-values when the sphericity assumption was violated.

6. Results

6.1 Learnability

The *Learnability* score indicated the number of times children requested to watch the video instructions before playing the game. We excluded the data from the first session because the research assistant showed the video instructions to all children once. Although possible, none of the children requested to view the video again during the first play session. Note that none of the children requested to view the video more than once in a session, constraining all values between 0 and 1, and that, in the fourth session, no children requested to watch the video instructions before playing.

We analysed the *learnability* score in a mixed ANOVA with Session [2, 3] as within-participants factor and Device [PC, Tablet] as between-participants factor. The main effects of Session [$F(1, 43)=12.39, p<.001, \eta^2_p=0.224$] and Device [$F(1, 43)=7.78, p=.008, \eta^2_p=0.153$] were significant. In contrast, the interaction between Session and Group [$F(1, 43)=1.56, p=.218, \eta^2_p=0.035$] was not. Overall, children in the tablet group requested to watch the video more often ($M=0.36, SD=0.29$) than children in the PC group ($M=0.13, SD=0.26$). Children displayed lower scores from the second to the third session, as illustrated in Figure 6. To further explore the effect of Session, we also run two t-tests with Bonferroni correction (2 comparisons) comparing the scores in the second session and the third session against 0 (i.e., the fourth session), separately. The scores in the second session differed from 0 ($M=0.36, SD=0.48; t(45)=4.93, p<.001$) whereas the scores in the third session did not ($M=0.09, SD=0.29; t(45)=2.07, p=.088$).

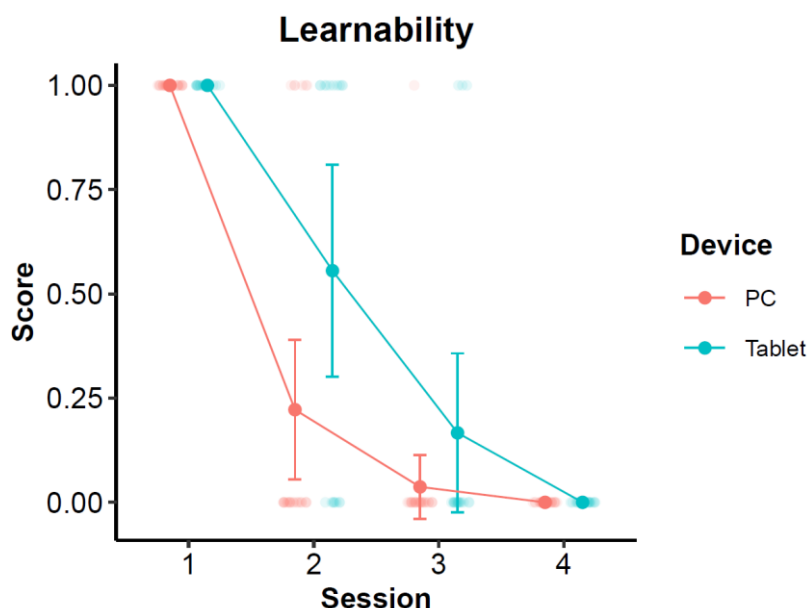


Figure 6: Means of the number of times (y-axis) children in the two groups (PC and Tablet) requested to watch the video instructions before playing the game across the four sessions (x-axis). The translucent points represent individual scores and error bars represent 95% CI

6.2 Memorability

The *memorability* score reflects children's ability to remember how to play the game after the first session, with higher values indicating a better ability to engage with the game without additional support from assistants. Please note that all children received a score of 10 in the fourth playing session.

We analysed the *memorability* score using a mixed ANOVA with Session [2, 3] as within-participants factor and Device [PC, Tablet] as between-participants factor. The main effects of Session [$F(1, 43)=15.14, p<.001$,

$\eta^2_p=0.260$] and Device [$F(1, 43)=8.04, p=.007, \eta^2_p=0.153$] were significant. However, the interaction between Session and Group [$F(1, 43)=1.16, p=.297, \eta^2_p=0.025$] was not significant. Overall, children in the tablet group showed lower memorability scores ($M=6.61, SD=2.4$) than children in the PC group ($M=8.65, SD=2.33$). To further explore the effect of Session, we also run two t-tests with Bonferroni correction (2 comparisons) comparing the scores in the second session and the third session against 10 (i.e., the fourth session), separately. The scores in the second session differed from 10 ($M=6.51, SD=4.24; t(45)=5.52, p<.001$) whereas the scores in the third session did not ($M=9.16, SD=2.48; t(45)=2.29, p=.054$). The pattern of results indicates that children progressively remember how to play the game, highlighting a more pronounced improvement from sessions 2 to 3, which reached a plateau in the third session, as illustrated in Figure 7.

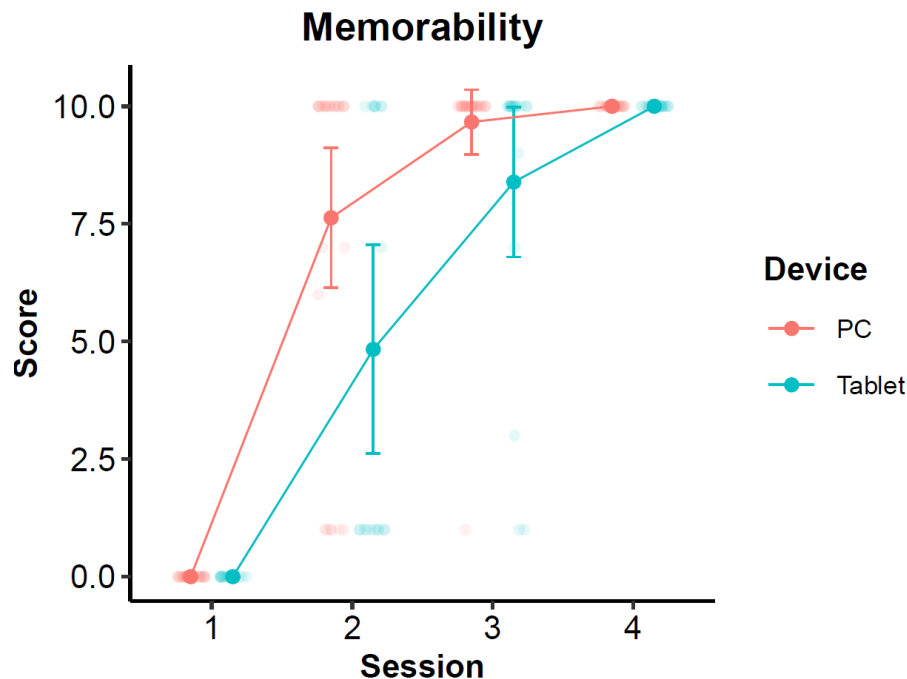


Figure 7: Mean scores of Memorability (y-axis) in the two groups (PC and Tablet) across the sessions (x-axis). The transparent points represent individual scores and error bars represent 95% CI

6.3 Effectiveness

We analysed the mean of the *Effectiveness* subscale in a mixed ANOVA with Session [1, 2, 3, 4] as within-participants factor and Device [PC, Tablet] as between-participants factor. The main effect of Session [$F(1.34, 57.8)=155.96, p_{\text{[sig]}}<.001, \eta^2_p=0.784$], the main effect of Group [$F(1, 43)=5.8, p=.02, \eta^2_p=0.119$], and the interaction between Session and Group [$F(1.34, 57.8)=5.06, p_{\text{[sig]}}=.019$] were significant. To further explore the significant interaction, three ANOVAs with Device as between-subjects factor and Session as within-subjects factors separately for session 1 and 2, 2 and 3, 3 and 4. The interactions between Device and Session were significant for the comparison of Session 1 and 2 ($p=0.019$), and 3 and 4 ($p=0.022$), whereas the tablet group seemed to show larger improvement in their memorability scores passing from session 1 to 2 and from session 3 to 4 compared to the PC group. We further investigated the main effect of Session by running post-hoc pairwise t-tests with Bonferroni correction (3 comparisons) comparing session 1 vs 2 ($t(44)=11.84, p<.001$), 2 vs 3 ($t(44)=3.67, p=.002$), and 3 vs 4 ($t(44)=2.37, p=.075$). Children became more effective in interacting with the game, with a more relevant improvement from sessions 1 to 2, which reached a plateau in the third session, as illustrated in Figure 8.

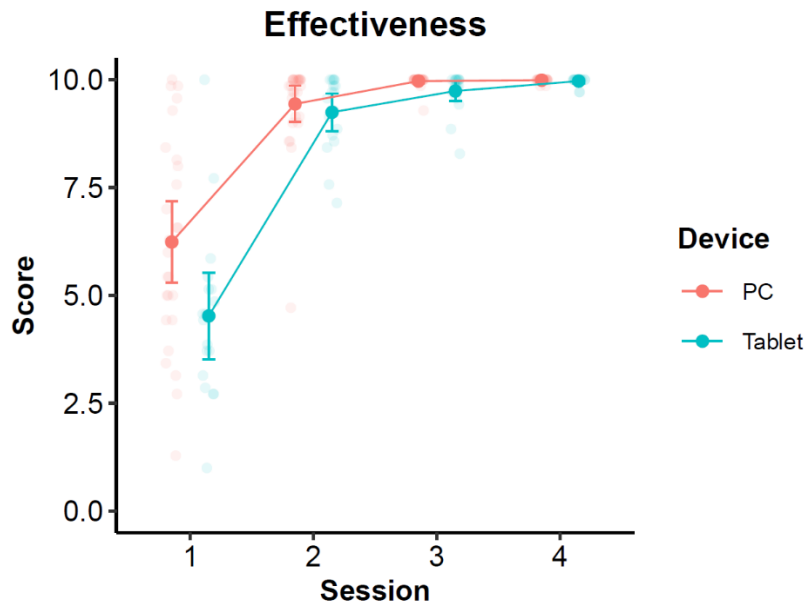


Figure 8: Mean scores of Effectiveness (y-axis) in the two groups (PC and Tablet) across the four sessions (x-axis). The transparent points represent individual values, and the error bars represent 95%CI

6.4 Error

We analysed the error item in a mixed ANOVA with Session [1, 2, 3, 4] as within-participants factor and Device [PC, Tablet] as between-participants factor. The main effect of Session ($F(1.9, 81.5)=89.27, p_{[.05]}<.001, \eta^2_p=0.675$) and the main effect of Group ($F(1, 43)=4.85, p=.033, \eta^2_p=0.101$) were both significant. In contrast, the interaction between Session and Group ($F(1.9, 81.5)=1.16, p_{[.05]}=.318, \eta^2_p=0.026$) did not reach statistical significance. Overall, children playing on the tablet displayed higher scores on the item Error ($M=2.89, SD=1.34$) than children playing on the PC ($M=2.19, SD=0.78$). To further explore the main effect of Session, we ran post-hoc pairwise t-tests with Bonferroni correction (4 comparisons) comparing session 1 vs 2 ($t(44)=8.54, p<.001$), 2 vs 3 ($t(44)=4.02, p=.001$), 3 vs 4 ($t(44)=2.07, p=.176$), 2 vs 4 ($t(44)=4.32, p<.001$). The pattern of results indicates that children committed fewer errors with a clear reduction from session 1 to 2 and reached a plateau in the third session, as illustrated in Figure 9.

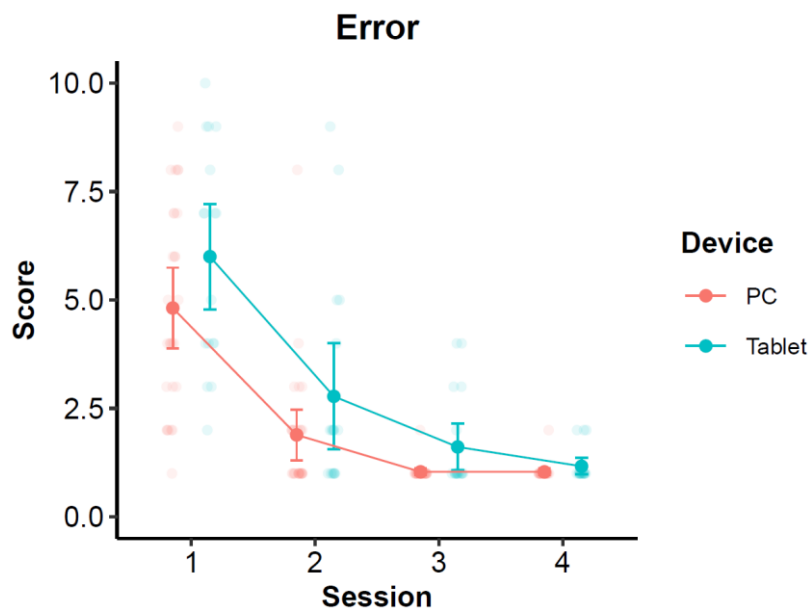


Figure 9: Means scores of Error item (y-axis) in the two groups (PC and Tablet) across the four sessions (x-axis). The transparent points represent individual values, and the error bars represent 95% CI

6.5 Self-Correction and Efficiency

The self-correction and the efficiency items entailed very low variability and reduced sample size. Therefore, we only reported descriptive statistics for these measures. Most children easily self-correct themselves, as highlighted by the high scores in the self-correction item across the four play sessions (Session 1: $M=9.56$, $SD=1.67$; Session 2: $M=9.67$, $SD=1.38$; Session 3: $M=10$, $SD=0$; Session 4: $M=10$, $SD=0$). Similarly, fewer children committed two consecutive errors in ordering numbers and were shown the number line as a scaffolding tool to order numbers correctly. Children were very effective in using the number line feedback as indexed by high scores in the Efficiency item (Session 1: $M=8.86$, $SD=2.66$, $n=22$; Session 2: $M=8.88$, $SD=2.94$, $n=16$; Session 3: $M=9.29$, $SD=1.9$, $n=14$; Session 4: $M=9.92$, $SD=0.29$, $n=12$).

6.6 User Experience

The scores for the five questions were very high and close to the maximum score of 5 (Question 1: $M=4.76$, $SD=0.71$; Question 2: $M=4.56$, $SD=0.66$; Question 3: $M=4.36$, $SD=0.96$; Question 4: $M=4.49$, $SD=1.04$; Question 5: $M=4.69$, $SD=0.67$), meaning that children enjoyed playing the game.

7. Conclusion and Future Perspectives

Number Express is a digital game designed to support basic numerical skills in pre- and primary-school children. We designed the game to accommodate crucial aspects of basic numerical development such as ordinality, the spatial representation of numbers (i.e., number line), and counting in 1s, 2s, 5s, and 10s.

In the current study, we describe how we sought initial feedback on the game following a design-based research method and a study piloting the game with a group of four to six-year-old children to evaluate its usability and likability.

The final version of the game was developed implementing an iterative design-based research approach where we consulted with expert educational practitioners and incorporated their feedback over several development circles which led to significant changes and adaptations of the original (design) ideas for the game.

During the pilot study, we investigated the usability of the game. Overall, the game proved to be simple to play, with instructions that were easy to memorise, the number line tool was effective in supporting the number ordering activity and the children enjoyed playing the game.

We found that while the children involved in the study watched a video tutorial during the first session of the study, only half of the children needed to watch the video tutorial during the second session of the study to remember how to play the game. By the third session, almost all the children remember how to play the game without the need to watch the video tutorial.

Since the first session, children have shown a good understanding and use of the elements of the game that improved over the sessions, as the analysis of the Effectiveness subscale showed. Children became more effective in interacting with the game, with a more relevant improvement from sessions 1 to 2, which reached a plateau in the third session. By the second session, children used all the features of the game optimally.

Less than half of the children needed the help of the number line to put the number in the right order. For them, this tool proved to be very effective.

Lastly, the results of the user experience questionnaire indicated a high level of satisfaction among the participants.

Of course, future research on the effectiveness of the game is needed. In the next step of the development process, we aim to evaluate the game's educational effectiveness in a controlled large-scale intervention study from which we expect a facilitating effect of playing the game on children's mastery of basic numerical skills. We consider the further development of the game an ongoing process during which we may keep adapting and optimising game elements to maximise its user experience as well as educational effectiveness according to incoming feedback and empirical evidence.

Taken together, the findings from this study indicate that Number Express is straightforward to engage with, features easily memorable instructions, and incorporates an effective number line tool that supports number ordering skills.

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Ethic statement: the project has been approved by the Ethical Committee for the Psychological Research of the University of Padova (5403).

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Data availability statement: data will be made available upon request.

AI statement: we have not used an AI tool.

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Playful Modular Robotics Among Children in Kyiv Under Condition of War and Ukrainian Refugees

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Abstract: Wartime is a highly stressful situation. In the context of the war in Ukraine, the chronic stress experienced by children could hinder the learning process but also creativity, which the emotional state of the learner-player can impact. In this study, we evaluated how stressful situations such as war conditions can impact divergent thinking (DT) in creative problem solving (CPS). Different educational contexts support CPS with activities that require learners to engage in creative problem-solving. In e-learning, CPS is expected to support the development of higher-order thinking skills (Setyosari, Kuswandi & Ulfa, 2023) but can be impacted by contextual factors such as chronic stress (Kassymova et al., 2019). This study aims to evaluate a CPS task in the context of the chronic stress of Kyiv learners but also the stress endured by Ukrainian refugees abroad. For this objective, we study three aspects of DT: fluency, flexibility, and originality. We did this by giving Ukrainian participants a CPS robotic task that made them think of ways to come up with new ideas while they were living in France as refugees during a war. We aim to identify how stressful situations affect divergent thinking by comparing these two groups of learner-players in the CPS task. The early results show that the participants from Kyiv, who had lived through almost a year of war, were much more flexible and creative in their DT than the refugee participants in France. This suggests that the stressful environment in Kyiv may have contributed to the development of more original and diverse ideas, possibly due to daily problem-solving activities within war constraints. Playful situations in wartime allowed Kyiv participants to exhibit higher divergent thinking than participants in France. This suggests that wartime constraints may enhance strategies for generating novel ideas while highlighting the positive impact of engaging in game activities on divergent thinking, even in stressful situations.

Keywords: Divergent thinking, Creative problem solving, Creativity, Chronic stress, War

1. Introduction

Over the past decade, there has been an active debate on how the key skills required to fulfil one's potential in the professional field and to live a full life in the modern digital society are changing. In particular, since 2015, analysts at the World Economic Forum (WEF) have been ranking *complex problem solving* skills and *creativity* among the top 10 important skills and competencies. According to the Digital Competence Framework for Citizens (*DigComp 2.2*) problem solving skills are one of the most important parts of Digital Competence for modern humans (European Commission, 2022). The forecasts for 2025 also include these skills (WEF, 2020). According to the Future of Jobs Report 2023 (WEF, 2023), *creative thinking* is the most sought-after skill in the forecasts until 2027. Thus, the need for specialists who are *creative problem solvers* will grow in the coming years.

Creative Problem Solving (CPS) involves breaking down a problem to understand it, generating ideas to solve it, and evaluating those ideas to find the most effective solutions. Osborn originated the CPS approach in the 1940s. Their CPS process has been taught at the International Centre for Studies in Creativity at Buffalo College since the 1950s (McDonald, 2019). While CPS has been studied in a diversity of tasks, the analysis of CPS in playful, educational robotics is still limited in creative studies. With this objective, we aim to contribute to supporting the CPS study through the use of educational robotics in order to better identify the CPS processes in the context of chronic stress indeed by the war conditions in Ukraine.

Analysis of similar studies has shown that stressful situations affect learners' educational opportunities and creative thinking. One of the aims of this study was to find out how playful modular robotics affects creativity and whether it can be used to maintain the motivation to learn and creative activity of children in war. The results of such studies will provide recommendations for teaching children in stressful situations and for using this approach for learners in similar situations. In turn, this will minimise educational losses and maintain students' positive motivation to learn.

2. Creative Problem Solving, Divergent and Convergent Thinking

Creativity is a complex human process that can be observed in a high diversity of learning, professional, and personal tasks. Nowadays, it's acknowledged that creativity is a result of a dynamic interaction of cognitive, affective, and contextual elements. As all these factors are present in human beings and all these variables affect us to a certain degree, it can be argued that a specific combination of them results in creativity (Kanlı, 2020). According to Lubart's (2017) 7C's framework for conceptualising work on creativity, it may take many various forms and encompass a wide range of activities, from the generation and context of ideas and outputs to their consumption.

Different evaluation methods of creativity are described by Kanlı (2020). The author notes that divergent thinking is primarily used in creativity assessment tests to evaluate the creative process. Divergent thinking (DT) is defined by Guilford (1968) as a method of thinking that produces original ideas by considering a wide range of potential answers. Convergent thinking focuses on arriving at the "correct" solution.

CPS is a way of using creativity to develop new ideas and solutions to problems. During CPS tasks, the learner is engaged in divergent thinking (*ideation*) and convergent thinking (*idea selection*) processes in different cycles of iterative improvement (Runco, 2011), Figure 1.

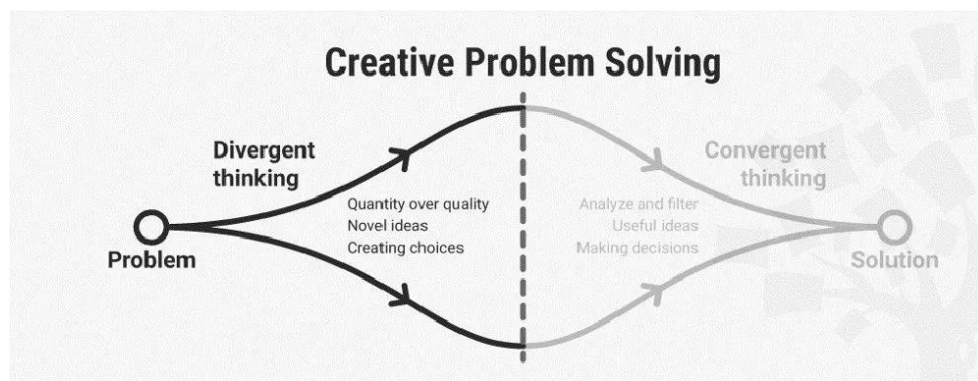


Figure 1: CPS, divergent and convergent thinking (Runco, 2011; IxD, Siang, 2016)

DT represents a cognitive process that results in the generation and exploration of various ideas in diverse directions within problem-solving scenarios. These ideas can range from conventional to original. DT necessitates coming up with several solutions through free-flowing, spontaneous thought, which is a crucial component of CPS (Runco, 2011, 2014). Within CPS, *divergent thinking* is associated with idea generation, and *convergent thinking* is associated with idea selection. Though the results of DT tests have shown to be instructive regarding the potential for CPS, DT is by no means synonymous with creativity. DT assessments provide data on originality, a component of the common definition of creativity, as well as idea fluency and adaptability (Runco, 2022). Guilford (1967) defines the three key components of DT as fluency, flexibility, and originality. DT is non-linear, offering users multiple paths instead of a straightforward route, providing enhanced flexibility, latitude, and a broad array of choices. Differentiating between idea fluency (whether or not an idea is original), idea flexibility (showing how an idea is different from previous ones), and idea originality (showing ideas that are uncommon in a certain reference group) are all possible with DT (Runco, 2022). Originality, as a crucial DT component, holds significant importance as it serves as a prerequisite for creativity (Acar et al., 2019).

In the context of CPS tasks, DT is the process of creating multiple, unique ideas or solutions to a problem that an individual is trying to solve. The assessment results of DT depend not only on the interindividual differences of the person but also on the task and the materiality of the artifacts engaged in the task (Leroy, Romero & Cassone, 2021; Romero & Barma, 2022).

3. Creative Problem Solving Using Playful Educational Robotics Under Stressful Conditions

CPS can be supported with visuospatial constructive play objects (VCPO) or artifacts such as modular robotics (Ness & Farenga, 2016). Educational robotics classes have the potential to support the implementation of interdisciplinary links with STEAM subjects, as well as the practical application of theoretical knowledge. Zhang and Zhu (2022) note the influence of educational robotics on creativity and problem-solving skills with the increasing use of robotics in education. To effectively increase students' creativity and problem-solving skills, educators and researchers should fully utilise its benefits. In the CPS tasks with modular robotics, creativity can

be observed not only by the analysis of the configurations but also by the behavioural learning analytics, including the gestures and actions of the participant engaged with the mediating artifacts (Strutynska & Romero, 2023).

In the present study, we highlight the designers' DT, and the real product generated through the configuration created using a series of modular robotic cubes. We organised CPS tasks by using a game approach with educational robotics. Tang, Vezzani, and Eriksson (2020) concluded the positive impact of the game approach on the development of critical thinking, collective creativity, and problem-solving skills. Our experiment was conducted during the sad and, at the same time, unique experience of teaching and learning during wartime in Ukraine. Children and adults experience many forms of chronic stress during times of war, which can have long-term effects. In this way, we had the unique opportunity to study how stress can impact creativity and CPS. Different research and opinions exist about how stress can impact creativity and CPS. Some researchers studying the impact of stress on creativity indicate that their relationship is controversial because stress can affect creativity either positively or negatively (Table 1).

Table 1: Research and opinions about the impact of stress on creativity and CPS

A positive climate is very important to support CPS	Stinkeste, Napala & Romero (2021)
Stress may boost creative thinking in organisations. Stress is a source of extrinsic motivation and raises arousal levels. When people are under stress, they may utilise a concentrated problem-solving method that promotes creativity	Anderson, De Dreu & Nijstad (2004)
Stress tends to reduce creativity by putting a strain on cognitive abilities, leading to the employment of straightforward cognitive techniques that are likely to decrease originality	Byron, Khazanchi & Nazarian (2010)
Stress and creativity interact ambiguously. On the one hand, stress suppresses creativity, like all other intellectual abilities. On the other hand, stress encourages people to search for new forms of response, i.e., to be creative	Kassymova, Tokar, Tashcheva, Slepukhina et al. (2019)
Individuals in the stress condition generate fewer divergent thinking ideas and fewer problem solutions than individuals in both the cope and relax conditions	Kobe (1999)

It is thought that to be nurtured, creativity needs a happy emotional environment. For example, Stinkeste, Napala, and Romero (2021) demonstrate that a supportive environment is critical to CPS in individual and group contexts. Team environment in STEAM activities has been found to facilitate co-creativity and the creative process. According to Anderson, De Dreu, and Nijstad (2004), stress in the workplace may foster innovative thinking. Their research indicates that stress increases arousal and serves as a source of extrinsic motivation. Because of this, people under stress could apply a focused approach to problem solving that encourages innovation. Other studies show that stress can reduce creativity (Kobe, 1999; Byron, Khazanchi & Nazarian, 2010). According to Byron, Khazanchi and Nazarian (2010) meta-analysis in psychology studies, stress tends to lower creativity by taxing cognitive capacities, which forces the use of simple cognitive strategies that are likely to lessen originality.

In their study, Kassymova et al. (2019) examined the impact of stress on students' health and academic performance. They also discovered that there was an unclear interaction between stress and creativity when they looked into the following dependencies. Stress inhibits creativity in the same way that it does all other intellectual capacities. On the other hand, stress encourages people to search for new forms of response, which is an essential aspect of creative behaviour. The *type of stress* experienced by the subject has a significant impact on how creative someone may be in a stressful scenario. A person's creative achievements are higher and more extensive when they are under more stress. A person's capacity for creativity makes it easier for them to handle stress, sometimes even without realising it. And the necessity for their realisation might put someone in complicated situations due to their creative ability (Kassymova et al., 2019). Thus, a person's creative abilities can be an important source of stress resistance.

3.1 Engaging Youngsters In Creative Problem Solving Activities With Educational Robots Under Conditions of War

Safety is an essential human need for all citizens. Adults and children experience different forms of chronic stress during times of war, and these effects can last for a long period. The literature review shows little research on how war affects learning abilities, creativity, and CPS. The impacts of war on a child's psychological development have been noted in the literature review by Elbedour, ten Bensel, and Bastien (1993), mainly if the adult figures in the child's life have not yet acquired coping mechanisms.

When the war in Ukraine started, we wanted to know how to help Ukrainian colleagues in the learning sciences and support their educational efforts during wartime. One of the study's aims is to determine whether the activities offered to students with modular robotics can contribute to achieving sustainable development goals (SDGs), particularly ensuring equitable and quality education. Université Côte d'Azur's *MSc SmartEdTech program's* research and social values aim to create educational materials that can help achieve the sustainable development goals (SDGs), with a particular emphasis on quality education (SGD4), which aims to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". We scheduled our first event for 2021 on Women's Day 2021 and invited female scholars in STEM education from Ukraine to participate in a special webinar. Following that, we got the chance to assist Prof. Oksana Strutynska, a full professor at Kyiv, in her participation in the *Let's STEAM!* and *ANR CreaMaker* initiatives in the LINE research lab. Next, we planned two seminars in Nice, where we supported computer science activities that were unplugged and produced as part of the Unplugged Quest project planned for 2022. Professor Strutynska took a plane back to Kyiv in January 2023 to conduct various one-on-one and group play sessions at the Dragomanov Ukrainian State University's Faculty of Mathematics, Informatics, and Physics.

To engage children in CPS, we offered them a learning task using modular robotics related to generating ideas (actually creating different configurations). Participants must use Cubelets modular robotics to construct an autonomous vehicle that can go from the starting point to the destination. Participants construct a variety of vehicle possibilities (fluency component), innovative ideas (originality component), and diverse concepts (flexibility component). These activities involved Ukrainian participants in a stressful situation, namely in the context of war. To evaluate DT, the students were asked to solve a game task with *CreaCube* (Figure 2). Solving a task with *CreaCube* involves manipulating and stacking cubes.



Figure 2: Cubelets modular robotics

Expanding robotics' application domain and increasing robotics' popularity are hallmarks of the current phase of science and technology development (Buchem & Bäcker, 2022; Chevalier et al., 2022). One aspect of student learning that crosses disciplines is educational robotics. Cybernetics, mechatronics, informatics, digital technology, and STEM (in the STEM area for educational robotics, we focus more on subjects such as physics, technology, and mathematics) are all integrated into its process.

Teaching educational robots enables students of all ages to participate in the process of invention scientific and technological creativity. It aligns with the concept of advanced training (learning the technologies that will be required in the future). Students' technical tendencies may be identified early on, and their technical inventiveness can be developed thanks to the usage of educational robots (Morze, Strutynska & Umryk, 2018; Strutynska et al., 2020). Teaching the younger generation how to build, program, and operate robots and robotic systems is connected to modern needs, such as the rise of new robotics-related occupations and the resulting demand for qualified professionals.

4. Methodology

4.1 Participants

The experiment involved 33 Ukrainian participants, who were divided into two groups: Ukrainian refugees in France and participants from Kyiv who were in the chronic stress situation of war. The participants were presented with a playful activity with modular robotics to evaluate divergent thinking, the *CreaCube* task.

Ukrainian families living in the Nice refugee community were involved in the experiments in 2022. The majority of the kids attend primary and middle schools successfully. Still, their fluency in French varies, necessitating the translation of certain terms, and their level of prior computer science knowledge varies as well. The participants were invited to the LINE lab in Nice. Following the exercises, we shared some snacks to foster teamwork and gave them a chance to reflect on their everyday struggles as well as the Unplugged Quest activities. In Nice, we engaged 17 people in a playful activity in Nice.

The workshops in Nice were organised on a non-school day to allow the parents to come with their children. We shared the Unplugged Quest activities with the parents. They appreciated the language diversity in the activities supporting their children's language learning.

In Kyiv, Prof. Strutynska proposed the participants join the Faculty of Mathematics, Informatics, and Physics at the Dragomanov Ukrainian State University (Ukraine), according to the safety measures during wartime. Participants reported enjoying the playful activities. 16 participants were involved in the experiment. During the workshop, we took all the necessary measures to ensure the safety of the participants. During air raid sirens, we went down to the shelter. After the danger was over, we returned to the game activities (Strutynska & Romero, 2023).

4.2 Evaluation of Divergent Thinking

DT has been thoroughly studied and is considered an important process in creativity research. DT tests are often used in creativity studies and as measures of creative potential (Runco & Acar, 2012; Runco et al., 2016; Acar et al., 2019).

To evaluate divergent thinking, learner-players are asked to solve the CPS *CreaCube* playful task. The resolution of the *CreaCube* activity involves the manipulation and assembly of cubes. To complete the game task, the player must explore unknown cubes and create an autonomous vehicle that can move from the starting point to the final destination using modular robotics (Romero, DeBlois & Pavel, 2018).

Participants are required to build an autonomous vehicle that can move from the starting point to the destination using Cubelets modular robotics. Participants build different options for vehicles (*fluency component*), including different ideas (*flexibility component*) and original ideas (*originality component*). Based on Guilford's operationalization of the Alternative Uses Test (AUT) (1967), we evaluate DT in the *CreaCube* task using the three DT components. *Fluency* corresponds to the total number of distinct ideas; *flexibility* corresponds to the number of distinct categories; and *originality* is the rarest response, corresponding to those provided by fewer than 5% of all participants within the same age category (Strutynska & Romero, 2023). This coding schema permitted the adaptation of Guilford's DT components into the modular robotic task. In this way, we could analyse the process of CPS to evaluate the DT components for every participant.

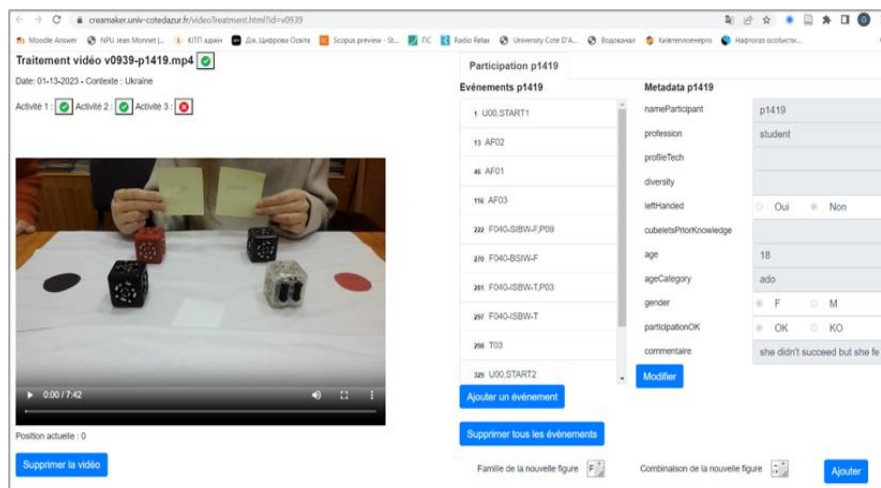
Participants are invited to play again after their first success in the *CreaCube* game. The purpose of the second attempt is to find out if the player has improved upon and taken into account the cubes' qualities from the previous effort and if they have attempted to solve the problem by coming up with a fresh solution or by trying to replicate the original answer precisely. These subsequent activities also evaluate the participant's DT.

Following the experiments, we scrutinised participants' actions in the videos using custom software featuring pre-set figure configurations (Figure 3).



Figure 3: Ad hoc developed software for analysis of DT components

Once the video is uploaded to the *CreaMaker* research platform, it undergoes a comprehensive analysis by integrating specific coding schemas within the framework of behavioural learning analytics. This process allows a meticulous examination of participants' interactions to be coded as unitary events to analyse DT. By systematically decoding the behavioural cues captured in the video, we obtain the indicators for constructing the DT components, including fluency, flexibility, and originality. This analytical approach permits us to understand the participants' cognitive dynamics in the context of CPS with specific observables without subjective evaluations of DT components (Figure 4).



We can observe in Table 2 a higher level of flexibility ($m = 2.18$; $sd = 1.97$) and originality ($m = 1.19$; $sd = 1.47$) in the first instance (A1) of the *CreaCube* task among the participants in Kyiv than those in Nice.

The next figures focus on the DT components with the highest differences between the Nice and Kyiv participants. Firstly, figure 3 shows the difference in the first instance of the *CreaCube* activity (A1) on the originality DT component. Kyiv participants demonstrate higher levels of originality ($m = 1.18$; $sd = 1.47$) compared to their counterparts in Nice ($m = 0.13$; $sd = 0.35$). The statistical analysis, utilising Welch's t-test ($t(16.821) = 2.784$, $p = 0.013$), indicates a noteworthy and statistically significant difference in originality scores between the Kyiv and Nice groups (Figure 5, Figure 6).

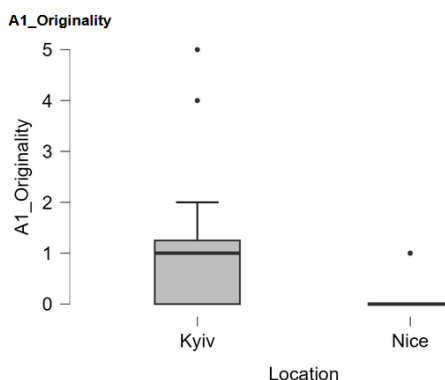


Figure 5: Originality in A1 among Kyiv and Nice participants

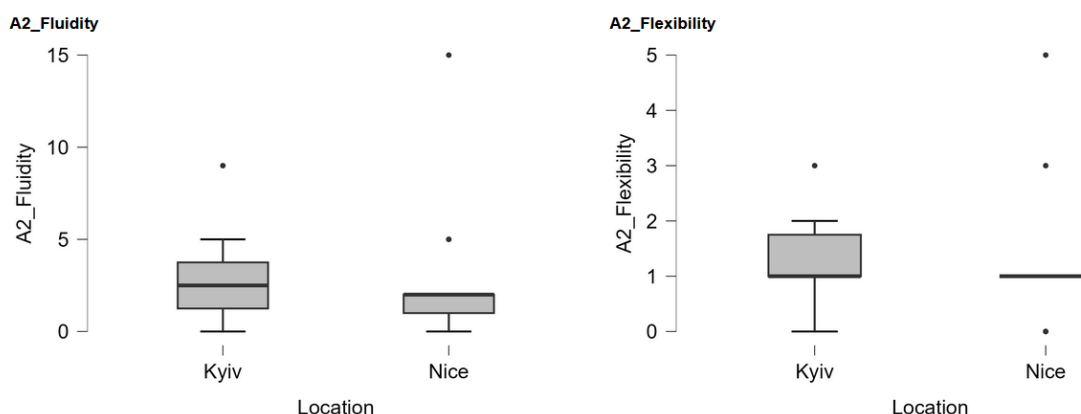


Figure 6: Fluency and Flexibility in A2 among Kyiv and Nice participants

Despite a similar average, we could observe that the distribution of the DT scores of fluency and flexibility in A2 are more diverse among Kyiv participants than those in Nice. There was no significant difference in fluidity scores between the Kyiv and Nice groups in A2, $t(27) = 0.218$, $p = 0.829$, neither in flexibility, $t(27) = 0.036$, $p = 0.972$.

6. Discussion

The analysis of the Nice and Kyiv participants shows some differences, especially in relation to originality in A1. The second activity (A2) shows a lower level on each of the DT components, which is a normal observation due to the prior experience acquired when solving the first instance of the task, which required fewer configurations (fluency), different configurations (flexibility) and events that did not require engaging in original configurations (originality) compared to the first instance (A1), in which the participants were required to engage in higher trial-and-error explorations of the configurations and generate a higher number of ideas (DT). Observing a lower number of original solutions compared to fluency and flexibility is part of the expected operationalisation of Guilford's DT components, in which originality is evaluated according to the rarity of the solutions within the same age category (Strutynska & Romero, 2023).

The elevated average value of the originality component (A1) among Kyiv participants compared to those in Nice is attributed to the daily challenges faced by learner-players in Kyiv amid wartime stress. This includes coping with issues such as power outages, lack of heating, occasional water shortages, cooking difficulties in the

absence of electricity, closed shops, malfunctioning household appliances, inoperable ATMs, the necessity to interrupt studies and work, and navigating the city amidst air raids. The chronic stress induced by wartime conditions contributes to the heightened readiness of Kyiv participants to tackle various problems, potentially explaining their superior performance in generating original ideas during the A1 instance of the *CreaCube* task. The variability of the results among Kyiv participants could be understood in the different ways this chronic stress affects the different participants.

Therefore, their readiness to solve problems in the novelty situation of A1 is higher among the Kyiv participants than that of the participants from the Nice group. In addition, in such difficult war conditions, the opportunity to attend a playful activity with modular robotics *CreaCube* also brought positive emotions to participants from the Kyiv group. It distracted them from the current situation in the country. This allowed them to relax, which can also serve as an additional factor in a higher level of CPS (Strutynska & Romero, 2023).

Despite a limited sample size, this study is an opportunity to consider playful interventions to help Ukrainians engage in creative activities and value the DT capacities developed under stressful war situations. The experimenters and participants in France and Ukraine reported a highly positive, playful experience that, beyond the DT components, is a positive intervention to support Ukrainians through game-based learning activities.

The higher levels of flexibility and originality observed among Kyiv participants in the first instance of the *CreaCube* task (A1) suggest a positive impact of the war-induced stressful conditions on their creative thinking abilities. The statistical analysis further supports the significance of these differences, particularly in the originality component.

In the second instance of the *CreaCube* task (A2), despite a similar average, the distribution of DT scores for fluency and flexibility is more diverse among Kyiv participants compared to those in Nice. While there is no significant difference in fluency and flexibility scores between the two groups in A2, the variation in the distribution indicates a nuanced response to the task among Kyiv participants, possibly reflecting a deeper exploration of creative solutions.

This study highlights the potential of game-based learning interventions, specifically the *CreaCube* task, to support the development of CPS skills, particularly in challenging contexts like wartime chronic stress. The positive experiences reported by participants and experimenters emphasise the broader impact of such interventions beyond measurable DT indicators. The findings underscore the importance of considering playful approaches as valuable tools for supporting individuals in creative activities and cognitive development, especially in the face of adverse conditions.

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AI Statement : We also declare that we did not use AI tools to develop this paper.

Ethics Statement: All procedures performed in studies involving human participants were in accordance with the ethical committee of Université Côte d'Azur (*Comité d'Ethique pour les Recherches Non Interventionnelles*, CERNI, 20196). Informed consent was obtained from all individual participants included in the study.

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