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MODESTUM

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Challenges and opportunities in applying constructionist digital games in secondary mathematics education

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ABSTRACT

The growing integration of technology into society highlights the need for educational transformation to better equip students for future challenges and the evolving labor market. Digital game-based learning (DGBL) has emerged as a promising strategy for enhancing learning using interactive digital games. This study investigates the implementation of DGBL in secondary mathematics classrooms, focusing on four digital math games grounded in a constructionist approach that enables adaptation by both teachers and students. Employing a mixed-methods research design, we collected and analyzed both qualitative and quantitative data. The findings reveal that although teachers integrated the games into their instruction, they did not involve students in modifying or creating the games, thereby leaving the constructionist potential largely unexploited. This study contributes to the DGBL literature by offering an integrated perspective (both students and teachers) on the opportunities and challenges of implementing constructionist DGBL in mathematics education.

Keywords: digital-game based learning, ICAP, SAMR, mathematics, teachers, students

INTRODUCTION

Traditional educational techniques may no longer be adequate to engage today's digital native students or to develop the skills required for success in a technology-driven world. Educational systems increasingly recognize the need to foster critical thinking, creativity, and adaptability by integrating technology to offer more interactive, personalized, and contextually relevant learning experiences (OECD, 2022). Digital game-based learning (DGBL) has emerged as a promising pedagogical approach that utilizes interactive digital games to enhance student engagement, motivation, and learning outcomes across disciplines (Ishak et al., 2021; Kukulska-Hulme et al., 2020). In mathematics education, digital games have attracted attention for their ability to make learning more engaging and meaningful (e.g., Hui & Mahmud, 2023) and for positively impacting cognitive and motivational dimensions of learning (Gui et al., 2023; Hussein et al., 2022; Pan et al., 2022).

Importantly, DGBL also offers opportunities for students to engage in the modification and creation of games, which aligns with constructionist learning theories (Hughes-Roberts et al., 2023; Puttick et al., 2024). In such environments, learners do not merely consume content but actively construct knowledge by designing artifacts that embody their understanding.

However, despite these possibilities, there is a gap in the literature concerning the implementation of constructionist DGBL approaches within the context of regular, formal classroom settings (Puttick et al., 2024; Tinterri et al., 2023). Much of the existing research on constructionist game-making or game-modding in mathematics education has taken place in informal learning contexts, such as afterschool programs, workshops, or extracurricular activities, often involving small groups of self-selected students (e.g., Kynigos & Grizioti, 2020; Kynigos et al., 2023; Tucker & Johnson, 2017). These environments differ significantly from typical school classrooms, where constraints such as time, curricular alignment, and teacher preparedness can limit the extent to which students engage in constructionist activities.

This study addresses the above issue by examining whether constructionist DGBL can be implemented in secondary mathematics classrooms as part of regular instruction. Within the context of a European project GAMMA, several digital math games were co-developed with teachers. These games were designed not only for play but also for modification and redesign by students and teachers. By investigating how these games are used and perceived in regular classroom practice, this study

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contributes to the body of research on the practical integration of constructionist DGBL. To achieve this aim, the study is guided by three primary research questions:

1. How do students use and experience digital math games during regular mathematics lessons?
2. How do secondary mathematics teachers implement digital games in their regular teaching practice?
3. What opportunities for transforming mathematics education can emerge from DGBL?

THEORETICAL BACKGROUND

Research on Digital Game-Based Learning

Digital games offer an innovative approach to education, as they can be designed well to meet the diverse needs of learners (Plass & Pawar, 2020). These games can facilitate the effective management of heterogeneity in the classroom by providing a secure learning environment that allows students to make mistakes and try again. Such opportunities for failure lead to mastery experiences, which in turn enhance students' motivation and self-efficacy (Plass et al., 2015). Establishing clear learning objectives that align with curriculum standards and implementing them in a student-centered manner further enhances the effectiveness of DGBL (Pan et al., 2022). The use of DGBL has numerous benefits that contribute to the improvement of learning quality. For example, DGBL can reduce cognitive load and thereby increase learning performance (Chang & Yang, 2023). In mathematics education, digital games can significantly enhance students' knowledge and skills (Pan et al., 2022), and they also positively impact perceptual, cognitive, motivational, and behavioral aspects of learning, such as memory, attitudes, motivation, interest, and engagement (Hui & Mahmud, 2023; Hussein et al., 2022). However, previous research indicates that digital math games are primarily used to supplement traditional teaching methods, mainly through drill-and-practice, rather than to introduce new mathematical concepts (Byun & Joung, 2018; Hussein et al., 2022; Pan et al., 2022). Additionally, much of the research has focused on primary education and arithmetic operations (Byun & Joung, 2018; Hussein et al., 2022), leaving a gap in the literature regarding the use of digital math games in secondary education, particularly the use of constructionist digital games in regular classroom settings. This gap underscores the need to explore how such games can be integrated into everyday teaching practices to promote deeper cognitive engagement and critical thinking skills among students.

The SAMR Model and Technology Integration in Education

The SAMR model (substitution, augmentation, modification, and redefinition) is a useful framework for understanding the integration of digital technology in education. It categorizes technology use into four levels, each representing a different degree of integration and impact on learning outcomes (Puentedura, 2014). *Substitution* occurs when technology replaces less efficient tools without any functional change. This involves changing an analog technology (Hamilton et al., 2016), or digital when it is less efficient (McKnight et al., 2016), by another digital technology, without causing changes in teaching practice. Substitution can help teachers to restructure their time and to be more efficient using tools such as PowerPoint presentations, online grade books, online quizzes (de Morais Bicalho et al., 2023). In *augmentation*, technology acts as a substitute but with functional improvements. It is possible to observe small-scale improvements, which do not yet imply robust changes in the teacher's practice system. Technology, at this level, enhances teaching experience by adding features to the process that would not be possible without it, in addition to enabling the deepening of content, learning and favoring student engagement (de Morais Bicalho et al., 2023). At the *modification* level, technology supports a meaningful redesign of learning tasks, leading to noticeable shifts in teaching practices that become more (de Morais Bicalho et al., 2023). Significant redesign can be also evident when technology facilitates a shift toward an active, student-centered instructional approach (McKnight et al., 2016). In *redefinition*, technology redesigns teaching practices by making it possible to design tasks, approaches, and strategies that would previously be unthinkable or inconceivable without digital technology. For example, teachers can encourage students to create collaborative, original texts that other students at the school can later use as research material.

The first two levels (substitution and augmentation) are frequently denoted as enhancements, while the two last levels (modification and redefinition) are referred to as transformation. Puentedura (2014) hypothesized that as the degree of functional change increases from substitution to redefinition, so does the potential to enhance learning. **Figure 1** provides an overview of the SAMR model.

The SAMR has been used in research because it provides a practical framework for analyzing how digital technologies are integrated into educational practices and their potential impact on learning outcomes (Sailer et al., 2024). However, the model has also been criticized for its lack of theoretical support and in particular by not taking learning context into account (e.g., de Morais Bicalho et al., 2023; Hamilton et al., 2016). Sailer et al. (2024) suggest that the shortcomings of the SAMR model might be addressed by combining it with another model that incorporates a learning activity perspective. This approach is described in the following section.

Integration of Technology in Learning Activities

Using digital technology in education is beneficial for learners when it aligns with the pedagogical objectives and activities. Therefore, when integrating technology into education, we need to understand how learners use it in relation to the learning activities they engage with. The ICAP (*interactive*, *constructive*, *active*, and *passive*) model offers a systematic method for categorizing observable learning activities as indicators of cognitive engagement (Sailer et al., 2024). Cognitive engagement refers to the mental effort invested in learning and different learning activities are likely to trigger certain cognitive processes (Chi et al., 2018).

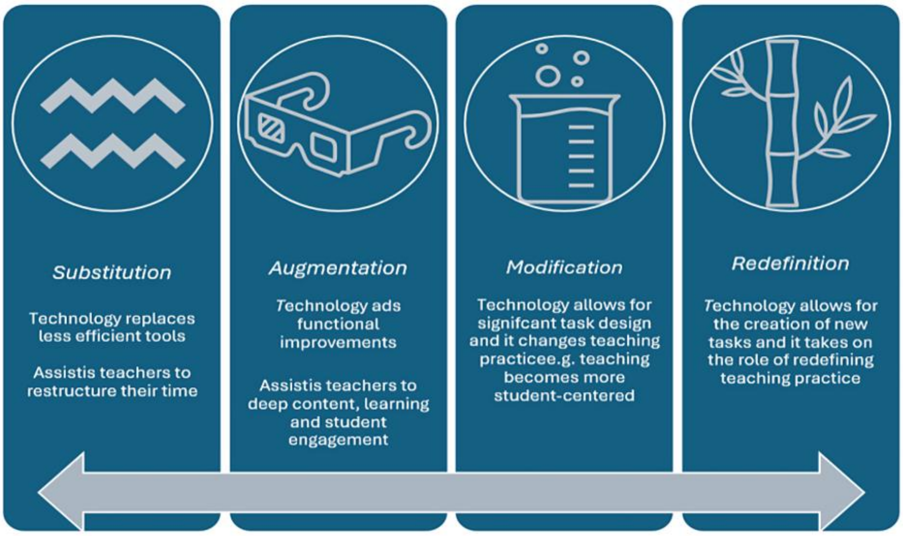


Figure 1. The SAMR model (Source: Authors' own elaboration)

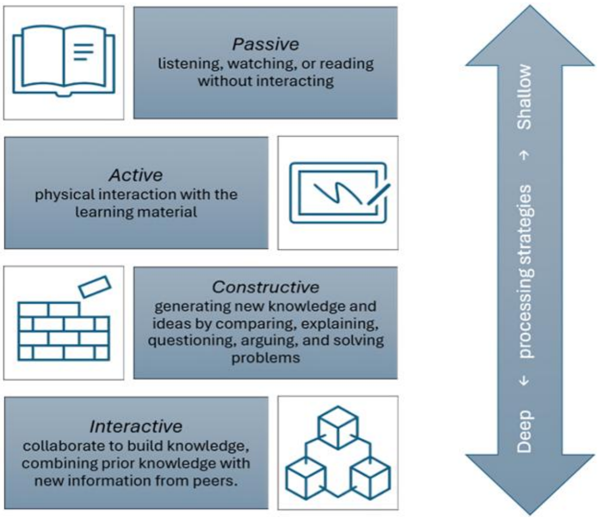


Figure 2. The ICAP model (Source: Authors' own elaboration)

Passive learning activities involve students absorbing information through listening, watching, or reading, which is effective for acquiring simple skills and recalling facts in similar contexts (Antonietti et al., 2023). *Active learning* engages students through hands-on interaction with materials, enhancing the integration of new information into existing knowledge frameworks (Antonietti et al., 2023). *Constructive learning* tasks require students to generate new knowledge by engaging in activities like comparing, explaining, and problem-solving, often extending to applications in new settings like simulations (Brod, 2020; Chi et al., 2018). This method activates prior knowledge to create and retain new insights (Antonietti et al., 2023). *Interactive learning* occurs when students collaborate, merging their knowledge with peers' insights, which enriches understanding and develops advanced skills like argumentation (Chi et al., 2018). The ICAP framework suggests that learning processes evolve from passive to interactive, with deeper cognitive engagement in the latter activities compared to the more superficial processing in passive and active learning (**Figure 2**).

Integrating SAMR and ICAP for DGBL Implementation

The SAMR model evaluates the extent of technology integration, while the ICAP focuses on cognitive engagement in learning activities. In the study, we will use both models because combining SAMR and ICAP provides a comprehensive approach to understand how digital games can be effectively integrated into mathematics education to maximize learning outcomes.

METHOD

Context of the Study and Participants

This study employs a mixed-methods research design to investigate the implementation and impact of constructionist DGBL in secondary mathematics education. The research was conducted as part of the European project GAMMA. This project involved

Table 1. Participant students for each game

Game played	Number of responses	Student's age	Grade
Hot Air Balloon	42	15-16	9th
E(qua)scape	9	15-16	9th
Yo-yo Bird	57	17-18	11th
Don't Blow up the Balloon	50	18-19	12th

collaboration between researchers, teacher educators, and secondary school mathematics teachers from four universities and four upper secondary schools located in Greece, Croatia, the Netherlands, and Finland. As part of the project, schoolteachers were tasked with incorporating GAMMA games into their mathematics lessons when specific mathematical topics were being taught.

We selected Croatian teachers (N = 9) as participants in this study, together with their students who took part in DGBL mathematics lessons. The selection was guided by several criteria. Firstly, the teachers themselves initiated participation in the GAMMA project. Secondly, their responses to a questionnaire on their experience with the GAMMA project revealed that their motivation stemmed from a desire for professional development. Specifically, they highlighted goals such as enhancing subject-specific competencies, increasing the relevance of their teaching, acquiring practical classroom-applicable skills, and exploring innovative instructional strategies. The teachers showed a positive attitude toward pedagogical innovation and a high level of intrinsic motivation to engage with new instructional strategies. Therefore, we identified them as suitable participants, with a willingness to actively contribute to and implement DGBL in their mathematics instruction.

Participating teachers got acquainted with the platforms used in the project (described later) and had the opportunity to play and modify existing examples of games on these platforms. They also participated in designing GAMMA games by providing feedback on several versions of these games. Each teacher used one GAMMA game in his/her lesson in the Spring of 2023 that took about 60-90 minutes. Teachers' implementation of GAMMA games was supported also by teaching scenarios (TS), which are described later.

Students were required to attend the lessons and use digital games as part of the instruction. Following the lesson, students were invited to voluntarily complete a questionnaire about their experience. Those who chose not to participate faced no negative consequences. A total of 158 responses were collected. **Table 1** provides data on students' engagement with the GAMMA games. Each student participated in one DGBL lesson and played only one game. As the questionnaire was completed by students who voluntarily chose to participate, their responses are considered reliable.

GAMMA-Digital Games

The four digital games used in this study were created in the GAMMA project using two platforms. ChoiCo (choices with consequences) is an online, open-source authoring tool for creating, playing, and modifying games (http://etl.ppp.uoa.gr/choico/). When playing a ChoiCo game, the player's goal is to keep making choices for as long as possible, not to go over one of the red lines of a respective consequence. In design mode, the user can design or modify the game's elements through the use of incorporated affordances. The second platform MaLT2 (http://etl.ppp.uoa.gr/malt2/) is an online programming environment with a Logo programming editor, a variation tool, and a 3D scene display (Kynigos & Karavakou, 2022). The programming language is an extension of Berkeley Logo, tailored to simplify updates in 3D Turtle Geometry. Instead of a traditional turtle icon, a sparrow represents spatial changes in MaLT2. The platform allows manipulation and animation of various two- or three-dimensional figures, with sliders for each variable.

Digital games developed on these platforms can be customized, and the platforms also support the creation of entirely new games. Within the SAMR and ICAP frameworks discussed in the theoretical section, these games would be considered technologies that enable

(1) the modification and redefinition of teachers' practice and

(2) deep processing activity by students.

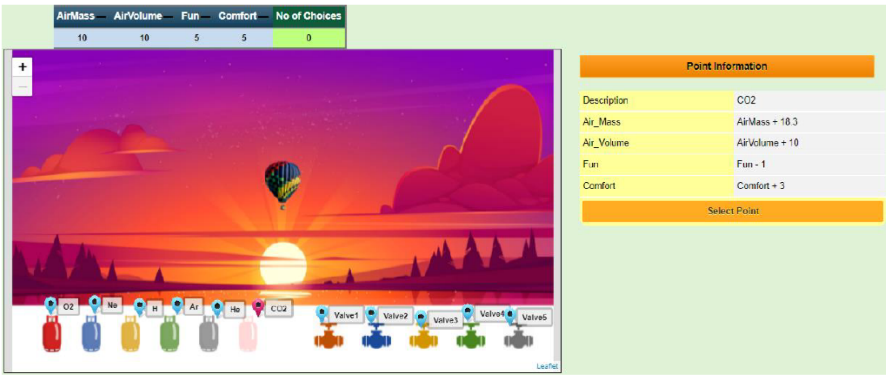
The games created in the GAMMA project (illustrated in **Figure 3**) involve mathematical content aligned with the Croatian national mathematics curriculum for high schools and vocational schools. The mathematics within these games is inherently embedded in the game mechanics. A description of the games and their main mechanics is provided in **Figure 3**.

Teaching Scenarios

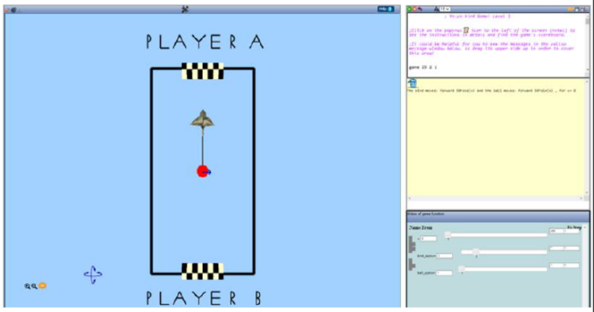
In order to assist teachers in planning and conducting DGBL lessons, a TS has been designed for each GAMMA game. Research indicates that integrating digital games into instructional practice demands increased effort and preparation time from teachers (Avidov-Ungar & Hayak, 2023). Teachers may also need support in planning and organizing different teaching activities before or after gameplay to help students learn more efficiently with the game-activity (Sun et al., 2021). Therefore, each TS consists of three parts. The *basic part* contains information about the game, prerequisite knowledge, and resources needed for enacting a lesson. The *core of the scenario* contains activities for the DGBL lesson: pre-game activities, in-game activities, and post-game activities (Bado, 2022). The *extended activities* address students who wish to know more and recommend further activities, e.g., changing parameters, adding their own functions, adding more choices or changing consequences, and exchanging versions with other fellow students so they can play each other's game. The *reflection after teaching* encourages the teacher to collect feedback on the enacted lesson from the students and to reflect on the lesson himself/herself. However, the TS outlines activities to be done but lacks comprehensive details on how to perform them.

Don't Blow up the Balloon
Online two-player ChoiCo game in which players compete against one another. The objective is to control the size of the balloon by selecting suitable rules for the magic pump, while preventing the balloon from bursting or deflating. The player must use knowledge of derivatives to make a strategic decision. For instance, in the Level Graphs, the player must read the size value from the graph and estimate the rate of change from the graph.

Hot Air Balloon
is an online ChoiCo game where players are required to make decisions that impact specific sectors, namely Mass, Volume, Fun, and Comfort. The objective of the game is to maximize the number of decisions made. The player has the option to choose between utilizing a gas cylinder to introduce a predetermined amount and type of gas into the balloon, or employing an air release valve to expel air from the balloon. In order to optimize their decision-making and minimize losses, players are required to take into account both direct and inverse proportional relationships while engaging in gameplay.



Yo-yo Bird Game
is a MaLT2 two-player game. Players can control the movement of a bird and a ball by selecting a specific trigonometric function for each. The winner is the player with the highest score.Players must take into account the characteristics of trigonometric functions in order to: (1) score a point; (2) stop the bird from striking the ball; or (3) make it harder for the other player to stop the bird from striking the ball.



E(qua)scape is a MaLT2 two-player game based on the escape room concept. In the game, players solve problems using simulations that help them interpret and solve systems of linear equations. The simulation has sliders representing parameters like time and speed (d), which the players adjust to affect the outcome of the problem (a). Players must solve the problems correctly and create a password that opens the next level. The correct passwords, highlighted in a yellow rectangle (c).

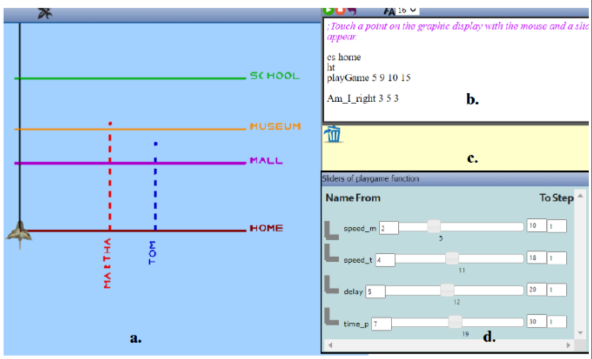


Figure 3. GAMMA games and their main mechanics (Source: Authors' own elaboration)

In terms of the ICAP framework, the core part of the TS includes learning activities that can engage students in a broad range of strategies: active, constructive and interactive learning. TS suggested collaborative game playing (in pairs) even in competitive games. The extended activities include mostly tasks for modification and creation of new games, which requires deep processing strategies. Therefore, taken as a whole, a TS encourages students to play a digital math game and modify it in ways they would fit their interest and learning needs. In terms of the SAMR framework, the digital games in the core part of the TS are primarily used to augment and modify teaching practice, while the extended activities create opportunities for teachers to use them in a more transformative way.

Table 2. Categories from the analysis cycle

Category	Description	Supporting quotes
Favorable aspects of enacted DGBL lesson		
Engaging and enjoyable	Lessons are fun, motivating, and positively received by students.	- "More fun to do math" - "Much more engaging"
Collaborative learning & social interaction	Promotes teamwork and socialization through collaborative tasks.	- "Work together to solve tasks" - "Playing with friends"
Easier and efficient learning	DGBL lessons simplify learning and enhance effectiveness.	- "Easier to learn math" - "Learning connection between sinus and cosines"
Innovative and interactive	Utilizes digital games and interactive technology for a modern approach.	- "Interactive piece of web-software" - "Feels better to use technology"
Hindering aspects of the DGBL lessons		
Boredom and lack of enjoyment	Some students find DGBL lessons boring and not enjoyable.	- "Boring" - "Game is boring"
Confusing and difficult	Complexity and initial confusion can make learning challenging for some students.	- "Complicated" - "Hard to play and confusing"
Not relevant for learning	Some students feel DGBL lessons are not effective for learning the subject matter.	- "Don't support learning" - "Not a good way to learn"
Technical and design issues	Issues with game design, graphics quality, and technical performance.	- "Poor game graphics" - "Need animations"
Less interaction and feedback	Compared to traditional lessons, there is reduced teacher-student interaction and feedback.	- "Less classroom interaction"
Inadequate time management	Time constraints and pacing issues affect lesson completion.	- "Too long" - "Not enough time to finish"
Support during lesson		
Understanding game rules	Difficulty in understanding game rules and instructions.	- "Rules were not easy to understand" - "Instruction about the game"
Need for teacher support	Reliance on teachers for guidance and assistance during DGBL lessons.	- "Needed more explanations from teacher" - "Teacher had to help"
Game design and presentation	Need for better design, clearer instructions, and visual improvements.	- "Could improve graphics" - "Needs better design with clearer text"

Data Collection

Data about implemented DGBL lessons were collected using questionnaires. The questions in the questionnaire for teachers inquired about their use of digital games and TS. Specifically, the questions inquired about their satisfaction with the lesson with games, their effort in preparing and conducting the lesson, and the learning gains from the lesson with games. The questionnaire for students inquired about students' perceptions of the DGBL lessons, learning gains, and need for support. No question was obligatory; students could skip these questions if they did not want to answer.

The questionnaires consisted of open-ended and closed-ended questions (see **Appendix A**). In the closed-ended questions, respondents were asked to select the appropriate category or rate their level of agreement. In the open-ended questions, respondents could write freely. The questionnaires were developed in several iterations among project members, consisting of researchers and mathematics educators. The primary objective of those iterations was to generate an adequate number of questions that could encompass the opportunities and constraints of DGBL implementation, while avoiding excessive complexity for teachers and students. Teachers from the project (N = 12) were involved in all the iterations, including pilot testing of both questionnaires. A total of 276 students were involved in the pilot testing.

Data Analysis

The data collected from the questionnaires were analyzed using both quantitative and qualitative methods:

- **Quantitative analysis:** Descriptive statistics was used to summarize the responses from the closed-ended questions, providing insights into the overall trends in teachers' and students' perceptions and experiences. Frequencies, percentages, and mean scores were calculated to assess the level of agreement or disagreement with various statements related to DGBL implementation.
- **Qualitative analysis:** Open-ended responses were analyzed using thematic coding to identify key themes and patterns related to the research questions (Saldaña, 2015). The analysis followed a three-step process:
  (1) identifying relevant text passages,
  (2) grouping similar passages into categories, and
  (3) defining themes that emerged from these categories.

Analysis of students' questionnaires involved several steps. In the first step, we identified text passages in students' answers which were related to aspects of enacted DGBL lessons. Secondly, passages with similar or equal meaning were combined into categories. For instance, the following text passages, "easier to learn math" and "good for learning", express two similar ways that DGBL lessons have facilitated learning and understanding of mathematical concepts for these students. Therefore, they were combined into the category that we named "learning and understanding." This process resulted in 13 categories, which are

Table 3. Teachers' categories from the first analysis cycle

Categories and sub-categories	Description	Supporting quotes
Teachers' practice		
Teachers' effort	Teachers found it hard or not to prepare and conduct the lesson, needed more time or extra preparation	"It took me a long time" "Not hard" "But I had to prepare myself more that for ordinary lesson"
Teachers' satisfaction	It refers to teachers' praising of the lesson or games	"An interesting game in which the definition of the derivative of a function and the rules of derivation are applied."
Teachers' suggestions		
Suggestions	Teachers' suggestions to improve the TS and the games	"Write additional instructions that the teacher must tell the students"
Teachers' use of the TS		
Deviation from TS	Refers to extra activities added by the teachers or activities of the TS that were skipped	"Formative - quiz for the end"
Lesson enactment	Refer to teacher's actions by the enactment of the lesson	"with good guidance at the beginning"
Lesson preparation	Refers to teacher's actions by the preparation of the lesson	"Investigate how hot air balloon work"
Students' learning	Refers to the way learning objectives were achieved or not with the aid of the game	"Some students did not understand the meaning of the derivation"
Students' attitude	Teacher's estimates about students' participation in the lesson	"The students had fun" "Students were motivated" "Lot of them are not interested"

summarized in **Table 2**. In the third step, we used the ICAP framework as a lens to understand students' use of digital games for learning. The students' answers about the favorable aspects of experienced DGBL serve as a window into the students' subjective experiences of the lesson and their level of cognitive engagement, as we believe that students emphasized the aspects that stood out most during their activity. By analyzing their responses through the ICAP framework, we can infer the modes of engagement (*interactive*, *constructive*, *active*, and *passive*) based on the aspects they find favorable.

Analysis of teachers' questionnaires followed similar procedures as students' questionnaires. In the first step we identified text passages in teachers' answers which were related to aspects of enacted DGBL lessons. Using descriptive and process coding (Saldaña, 2015), 40 codes were identified. Later, codes with similar or equal meaning were combined in subcategories, which led to the eight subcategories summarized in **Table 3**. These subcategories were grouped in three categories: teachers' practice, teachers' suggestions and teachers' use of the TS. Previous analysis of the four TS revealed that these ones supported the implementation of digital games within the modification and re-definition levels of the SAMR framework. Therefore, we investigated the extent at which teachers were using the whole of part of the scenario and whether they deviated or not from it; we also looked in the data for teachers' descriptions of its use.

Several steps were taken to ensure the validity and reliability of the study findings. The questionnaires were developed iteratively by a team of researchers and mathematics educators to ensure that the questions were clear, relevant, and comprehensive. Data triangulation was achieved by combining quantitative and qualitative data, providing a more robust understanding of the research questions. In the initial phase of the analysis, both researchers independently coded a subset of the data to ensure inter-coder reliability. Discrepancies in coding were discussed and resolved through consensus. Following this process, one researcher proceeded to code the entire data set, while the second researcher served as a critical reviewer, conducting a thorough audit of the coding to ensure consistency and transparency (Saldaña, 2015).

Ethical Considerations

Ethical approval for the study was obtained from the relevant institutional review boards. All participants were informed about the purpose of the study, procedures, and their right to withdraw at any time without penalty. Informed consent was obtained from all participants, and data were anonymized to protect their privacy and confidentiality.

RESULTS

Students' Experience, Learning Gains, and Activity in the DGBL Lessons

Students (N = 158) reported varying levels of emotional and motivational experiences during DGBL lessons (**Figure 4**). Specifically, 49% of students indicated that DGBL lessons were more engaging and motivating compared to regular mathematics lessons (part a in **Figure 4**). A slightly higher percentage, 54%, found these lessons to be more enjoyable than their regular math classes. On the other hand, about 40% of students perceived the DGBL lessons to be more frustrating than their usual math lessons, whereas a smaller group of students, i.e., 12%, found the DGBL lessons to be more confusing (part b in **Figure 4**).

Learning gains

A small subset of students (17%, 26/158) reported no learning gains from the experienced lessons. However, a significantly larger proportion (83%, 132/158) indicated that they experienced positive learning gains, although these outcomes varied in terms of alignment with the established learning goals. Specifically, 44% of students reported that the concepts they learned were fully

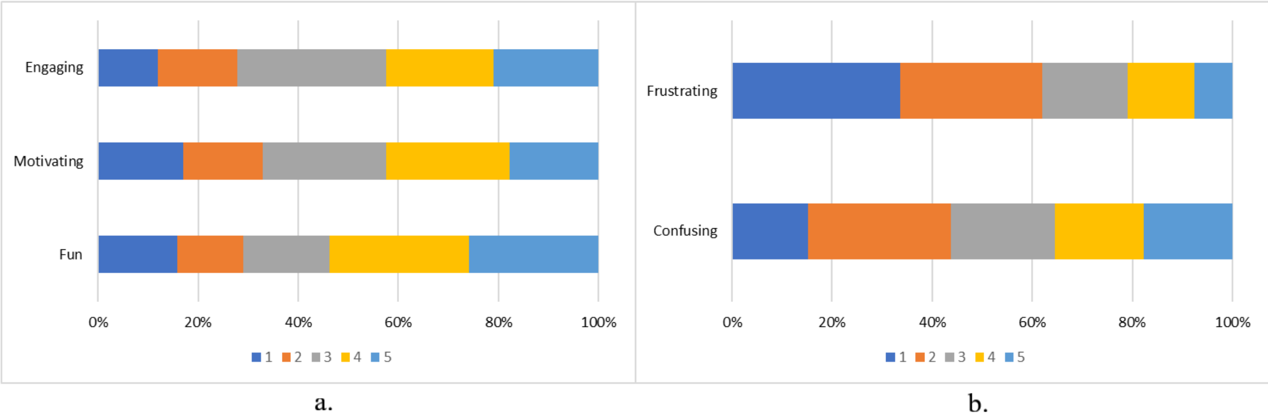


Figure 4. Students' experience in DGBL lessons (Note. *1: Strongly disagree, 2: Disagree, 3: Do not agree nor disagree, 4: Agree, & 5: Strongly agree) (Source: Authors' own elaboration)

aligned with the intended learning objectives, whereas 6% indicated that their learning was only partially aligned. For instance, for the Don't Blow up the Balloon game, students mainly stated they learned "derivatives" and "functions and derivatives," whereas one student said: "I learned to apply differentiation rules and gained a better understanding of how rate of change relates to the derivative of a function." For Hot Air Balloon, most students claimed they learned about "proportionality" or "proportions." In the case of E(qua)scape, most students identified "linear equations" as the mathematical concept they learned, and for Yo-Yo Bird, "trigonometric functions" or "trigonometry." Partially aligned goals were related to the concepts identified as part of the game in E(qua)scape, like "coordinates," or "volume, mass, and density" for Hot Air Balloon.

The responses from the remaining students were either ambiguous or not specified. This variability in learning outcomes reflects the complexity of educational interventions and points to the need for deeper investigation into the factors that shape the effectiveness of DGBL lesson design and implementation, which we explore in the following sections.

Need for support during the lesson

The findings show that 57% (90/158) of students reported not needing any assistance, whereas 43% (68/158) acknowledged needing help in specific parts of the lesson. We describe the explanations from those who provided them.

Students (8/68) who needed more explanations and detailed clarifications from teachers were likely struggling to construct their understanding of the game rules and mechanics. Comments such as "I needed more explanations from my teacher" and "The teacher had to help more than usual" reflect that students required additional support to build their understanding, indicating a gap in constructive engagement facilitated by the games.

Some students (22/66) had difficulty understanding the rules and mechanics of the games, which suggests that the games were not sufficiently intuitive to support active learning. Comments such as "I wasn't sure how exactly the rules worked" and "The rules were not easy to understand" suggest that unclear or insufficiently explained instructions hindered student engagement. Additional remarks reinforced this observation, including statements like "I had to ask my teacher how to even play the game," "Yo-Yo Bird was hard to learn how to play," and "The game was not explained well enough." Other students noted that "The win conditions and rules were very unclear," "The game needed a 10-minute briefing before playing," and "There were no explanations for the tasks in the game." One respondent explicitly noted that including an example in the rules or instructions would have helped them better understand the gameplay. Collectively, the feedback shows that the lack of clarity in game instructions likely impeded effective interaction with the educational content and may have reduced the overall efficacy of the DGBL experience.

Favorable aspects of DGBL lessons

About 95 students described favorable aspects regarding experienced DGBL lessons. This group comprised students who reported positive learning gains and four students who did not experience learning gains. The thematic analysis identified four key positive aspects:

(1) *Lessons are fun and enjoyable*. Most students (36/95) reported that the DGBL lessons were engaging and enjoyable. Their responses indicated that the lessons incorporated elements of fun ("more fun to do math", "more fun than usual"), motivation ("more fun and more motivating"), and overall positive sentiment towards the learning experience ("This type of lesson is much more engaging than normal math lessons", "The lesson with the game was very fun", "fun and entertaining").

(2) *Learning is easier and efficient*. Students (40/95) reported that the DGBL lessons improved their comprehension of mathematical concepts, thereby making the learning process easier, more effective, and more time-efficient. This sentiment was reflected in student comments such as "easier to learn math," "good for learning," and "You can learn a lot." Additional remarks including "You can actually learn something" and "I learned new things," and references to faster learning highlight the perceived benefits of DGBL.

(3) *Collaborative learning and social interaction.* Some students (10/95) highlighted the benefits of collaborative learning and social interaction, noting that working together on tasks and socializing through play were significant aspects of their

Table 4. Students' engagement

Mode	Description	Favorable aspect of DGBL lesson	Reported learning gains (N = 96)
Interactive	Responses emphasize collaboration, competition, and peer interaction, highlighting the social aspects through interactive learning.	Collaborative learning and social interaction	All (n = 1) Partially (n = 9)
Constructive	Responses reflect the ways in which DGBL lessons make learning easier and more effective.	Learning is easier and efficient	All (n = 8) Partially (n = 30) No (n = 2)
Active	Responses reflect more enjoyment and innovative approach of DGBL lessons compared to conventional methods.	Innovative approach Lessons are fun and enjoyable	All (n = 17) Partially (n = 26) No (n = 2)

Note. *All: Student reported learning new content successfully; Partially: Student reported learning new content partially; & No: Student reported no learning gains

experience. Their responses included remarks like "We work together to solve tasks," "fun to work together or to try to beat each other," and "We collaborate when playing." Some students also mentioned experiences like "socializing with others while learning" and "playing with friends," pointing to the value of peer interaction, which makes the DGBL environment both more engaging and educationally meaningful.

(4) *Innovative and engaging approach.* Students (9/95) appreciated the innovative and interactive approach of the DGBL lessons in contrast to the conventional methods employed by their teachers. The use of technology and interactive software was seen as enhancing the learning experience, as expressed in comments like "not like a normal math class, feels better to use technology", "interactive and engaging", or "It is easier to learn in interactive lessons."

Hindering aspects of DGBL lessons

Approximately 68 students provided feedback on the hindering aspects of their experiences with DGBL lessons. This group also includes 16 students who reported no learning gains. The thematic analysis identified six negative aspects of the DGBL lessons:

(1) *Lesson is boring and not enjoyable*. A small number of students (4/68) found the DGBL lessons boring and unenjoyable, indicating a mixed reception. Their feedback included comments such as "boring," "kind a boring and just plain," and "not enjoyable."

(2) *Confusing and more difficult*. A significant portion of the students (29/68) reported issues related to the complexity and comprehensibility of the DGBL lessons. Many expressed confusion, frustration, and difficulty understanding the tasks and game mechanics. Representative statements include: "hard to play and confusing." "It was a bit confusing," and "It is confusing because of the rules; they need to be simplified, I believe." Some students emphasized the need for better guidance, stating "It would be better if there were some good instructions in the beginning of the game."

(3) *Not relevant for learning*. Students (12/68) felt that the DGBL lessons did not adequately support their learning or failed to align with mathematical content. This concern was reflected in comments such as: "don't support learning," "not gaining adequate knowledge," and "I didn't get anything math-related out of this game." One student even noted, "You can solve it without knowing math and proportions," highlighting a disconnect between gameplay mechanics and learning objectives. These responses indicate that, for some learners, the game-based approach did not translate into meaningful educational context.

(4) *Technical and design issues*. Some students (13/68) highlighted technical and design issues, noting poor game graphics, low-resolution pictures, and the need for better animations and clearer instructions. Their feedback included comments such as "needs animations," "The pictures are low res so the graph lines disappear," and "Unable to zoom photos and it takes a lot of time to load games." Even when enjoyment was present, technical limitations were noted, as in "Game graphics were awful but it was enjoyable nonetheless." Additionally, functional issues were highlighted, such as "The second level was a bit confusing and it didn't really work as intended."

(5) *Inadequate time management*. A small number of students (4/68) pointed out issues related to the time required to complete DGBL lessons and problems with pacing. They found the lessons either too long, as indicated by the comment "long time," or too short, as noted in "not enough time to finish the game/lesson."

(6) *Limited interaction and feedback***.** A few students (2/68) felt that the DGBL lessons offered less opportunity for interaction and feedback compared to traditional classroom settings. They emphasized the importance of being able to ask questions, receive explanations, and discuss mistakes with the teacher. As one student explained: "In normal lessons we learn more, can talk and ask more, get more information on our mistakes ..." Such comments suggest that, for some learners, the more structured nature of conventional teaching provides clearer support for understanding and reflection.

However, four students expressed general dissatisfaction with experienced DGBL lessons.

Students' engagement during the lessons

Table 4 shows the categorization of students' engagement during the lessons, along with the reported learning gains. The students' responses that indicate that DGBL lessons fostered collaborative learning environments, enhancing social interaction and competition, were placed in the interactive mode. The responses that reflect the ways in which DGBL lessons make learning

Table 5. Teacher actions by lesson preparation and lesson enactment

Categories	Codes
Lesson preparation	Playing the game (2 times) Preparing formative assessment (1 time) Preparing game introduction (1 time) Solving the tasks (1 time) Translating to English (1 time) Understanding details (1 time)
Lesson enactment	Guiding the students (2 times) Understanding how game works (1 time)

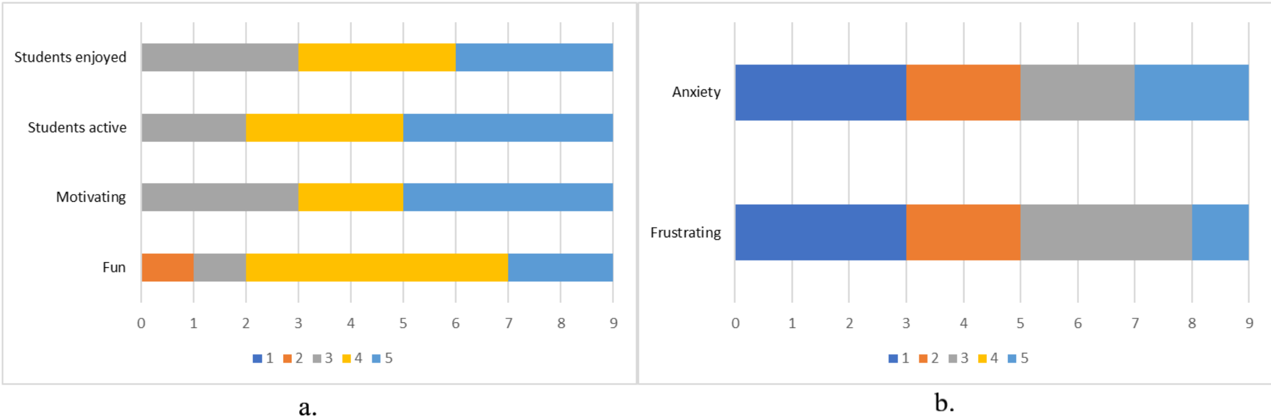


Figure 5. Teachers' perception of DGBL lessons (Note. *1: Strongly disagree, 2: Disagree, 3: Do not agree nor disagree, 4: Agree, & 5: Strongly agree) (Source: Authors' own elaboration)

easier and more effective are categorized as constructive, while responses that reflect more fun and enjoyment, and the innovative approach of DGBL lessons compared to conventional methods, were categorized as the active mode of engagement.

The majority of students were primarily categorized as being in an active and constructive mode, whereas a considerably smaller proportion of students were classified as being in an interactive mode. The reported learning gains support our categorization. Nevertheless, students who indicated successful learning and were placed in the active mode are positioned somewhere between constructive and active engagement. Similarly, students who acquired only a partial understanding of new content and were placed in the constructive mode are between constructive and active engagement. Namely, according to Chi et al. (2018), certain engagement activities do not neatly fit into one mode or another but fall somewhere in between when considering the students' outcomes, i.e., gained knowledge in our case.

Teachers' Implementation of Digital Games in Regular Classrooms

Teachers' use of TS

The data from the teachers' questionnaire reveals insights into their engagement with the TS. All teachers reported using the TS, though three teachers made small deviations from the provided guidelines. For example, one teacher added a quiz at the end of the lesson, while two others skipped a hands-on activity in the Don't Blow up the Balloon game scenario. Interestingly, all teachers implemented the core part of the TS, which required the use of digital games at the modification level of the SAMR framework. However, none of the teachers incorporated the extended activities, which would have required a redefinition of their teaching practices and deeper integration of digital games

Preparing for DGBL lessons required teachers to familiarize themselves with the game and understanding TS (**Table 5**). One teacher noted, "I had to play and it took me a long time to understand all the details" (T05). Although TS was designed as the support in planning and enactment, the TS was not a detailed lesson plan, thus teachers had to prepare an actionable guide from TS to conduct a specific lesson. One of the activities was preparing formative assessment. One teacher mentioned, "I needed to prepare myself for the lesson. Investigate how hot air balloons work and prepare some formative assessment" (T06). Conducting the lesson required both the teacher's guidance and a thorough understanding of the game. One teacher commented, "It was not difficult with good guidance at the beginning" (T07), while another added, "Not too much once I understood how the game works"(T05).

Teachers' perceptions of the DGBL lessons

The majority of teachers (5/9) perceive that the DGBL lessons only partially achieved the learning objectives. Generally, they reported that students struggled to understand or recognize mathematical concepts within the game without additional explanation. For example, in the Hot Air Balloon game, one teacher remarked, "Students didn't understand which quantities are proportional and which are inverse-proportional without additional explanation" (T03). Similarly, in the Yo-yo Bird game, another teacher observed, "Only a small number of students understood the change in amplitude and period" (T05). The teacher's feedback aligns with the students' responses regarding their learning gains and level of engagement.

The data on teachers' satisfaction and effort reveals a range of experiences and perceptions. Among the positive feedback, one teacher praised the game "An interesting game in which the definition of the derivative of a function and the rules of derivation are applied" (T09), while another praised the lesson itself "Nice, it can be fun" (T06), highlighting specific aspects they found effective. Quantitative analyses showed that most teachers found the lessons incorporating games to be more fun and motivating compared to their regular lessons (part a in **Figure 5**), without experiencing increased frustration or anxiety (part b in **Figure 5**). Teachers also noted that students were actively engaged and enjoyed the lesson (part a in **Figure 5**, variables 'students active and students enjoyed').

Preparation for the lessons also required significant effort for some teachers, reflecting a diversity in the preparation experiences among the teachers. Three teachers indicated they had to prepare more than for regular lessons ("I had to prepare myself more than for usual lesson" (T06),) and two mentioned that the preparation took a lot of time ("it took me a long time" (T05)). Additionally, one teacher found the preparation process to be especially demanding: "It took a lot of time to think how to introduce rules of the game to pupils" (T01). Interestingly, only one teacher had prior experience using the TS before, indicating that the majority of the teachers were implementing it for the first time. The process of enactment presented varying levels of difficulty. One teacher reported that the enactment "(…) was hard. Students did not understand the rules and did not work properly" (T01), but four teachers did not find it not difficult ("It was not difficult, with good guidance at the beginning" (T07)). Three teachers considered it was not so hard "(…) after I understood how the game works" (T05). This suggests that while some teachers struggle with the enactment, others manage it with relative ease.

DISCUSSION

The findings from this study provide insights into the implementation of DGBL in secondary mathematics education. The results indicate that while DGBL lessons using GAMMA games were generally well-received by both teachers and students, several challenges and opportunities were identified regarding the effective integration of these digital tools into regular classroom practice.

Student Engagement and Learning Outcomes

Students were primarily engaged at the active level of the ICAP framework, with a notable number of students reporting increased motivation and enjoyment during the lessons. This suggests that digital games can indeed make learning more engaging and accessible, which aligns with previous research emphasizing the motivational benefits of DGBL in mathematics education (Hui & Mahmud, 2023; Hussein et al., 2022). However, fewer students were engaged at constructive and interactive levels which entail generating new knowledge or collaborating with peers. The limited engagement at these higher levels could be attributed to several factors. First, the findings suggest that the design of the GAMMA games and their instructions were not always clear or intuitive, leading to confusion and frustration among some students. Although GAMMA games had successfully integrated mathematics into the game mechanics and avoided the traditional drill-and-practice format, these features were insufficient to overcome the barriers created by unclear design and instructions. This aligns with Gui et al.'s (2023) meta-analysis, which found that game quality–particularly elements like graphics, mechanics, and interactivity–significantly affects how students perceive and engage with educational games, especially in subjects like mathematics. Games with adaptive features, multiplayer options, and visually appealing designs tend to enhance both student engagement and enjoyment. Second, the study revealed that the games were not utilized at the redefinition level of the SAMR model, where digital tools enable entirely new forms of learning (Puentedura, 2014). Platforms like ChoiCo or MaLT2 focus less on visual design and more on enabling students to create and modify games as a means for students to engage with complex mathematical models (Kynigos, 2024; Kynigos et al., 2023). These platforms promote the development of higher-level thinking and problem-solving skills, encouraging students to explore and experiment with mathematical concepts actively. Therefore, addressing these issues by either improving game design or allowing game modification can guide students toward deeper learning experiences.

Teacher Implementation and Challenges

This study also identified several challenges teachers faced when implementing DGBL lessons. These challenges included the additional time and effort required to prepare lessons, familiarize themselves with digital games, and adapt TS to meet their specific classroom needs. While the use of TS was generally helpful, some teachers found them lacking in formative assessment activities, which required them to spend additional time preparing supplementary materials. The findings also suggest that the implementation of DGBL using non-drill-and-practice games is not always successful, even when teachers have participated in DGBL-related activities and contributed as co-designers of TS and games. Although previous research indicates that such participation can enhance teachers' ability to implement digital games effectively (An & Cao, 2017; Zhang & Chen, 2021), the results show that teachers still need sufficient time and resources to become proficient in using digital games as educational tools.

From the teachers' perspective, digital games were implemented at the modification level of the SAMR model, where technology is used to redesign learning tasks, enhancing interactivity and engagement. However, there was no evidence of digital games being used at the redefinition level, where technology would allow for entirely new learning experiences that were previously inconceivable (Puentedura, 2014). Although teachers adhered to the core aspects of TS, extended activities like modifying existing GAMMA games or creating new ones were not included in the DGBL lessons. Moreover, the students' feedback shows that extended activities were not implemented.

This is not unique to mathematics education. Previous studies have shown that lessons in which students create or modify games present various challenges for teachers (Hughes-Roberts et al., 2023). These challenges include limited knowledge of constructionist principles, a lack of programming skills, the complexity of managing collaborative projects, and difficulties in aligning such tasks with clearly defined learning objectives (Broza et al., 2023; Holstein & Cohen, 2025; Hughes-Roberts et al., 2023; Kelter et al., 2021; Puttick et al., 2024). Institutional and curricular factors also hinder the adoption of constructionist DGBL approaches. Teachers often work within educational systems that emphasize standardized testing, strict curriculum requirements, and fixed pacing guidelines, leaving little opportunity for student-driven activities such as game design (Broza et al., 2023; Holstein & Cohen, 2025). Moreover, many schools lack the support mechanisms or flexibility needed to encourage innovative teaching strategies.

These conditions raise important questions about teacher preparedness for lessons that involve game creation. To what extent should teachers be expected to possess programming or design expertise? And does the current curriculum provide adequate time for such activities? One promising approach that addresses some of these challenges is *constructionist co-design* which brings together constructionist learning principles and collaborative curriculum development (Kelter et al., 2021). In this approach, teachers work closely with professional development facilitators to design instructional materials that they will later implement in their own classrooms. Kelter et al. (2021) note that teachers who work only with pre-designed materials may not fully understand the rationale behind instructional decisions. This limits their ability to adapt lessons or respond flexibly to student needs. A deeper engagement with the design process supports more confident and responsive teaching and fosters greater alignment between instructional goals and classroom practice.

Teachers in our study expressed openness to using digital math games and TS and were already familiar with platforms such as ChoiCo and MaLT2 but chose not to incorporate extended constructionist activities. This decision reflects a need for additional support, likely related to programming, addressing curriculum constraints, or opportunities to engage in design activities. These considerations suggest that professional development should go beyond introducing new tools and instead provide opportunities for practice, reflection, and collaboration in constructionist co-design. Moreover, teachers need adequate time and support to build confidence in using constructionist approaches. Schools as institutions could help by offering more flexible schedules and dedicated time for design activities. Without such provisions, it is unlikely that regular teachers will adopt a constructionist DGBL approach to support transformative learning experiences.

Opportunities for Transforming Mathematics Education

We argue that transformative activities–those that encourage students to modify or create digital games–should be central to the TS if mathematics teachers are to implement them effectively in the classroom. Our perspective aligns with research on mathematics textbook use, which shows that teachers often bypass challenging tasks, likely due to time constraints or a preference for more accessible material (Boston & Smith, 2011; Kaur & Chin, 2022). Omitting such tasks can result in missed opportunities for students to engage in higher-order mathematical thinking. In the same way, integrating transformative learning activities into DGBL lessons enables mathematics teachers to foster more engaging and effective learning experiences. In doing so, DGBL becomes not only an innovative approach to mathematics education but also a means of expanding opportunities for students to explore and apply their knowledge in new contexts.

We believe that transformative activities would help students to overcome or disregard concerns about design and graphics in digital math games, such as GAMMA games. When students are given the opportunity to modify or create games on these platforms, they often become more engaged, especially in collaborative settings (Kynigos & Grizioti, 2020; Kynigos & Karavakou, 2022). This engagement helps to shift students' focus away from concerns about game design and graphics, as they become more invested in the creative process. Research by Ding and Yu (2024) compared students in two DGBL environments: one focused on playing games and the other on creating games. The results showed that students involved in game creation outperformed their peers in posttests, demonstrating the potential of learning by making games to deepen students' understanding.

Limitations

One limitation of this study lies in the methods employed. We used questionnaires to gather data about students' experiences during DGBL lessons and asked teachers how they integrated digital games into their teaching. While informative, this approach may lack depth. To overcome this limitation, future research should incorporate classroom observations and interviews. These methods would provide more detailed and precise insights into how students engage with DGBL and how teachers implement it in their instructional practices.

Furthermore, assessing the SAMR level can be challenging. For example, while adapting or modifying a game could be viewed as redefinition, this is not the only pathway to achieving it. Redefinition can also occur through gameplay when students are fully immersed in the game and the mathematical content is seamlessly integrated into the mechanics. This allows students to engage with complex mathematical concepts interactively, transforming their learning experience and meeting the criteria for redefinition within the SAMR model.

CONCLUSION AND FURTHER DIRECTIONS

The combination of playing and modding, as proposed by Kafai and Burke (2015), provides a framework to integrate instructionist and constructionist approaches in education. Based on this, it can be hypothesized that TS, as a whole, supports teachers in experimenting with and using DGBL across a continuum from instructionist-driven to constructionist-driven environments. In instructionist-driven environments, digital games are likely to be used by teachers to substitute or augment traditional teaching methods, engaging students primarily in passive and active learning activities. In contrast, constructionist-driven environments leverage digital games to modify and redefine teaching practices, encouraging students to engage in constructive and interactive learning activities.

Our findings reveal an important outcome: the constructionist approach to DGBL, which involves modifying or creating games, presents significant challenges in regular mathematics classrooms. Overcoming these challenges will require a multifaceted approach involving professional development for teachers, improvements in game design, and better alignment of the curriculum to support the use of digital games. Further research is necessary to explore how constructionist gaming in mathematics education can be effectively implemented on a larger scale. Such research should focus on strategies for supporting teachers in facilitating game-modification activities and ensuring that these activities align with curriculum goals. By addressing these challenges, DGBL can become a transformative tool in mathematics education, fostering deeper learning and greater engagement through the creation and modification of digital games.

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APPENDIX A

Table A1. Teacher's questionnaire

No	Questions	Type	Variables
Q01	Which scenario was used in the lesson?	MC	Context aspects
Q02	My first thoughts after the lesson. Please, state briefly.	Open	Teachers' experience
Q03	Time for lesson preparation was as predicted in the teaching scenario.	MC	Use of TS
Q04	Time for lesson enactment was as predicted in the teaching scenario.	MC	Use of TS
Q05	Did you use the whole scenario?	MC	Use of TS
Q06	Please specify which parts you used, or which parts were skipped.	Open	Use of TS
Q07	How hard was it to prepare for the lesson?	Open	Use of TS
Q08	Was the scenario adequate for lesson preparation?	MC	Use of TS
Q09	What extra material did you need?	Open	Adaptation of TS
Q10	What would you add to the teaching scenario?	Open	Adaptation of TS
Q11	Did you use any additional activities that were not in the scenario?	MC	Adaptation of TS
Q12	Please describe them briefly.	Open	Adaptation of TS
Q13	Compared with a regular lesson, this lesson was more fun	Scale, 1-5	Teaching practice
Q14	Compared with a regular lesson, this lesson was more motivating	Scale, 1-5	Teaching practice
Q15	Compared with a regular lesson, this lesson was more frustrating	Scale, 1-5	Teaching practice
Q16	Compared with a regular lesson, in this lesson I experienced more anxiety	Scale, 1-5	Teaching practice
Q17	The students needed additional explanations.	MC	Teaching practice
Q18	The intended learning outcomes from the scenario were achieved.	MC	Learning gains
Q19	If no or partially, please state which were not achieved.	Open	Learning gains
Q20	Estimate students' engagement during lesson.	Scale, 1-5	Learning gains
Q21	Estimate students' enjoyment during lesson.	Scale, 1-5	Learning gains
Q22	While gaming, students worked	MC	Context aspects
Q23	The dominant technology for students' gaming was	MC	Context aspects
Q24	Place of implementation for lesson part with game.	MC	Context aspects
Q25	How hard was it to enact the lesson? Please state briefly	Open	Teaching practice
Q26	Would you recommend using this game and scenario to a colleague?	MC	Use of TS
Q27	Please specify.	Open	Use of TS
Q28	Do you have suggestions for improving the scenario?	MC	Adaptation of TS
Q29	Please describe briefly.	Open	Adaptation of TS

Table A2. Students' questionnaire

No	Questions	Type	Variables
Q01	What game did you play in the lesson?	MC	Context
Q02	Compared to a regular mathematics lesson, this lesson with a game was more fun.	Scale, 1-5	Experience
Q03	Compared to a regular mathematics lesson, this lesson with the game was more motivating.	Scale, 1-5	Experience
Q04	Compared to a regular mathematics lesson, this lesson with game was more engaging	Scale, 1-5	Experience
Q05	Compared to a regular mathematics lesson, this lesson with games was more confusing.	Scale, 1-5	Experience
Q06	Compared to a regular mathematics lesson, this lesson with game was more frustrating.	Scale, 1-5	Experience
Q07	What are favorable aspects (activities, engagement, etc.) of the experienced DGBL lesson?	Open	Favorable aspects
Q08	What are hindering aspects of the experienced DGBL lesson?	Open	Hindering aspects
Q09	Do you require further explanations? Please specify briefly.	Open	Support during lesson
Q10	Assess the quality of your learning.	MC	Learning gains
Q11	What mathematics did you learn? Please describe.	Open	Learning gains