Title

How Digital Game-based Learning Impacts Student Motivation And Achievement In An Elementary Classroom: A Systematic Review Of Empirical Research

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Publication Date

2023-06-16

HOW DIGITAL GAME-BASED LEARNING IMPACTS STUDENT MOTIVATION AND ACHIEVEMENT IN AN ELEMENTARY CLASSROOM: A SYSTEMATIC REVIEW OF EMPIRICAL RESEARCH

By

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A capstone project submitted for Graduation with University Honors

May 12, 2023

University Honors
University of California, Riverside

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Abstract

The use of technology has become increasingly prevalent in the education system. As we continue to adapt to technology and implement the latest apps, games, and websites into classroom lesson plans, it’s essential to assess whether these technologies are effective in improving students' learning experiences. This study aims to investigate this by looking at the effects of gamifying learning on students’ motivation and academic achievement in mathematics. This systematic literature review synthesized existing research findings that examined the effects of digital games on elementary students' mathematics motivation or achievement. First, a search for peer-reviewed, experimental research articles was conducted via Google Scholar and Web of Science. Keywords were used to narrow the search, as well as limits on publication dates to ensure the search only included articles from 2010 to present. After the initial search, 19 articles that met the eligibility criteria to answer the research questions were chosen to be included in the analysis. These articles were coded and analyzed to assess whether there was a significant relationship between digital game-based learning (DGBL) and student motivation or achievement. This review found that there was a positive effect of DGBL on both motivation and achievement for the majority of studies used in the review. It also provided insights on the major gaps in the literature on this topic, highlighting the need for more research to be done in this area.

Acknowledgements

I would like to thank my project mentor, Dr. Anthony Muro Villa III, for his guidance, support, and expertise throughout the last 1.5 years. This project started out with a broad idea, and throughout the many obstacles and redirections along the way, he always had solutions and ideas that ultimately resulted in a project I'm extremely proud of. Thank you for your time and dedication to this project, I am grateful to be your first Honors mentee.

I would also like to thank Dr. Richard Cardullo and the UCR Honors Program. This program has pushed me academically to achieve things I never would have thought possible. I am grateful for the opportunities and support I have received over the last 4 years.

Lastly, thank you to the loved ones in my life who offered support throughout my undergraduate career. You were all there whether I needed advice, company during late night writing/researching sessions, or encouragement in my difficult moments. I wouldn't be where I am without you all.

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1. Introduction

With digital technology use in schools skyrocketing in the past couple of years especially due to the COVID-19 pandemic, online learning has become more accessible and widespread than ever before. Although distance-based online learning for K-12 U.S. education was a temporary implementation, some aspects of digital learning may be here to stay, including the electronic gamification of learning.

Gamification can be defined as utilizing game-based dynamics, aesthetics, and thinking processes to promote motivation, learning, and problem solving (Kapp, 2012). While gamification can be applied to both traditional and digital learning, this paper focuses on gamification through online games, as digital learning is the more modern approach to gamifying learning. This concept is known as Digital Game-Based Learning (DGBL), which can be defined as the use of digital games for the purpose of education (Prensky, 2001). This form of learning is becoming increasingly popular in classrooms as we continue to adapt to the latest technology and implement apps, games, and websites into classroom lesson plans. Because academic content is becoming increasingly digitized, it is crucial to assess whether digital game-based learning has a positive impact on student experiences and outcomes.

Some of the most important areas of student experiences to assess are achievement and motivation. These areas encompass both students' cognitive and social emotional educational experiences for which educators are constantly seeking the best approaches. While the education research community has been studying the effects of digital learning on student outcomes for years, this paper seeks to narrow the scope by specifically looking at its effects on primary school students' outcomes in mathematics. Mathematics in the primary grades has a large impact on students' motivation and achievement. In a study on primary school students' attitude towards school subjects, Dündar et al. (2014) found that students who reported mathematics as their least favorite subject did so because they found it difficult. DGBL is a promising method for improving students' motivation for mathematics regardless of its difficulty (Hussein et al., 2022) Moreover, it is important to improve students' achievement for mathematics early on in their education as we know that students need to establish a solid foundation of mathematics in order to later transfer those skills to more complex computational problems (Aubrey & Godfrey, 2003). Thus, it is imperative to analyze the impact of methods that may help students build mathematical skills early on to support their overall academic performance in the long run.

Given the broadened access and potential effectiveness of DGBL, it is crucial for researchers to provide evidence of positive learning outcomes before the wide scale implementation of them into classrooms. Many studies have sought to do this, but few have synthesized the findings of these studies to provide a well-rounded answer. This systematic review seeks to aggregate the existing research to answer important questions about DGBL that can both guide future research and help educators better understand which methods are most effective in the classroom for improving motivation and achievement. This systematic review is guided by the following research questions:

RQ 1: What DGBL research is being conducted in primary mathematics classrooms?

RQ1a: What kinds of games/technologies are being utilized in these studies?

RQ1b: What type of intervention was utilized?

RQ 2: How does DGBL affect students' motivation and achievement in mathematics?

RQ2a: Does DGBL increase student motivation?

RQ2b: Does DGBL increase student mathematical achievement?

2. Theoretical Framework

2.1 Motivation

Student motivation is a significant factor in determining students' academic success (Busato et al., 2000). Intrinsic motivation in particular has shown to be the only type of motivation to be positively associated with increased academic achievement over time (Taylor et al., 2014). Intrinsic motivation is when we do something for our own personal enjoyment and interest as opposed to extrinsic motivation, which is when we do something for an external reward or outcome (Ryan & Deci, 2000). The concept of intrinsic motivation comes from Deci & Ryan's (1985) work on Self-Determination Theory (SDT), which suggests that people can become self-motivated once their basic needs for autonomy, competence, and relatedness have been met (Deci & Ryan, 1985). Moreover, one mini-theory within SDT, Cognitive Evaluation Theory (CET), asserts that mobile applications can promote students' intrinsic motivation by enhancing their experiences of autonomy and competence (Ryan & Deci, 2017, as cited in Jeno et al. 2018). Given the benefits of motivation, it's essential to discover the best methods to increase this type of motivation, and this study investigates whether DGBL is a promising approach to doing so.

Various studies have looked at how DGBL impacts students' outcomes. However, most studies have looked at the effects of gamification on academic achievement, and only few have investigated the effects of gamified learning on intrinsic motivation in particular. For example, Yildirim's (2017) study found that the gamification of learning positively impacted student achievement and students' attitudes towards their lessons (Yildirim, 2017). While Yildirim's (2017) study and others like it offer important information on the effects of gamification on achievement and student attitudes, their research cannot conclude how gamification impacts intrinsic motivation in students (Yildirim, 2017). One of the few studies that has done this, however, comes from Jeno et al. (2018), who looked at the effects of mobile learning on undergraduate biology students' motivation, achievement, and well-being through a self–determination theory perspective (Jeno et al., 2018). Their study found that students who studied biology using a mobile application experienced significantly higher levels of perceived confidence, perceived autonomy, and intrinsic motivation than students who used the traditional textbook (Jeno et al., 2018). While Jeno et al. 's (2018) study offers important findings concerning the effects of gamification on intrinsic motivation, this study builds upon their research by looking at how gamified learning impacts younger students as opposed to college students, which is a scarcely researched topic (Jeno et al., 2018).

Another important theory within motivation is the ARCS model of motivation which was proposed in the 1980s by Keller (1979, 1983). This theory suggests that the 4 major components of motivation; Attention, Relevance, Confidence, and Satisfaction (ARCS), must be met in order for motivation to take place. "Attention" refers to the learner's gained and sustained interest, "relevance" is whether the learner perceives the lesson as relevant to them, "confidence" is the learner's expectancy for success, and "Satisfaction" refers to the learner's contentment with their learning accomplishments (Keller, 1987). This model has been applied to various studies to evaluate the motivational effectiveness of certain educational stimuli. For example, Cheng & Su (2012) used the ARCS model to evaluate the effects of an online game-based learning (GBL) system on student's learning achievement in a system analysis course, finding that the GBL had significant positive effects on student achievement (Cheng & Su, 2012). Thus, this theory has a large impact on the design of learning environments to best enhance and sustain student motivation.

Another theory that largely guides motivation research is flow theory which was first introduced by Csikszentmihalyi (1975) in his book *Beyond Boredom and Anxiety* (Csikszentmihalyi 1975; Abuhamdeh, 2020). When students enter a state of flow, they are in a psychological state where they are so absorbed in a task that they become dissociated from the world around them (Nakamura & Csikszentmihalyi, 2002). Past research has found that entering a flow state positively impacts learning, thus making this an optimal theory for researching motivational effects of various learning contexts (Webster et al., 1993). When it comes to DGBL, flow experience is especially relevant as many games are designed with a purpose to intrinsically engage players for hours on end. Several studies have measured students' flow experiences in DGBL environments in order to understand which gaming elements best improve learning motivation. One important study has stated that games can implement features such as immediate feedback, concise goals, and challenges that are at the same level as the players' skills to increase players' flow and enhance their educational outcomes (Kiili, 2005).

2.2 Achievement

Academic achievement is an important student outcome to assess when looking at the effects of a classroom intervention as it can tell us valuable information about how the intervention is impacting students' learning status in the classroom. Academic achievement, especially at the elementary school level, not only demonstrates a school's success in educating their students, but also considerably determines the success and future of youths (Dev, 2016). Academic achievement in mathematics is particularly significant and researchers have been increasingly interested in studying it due to its importance in both formal education and people's everyday lives (Jensen et al., 2019). For example, Jain & Dowson (2009) assert that mathematical comprehension is vital for occupational and personal success in one's daily life.

Moreover, Lipnevich et al. (2016) state that mathematical achievement is related to various life outcomes such as well-being, satisfaction with life, health, wages, employability, and longevity (Lipnevich et al., 2016). Due to the importance of improving mathematical achievement, education researchers have been interested in the influence of DGBL on mathematics achievement.

Education research utilizes several different methods to measure mathematics achievement within the context of DGBL. Among these methods are student grades, GPA, academic proficiency, the accomplishment of learning objectives, dropout rates, and, most notably, achievement tests. Achievement tests are a form of standardized tests that have a long history in education. Though their use is widely debated when it comes to predicting future success or accurately measuring intelligence, they are a generally accepted method by researchers for assessing the proficiency of state-defined standards in core academic disciplines (Finn et al., 2014).

One of the most common ways academic achievement tests are utilized in research on DGBL is through a pre- and post-test method, though the content and learning objectives of these tests differ greatly among different studies on DGBL. For example, one study used tests that were specifically developed by experienced elementary teachers in order to tailor the tests to the students' current progress in their curriculum (Hung, 2015). Another study by O'Rourke et al. (2017) used a norm-referenced mathematics numeracy test, which are designed to compare student knowledge to the norm of the class as opposed to a criterion-referenced test which are designed to compare student knowledge to a specific standard (Lok et al., 2016). Other studies used similar methods but with mathematical assessments that measured students' achievement based on district or national standards (Ahmad et al. 2018; Foster & Shah, 2015; Gresalfi et al. 2018).

2.3 Digital Game-Based Learning

Digital Game-Based Learning emerged in the classroom in the "last decades of the 20th century" according to Prensky (2001) and has revolutionized the way that recent generations engage with learning material. Prensky argues that students today have a fundamentally new way of thinking and processing than their predecessors, and that teachers must adapt to these changes to meet the needs of their students by implementing more technology and DGBL paradigms in the classroom. With adolescents' pre-existing positive attitude toward video games, researchers have been increasingly interested in finding ways to utilize this interest in an educationally stimulating way. Thus, the main purpose of much of the research surrounding DGBL has been about how it can be used to increase student's engagement and motivation to learn.

While empirical research has suggested that DGBL has a strong effect on cognitive competencies, it's important to differentiate between the different types of games implemented in the classroom (Clark et al., 2013). Researchers typically divide these games into serious and non-serious games (also referred to as leisure games or entertainment games). While the definition of these terms varies greatly across educational literature, it is generally agreed upon that serious games are games in which pedagogy is infused into the gameplay (Klopfer et al., 2009). On the other hand, non-serious games, referred to in this paper as entertainment games, are games that have the sole purpose to entertain and have no pedagogical purpose (Martinez et al., 2022)

Serious games for education purposes have been the more widely researched type of game in the education field as these games are typically tailored for student learning. Meta-analyses that investigated the impacts of serious games on student learning found that they had positive effects on students' reading, vocabulary, and natural sciences knowledge (Cheung & Slavin, 2012; Riopel et al., 2019; Thompson & von Gillern, 2020). The key component of serious games is that the learning takes place in a way that is meaningful to the context of the game, therefore the student's learning is directly related to the environment they learn it in (Van Eck, 2006). This gives students the opportunity to apply their learning in a relevant way.

Within serious games there are several types of games including challenging games, matching games, scenario games, and problem-solving games (Hung et al., 2015). Challenging games in particular are useful in the classroom as they require students to utilize more complex strategies during gameplay. These types of games are most efficient when it comes to increasing motivation as the challenging aspect of the game has been shown to have positive effects on student engagement (Hamari et al., 2016). This is due to the way that challenging games tap into one of the most essential conditions for flow to occur, which is utilizing a high level of skill to overcome challenges (Csikszentmihalyi, 1990). According to Csikszentmihalyi (1990), students become more deeply engaged when content is more cognitively complex and challenging. Thus, by combining entertainment, pedagogy, and a challenge, challenging games are an optimal choice for increasing student engagement.

Another important aspect of digital games is their genre. According to Apperley (2006), the genre of digital games can be separated into four categories: simulation, strategy, action, and role-playing. Simulation games include digital games that center around simulating an experience such as driving, flying, sports, and games that simulate things like cities and towns. Strategy games are games that involve strategic decision-making, and this genre is split into real-time strategy (RTS) and turn-based strategy (TBS). Action games are centered around technical skills such as reaction time or hand-eye coordination, and these games are divided into first-person and third-person games. This genre is more uncommon when it comes to serious game research as these games tend to serve more of an entertainment purpose. Lastly, the role-playing genre includes games where the player takes on the role of a character and carries out their tasks.

The characteristics of digital games and serious games are important features when it comes to assessing the educational effectiveness of DGBL. One of these characteristics is the way that game elements are integrated with learning elements, which can be done either intrinsically or extrinsically. Intrinsic integration embeds learning into the game mechanics, most commonly during the most fun parts of the game in order to maintain and not diminish the state of flow produced by the game (Habgood et al., 2005). On the other hand, extrinsic integration separates gameplay from instructional activities, commonly using gameplay as a reward for learning as opposed to integrating the learning with the gameplay. Extrinsic integration risks interrupting students' state of flow as they are constantly switching between flow-inducing activities (Habgood & Ainsworth, 2011). With intrinsically integrated games, however, the state of flow is experienced in both the gameplay and the learning, which is why this kind of DGBL increases motivation for learning (Habgood & Ainsworth, 2011).

While serious games have a staple place in the classroom environment, entertainment games tend to be the more popular type of game among youth. Entertainment games come in a variety of genres such as traditional video games, strategy video games, simulation video games, fantasy video games, action video games, etc. (Martinez et al., 2022). These games include widely popular games such as Sims, Minecraft, Call of Duty, etc. While these games are often criticized for their lack of educational value, researchers have found other benefits of entertainment games. Recent research has found that entertainment games have a positive effect on cognitive functions such as executive functioning (McCord et al. 2020). For example, one study on college students found that video games showed improved decision making and problem solving for college students (Buelow et al., 2015). Additionally, a meta-analysis on the impact of video games found that action video game play enhances attention, visuospatial, and perceptual skills of the players (Bediou et al., 2018). Thus, although entertainment video games aren't as popular in the education field, they have important effects on human cognition that can be useful to enhance in the classroom.

3. Methods

This systematics review focused on empirical studies that looked at the effects of digital game-based learning on student motivation and achievement in mathematics at the elementary level. At the beginning of this study, a very narrow research question was proposed. I originally intended on reviewing literature that studied the effects of DGBL on intrinsic motivation for elementary students. As I began my search, I gradually broadened my research question and search terms as I was finding very few results that fit my narrow criteria. By the end of the review process, a total of 19 studies were selected for analysis.

3.1 Search Strategy

This systematic review utilized Google Scholar and Web of Science to conduct the initial search for articles relating to my research questions. I used Publish or Perish to retrieve academic citations from Google Scholar. The search started broadly to get an idea of what articles were available. This search included many keywords including the following: "elementary" OR "primary school" and "education" OR "school" and "intrinsic motivation" and "motivation" OR "enjoyment" and "engagement" and "mathematics" OR "math" OR "numeracy" OR "number sense" OR "gamification" OR "digital game" OR "game-based learning" OR "computer game" and "effect size" and "experiment" OR "RCT" OR "control group." This search resulted in 1000 articles. After an initial examination of a small sample of these first results, I realized that it included many articles that were not relevant to my topic, so I refined my search.

For my refined search, I started by editing the publication years to include only studies done from 2010 to present. This is because although DGBL has been used in education since before 2010, I was interested in only the more modern approaches to digital games that could still be seen in schools today.

Next, I refined my search to include fewer terms and fewer alternative terms by reducing the number of OR operators. The final search included the following terms: "elementary" OR "primary school" and "education" OR "school" and "intrinsic motivation" and "motivation" OR "enjoyment" and "engagement" and "mathematics" OR "math" and "gamification" OR "digital game" OR "game-based learning" OR "computer game" and "effect size" and "experiment" OR "RCT" OR "control group.” This search resulted in 513 studies with many more articles that were relevant to my topic, so this was the list of articles that were used for the study selection.

The Web of Science search required a different method of searching, as this search was conducted based on topic instead of keywords. When using the same search terms from the Google Scholar search, the results were 518,763 studies, so I needed to modify this search to better fit this database. After experimenting with different search terms, the final search included only articles from 2010 to present and only my major search terms with no synonyms or alternative terms. The final search string for Web of Science was as follows: “digital games mathematics learning motivation.” This search resulted in 89 articles that were included in the study selection.

3.2 Study Selection

The online database searches resulted in a total of 602 articles. This number was then narrowed down using a selection criteria to filter out studies that would not be useful for the review. First, each paper was categorized into one of 11 categories: Research article (243), practitioner article (3), proceeding (12), thesis (204), book (19), chapter (12), review article (7), meta-analysis (41), literature review (12), conference paper (15), and other/unknown (34). Next, the list was scanned to remove any duplicate articles and papers that were not relevant to the topic based on their titles. The following selection criteria was then applied to the remaining articles:

- Paper category: Study had to be a research article. Proceeding or conference papers were accepted only if the original study could be found and used instead. Articles had to be published in peer reviewed journals. Theses, meta-analyses, books, or book reviews were not included.
- Study design: Studies must follow empirical research methods.
- Participants: Students included in the study had to be in grades preschool through. Seventh and eighth grade students were included because of different schools' grade cut offs for elementary school.
- Definition of digital games for learning: Digital math games must be played on a digital device such as tablet, laptop, smart phone, virtual reality (VR), or other device. VR was included due to the rapidly changing technology being introduced to the classroom. Digital games had to be intended for learning and not just entertainment.
- Measures of motivation: Studies that include measures of motivation must include a form of self-report data such as a survey or interview. Definitions of motivation that included

other components of intrinsic motivation such as engagement and enjoyment were also considered.

- Measures of achievement: Studies that include measures of achievement must test mathematics achievement through a form of pre and posttest.
- Language: Studies had to be available in English.
- Publication date: Studies must be carried out between 2010 and the time of this systematic review (2022).

After first pass deletion, 103 articles were left that were relevant to the topic according to the title and abstract. These 103 articles were then looked at closer using the selection criteria to assess whether they could be used in the review or not. In addition to their title and abstract, these articles were assessed based on their methods, results, and discussion. After this, 28 articles were left that met the criteria. With these remaining articles, their introduction and references sections were examined to determine whether there were any extra articles that weren't included in the initial search that may be useful for this review. One article (S19) was found through the references section that met the inclusion criteria and was therefore included in the final list of articles. Articles that were relevant but did not meet the eligibility criteria were excluded but were recorded to further inform my background research. This resulted in 29 articles. With the final articles, I discussed with another expert in mathematics educational research about uncertain cases. Ultimately, 10 more articles were excluded for not including full details of the experimentation, not being conducted in an elementary school, and one was excluded because we were unable to find the full article in English. This resulted in 19 articles that both researchers agreed met all the criteria and could be used in the review (See Appendix for full list of studies labeled S1-S19). Figure 1 shows the flow of the research and review process.

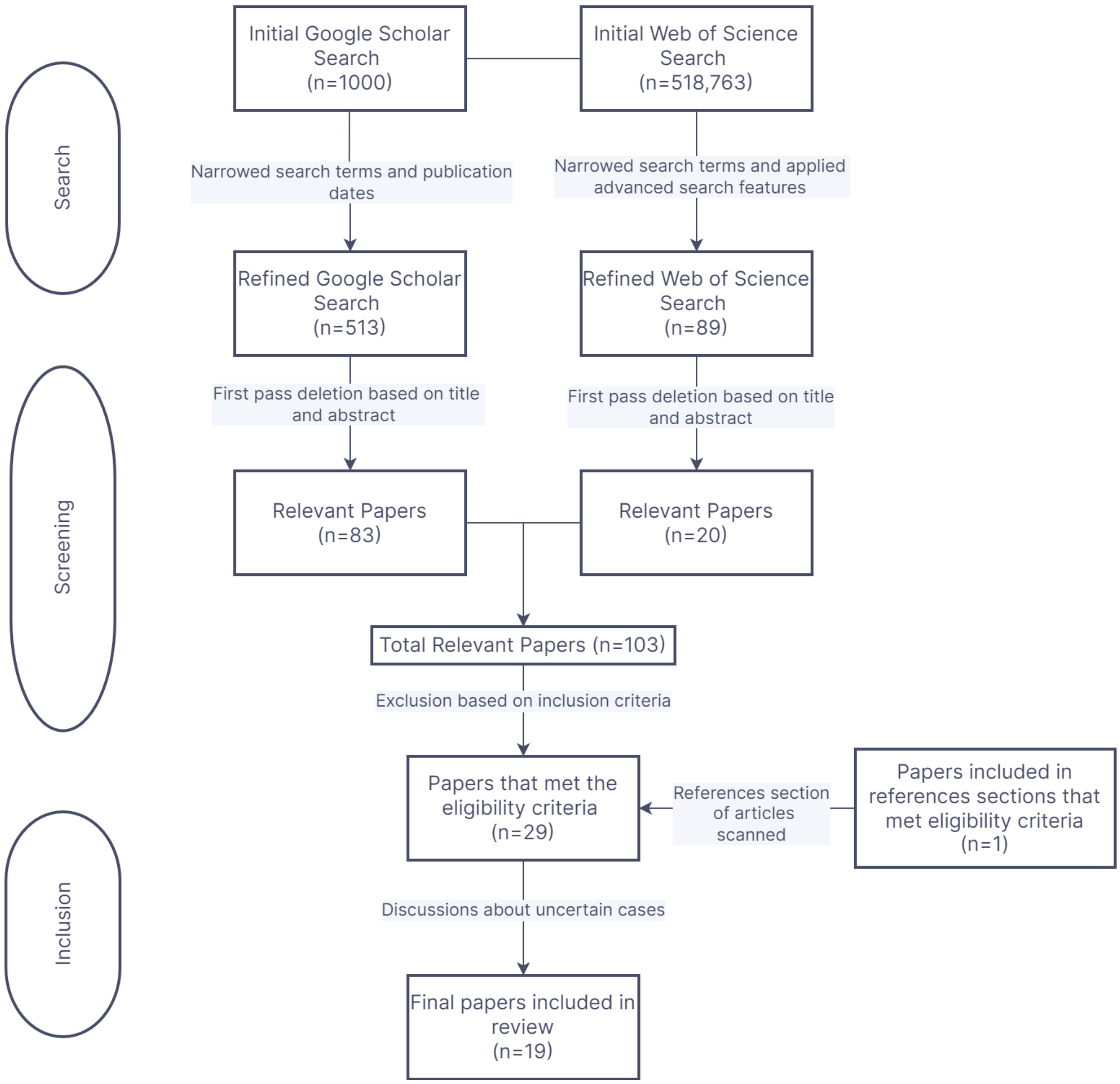

Figure 1. Study Selection Flow Chart

3.3 Coding

The first step of coding the included articles was extracting basic information from each publication and inserting this information into a spreadsheet. This included information such as title, authors, publication year, type of manuscript (journal, proceeding, etc.), student classification, research design, and their dependent variables (motivation, achievement, or both). At this stage, three quantitative articles and three qualitative articles were chosen at random to be validated to test intercoder agreement. After each researcher coded the articles independently, we met and reconciled any disagreements, for which there were very few.

Next, a more rigorous coding scheme was added to the spreadsheet that included more detailed information about the publications such as sample size, age, grade, and sex of participants, country the study took place in, setting, dosage, number of groups, specific intervention, measurement time points, units of measurement, and summary of data. For the sake of classifying the outcomes of the studies into categories that can be cross analyzed, the results of publications were further coded as positive, negative, or no significant effect. In cases where evaluations were conducted on multiple variables, the result was coded in favor of the outcome that had the majority effect. For example, McCarthy et al. (2018) (S14) included two studies in their publication, and the effect of the digital game used in their experiment was significantly positive for both studies, therefore a positive outcome was coded. If at any point during data extraction an article was found to not meet the selection criteria upon closer examination, it was discarded from the list of final articles. A full codebook glossary with all included categories can be seen in Table 1.

Table 1. Codebook Glossary

Category	***Overview***
Author Information	• Author names • Year of publication
Manuscript Information	• Title of manuscript • Type of manuscript (research articles, meta-analyses, book chapters, conferences etc.) • Name of journal
Student Classification	• Sample size • Grade • Age • Sex
Setting	• Country • School's setting

<table>
<caption>**Table 1**. Codebook Glossary</caption>
<tr><td>Research Design</td><td>
Quantitative
Experimental
Quasi-experimental
Qualitative
Case study
Mixed Methods
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Motivation
Self-report survey
Interviews
Observations
Academic achievement
Pretest-posttest scores
Independent measure
Digital math game
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Number of groups
Measurement time points
Units of measurement
Specific intervention
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<tr><td>Results</td><td>
Missing participants
Summary of data
</td></tr>
</table>

4. Results

4.1 RQ 1: What DGBL research is being conducted in primary mathematics classrooms?

4.1.1 Study Attributes

Although this systematic review only included studies conducted in English, various studies were included from around the world. Figure 2 shows the number of publications corresponding to the country they were conducted in. Taiwan and the US together made up almost half of the studies included in this review, with 9 (47%) publications total. Taiwan had the most studies with five (27%) publications while the US had the second most with 4 (21%) publications. The rest of the studies were evenly distributed across 10 different countries with each country producing one (~5%) study.

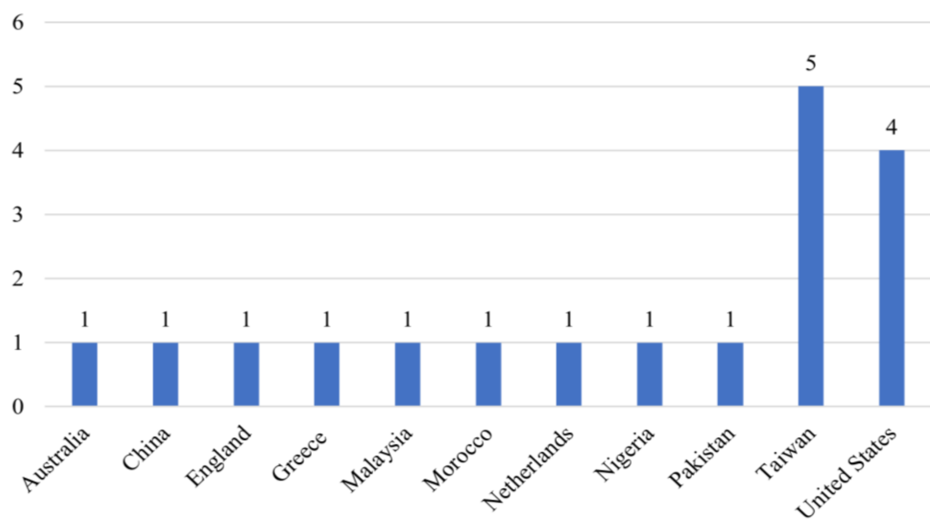


Figure 2. Count of Studies Conducted in Different Countries

Figure 3 presents the chronological order of publication for studies included in this review. This systematic review focused on studies published from 2010-2022, however the earlier years from 2010 to 2013 contained very few studies on this topic with only one (5%) conducted in 2011. The years 2017-2020 had the majority of publications as 14 studies (74%) took place during these years. The year 2018 had the most publications in this review, with five studies (26%) conducted during this time.

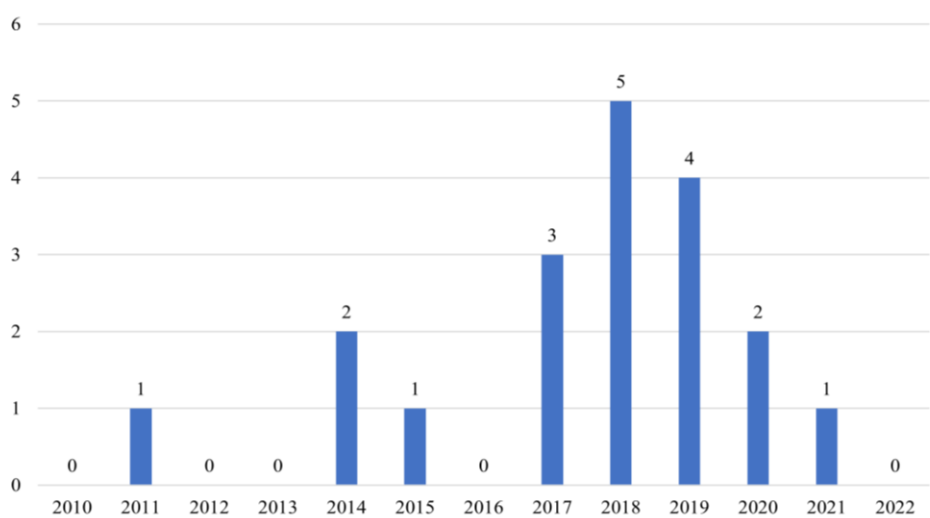


Figure 3. Chronological Order of Publication of Studies

4.2 RQ1a: What kinds of games/technologies are being utilized in these studies?

To explore the various games and technologies that were utilized in the selected studies, a table was created that mapped the various games, game genres, game developers, and game objectives (Table 2). Across the 19 studies selected for this review, no two publications used the same game.

Table 2. Study Information and Interventions

Study	N	Grade Level(s)	Game	Genre	Game developer	Objective	Design	Intervention
Ahmad et al. (2018)	200	1st	Measure Lands	Strategy	Commercial	Interactive activities to learn measurement concept	Quasi-experimental	Experimental group was taught the "measurements" topic through game-based teaching tablet technology while control group was taught the same topic through traditional teaching pedagogies
Dele-Ajayi et al. (2019)	60	4th	Speedy Rocket	Strategy	Researcher	Calculate time and fuel values to launch rockets	Experimental	Experimental group played SpeedyRocket for 160 minutes over two weeks (an average of 15 minutes per session) while control group had traditional mathematics lessons for 30 minutes every day
Deng et al. (2020)	45	2nd	Wuzzit Trouble	Strategy	Commercial	Align numbers according to multiples of a given digit on a gear to free a trapped character	Case study	Digital game-based learning was conducted for 6 days in one second-grade math class for one 35-min period each day
Es-Sajjade & Paas (2020)	227	5th & 6th	MATHERIAL	Strategy	Researcher	Two-player game; solve and create math problems while competing	Quasi-experimental	Experimental group played MATHERIAL for 2 hours per week, spread over four days, over a period of 4 weeks. Students in the control group were taught the regular math lessons without the intervention
Fokides (2018)	201	1st, 4th, & 6th	Kodu Game Lab	Strategy	Teacher	Drill and practice math levels	Experimental	Students were split into one experimental and two control groups. Experimental groups used games to learn. Conventional groups used textbooks without any additional learning material and activities. For the contemporary group, students worked on worksheets in pairs, collaborated and discussed with each other, and teachers actively participated and guided them.
Gresalfi et al. (2018)	95	3rd	Slice Fractions & Motion Math: Fractions!	Strategy	Commercial	Slice Fractions: Slice pieces of ice using fractions to make them fall into a fire; Motion Math: tilt tablet to make a ball fall into place on a number line	Experimental	On day 1, the experimental group took 30 minutes working on an app while the control group worked on worksheets. On day 2, the experimental group took another 30 minutes of working on a new app while control group worked on worksheets
Habgood & Ainsworth (2011)	74 (Study 1: 58; Study 2: 16)	7th & 8th	Zombie Division	Role-Playing	Researcher	Adventure game with different attacks using number patterns and sequences to divide opponents	Experimental	Experimental group gameplay for up to 40 minutes; followed by all students receiving teacher-led reflection session; After, experimental group continued gameplay up to a maximum of a total of 100 minutes
Huang et al. (2014)	56	2nd	virtual store with diagnostic mechanism	Simulation	Researcher	Addition and subtraction by completing transaction activities in a virtual store	Quasi-experimental	Over six weeks there were two 40-minute lessons for the kids per week. The experimental and control groups both had a lesson in addition and math, then the experimental group used the DGBL system with a diagnostic

Table 2. Study Information and Interventions

Study	N	Grade Level(s)	Game	Genre	Game developer	Objective	Design	Intervention
								mechanism for 40 minutes while the control group used the version without the diagnostic mechanism.
Hung et al. (2014)	68	5th	Brick Breaker	Strategy	Researcher	Break bricks to reveal a question related to symmetry	Quasi-experimental	Experimental group A learned with a DGBL approach on e-books; Experimental group B learned with the learning system on e-books; the control group learned with traditional teacher-led instruction all for a total of 240 minutes.
Hung et al. (2015)	52	2nd	Motion Math: Hungry Fish	Strategy	Commercial	Identify combinations of numbers to total number displayed on a fish	Quasi-experimental	Experimental group participated in challenging learning games for 40 minutes per level. The control group undertook matching learning activities for 40 minutes each.
Hwa (2018)	20	3rd	DigiGEMs	Strategy	Researcher	Complete a series of lessons on different topics that include game-based drill activities	Quasi-experimental	Experimental group worked on the DigiGEMs at their own pace for 5 weeks. The control group did not practice the DigiGEMs.
Ke (2019)	63	6th	E-Rebuild	Simulation	Researcher	Solve problems using area, surface area, and angle measures to design buildings	Experimental	Experimental group played E-Rebuild for two 50-minute sessions per week for 6 weeks. The control group did conventional class activities, such word problems that cover the same math topics as those in game tasks.
Kim & Ke (2017)	132	4th	Open Simulator (OpenSim)	Simulation	Commercial + Researcher	Practice with fractions with word problems in a virtual reality simulated sandwich shop	Experimental	All students participated in the preliminary instruction for ~10–15 minutes. Experimental group participated in solving four tasks on the digital game for ~ 30-40 minutes.
McCarthy et al. (2018)	151 (Study 1: 68; Study 2: 83)	Pre-K	Curious George Math	Strategy	Commercial	Basic mathematics concepts through a variety of minigames	Quasi-experimental	Study 1: All students played the Curious George game for 30 minutes a day twice a week for 4 weeks and spent 60 minutes viewing Curious George videos. Study 2: All students carried out the intervention. School activities for 4-6 days for 15-30 minutes, which included online games. There was also an optional home-based activity from the Odd Squad transmedia suite.
Ninaus et al. (2017)	32	6th	Semideus Sch ool	Strategy	Researcher	Find gold coins on a number line and compare numbers by putting items in the correct order	Experimental	Over one week, all students played the Semideus School game for ~2 hours (4 sessions of ~30 minutes each).
O'Rourke et al. (2017)	236	4th & 5th	Dr Kawashima's Brain Training	Strategy	Commercial	Variety of computational games that require rapid recall of mathematical facts	Quasi-experimental	Experimental group played the brain training game for 20 minutes a day, every day for 10 weeks. Control group was taught with traditional teaching methods.
Tazouti et al. (2019)	60	5th & 6th	JEUTICE	Strategy	Researcher	A variety of minigames which each deal with a specific learning task	Quasi-experimental	All students played the JEUTICE game for 120 minutes total during math time over the span of 3 weeks.
Yang & Chen (2021)	52	5th	RPG Maker	Role-Playing	Researcher	Mathematical challenges to recover the stolen "Nine Yang Manual"	Quasi-experimental	Experimental group learned with the digital game that had a POE strategy, while those in the control group played a similar digital game without the POE strategy for a total of 120 minutes of gameplay.
Yeh et al. (2019)	215	2nd & 3rd	Math-Island	Simulation	Researcher	Solve mathematics problems to earn virtual money for unique buildings on islands	Experimental	Over the course of 2 years, the experimental group learned with the Math-Island system while the

Table 2. Study Information and Interventions

Study	N	Grade Level(s)	Game	Genre	Game developer	Objective	Design	Intervention
								control group learned mathematics in a traditional way.

4.2.1 Game Developer

Researcher-developed games are those that were created by the researcher for the purpose of the study. Commercially developed games include all games that were created by a third party and therefore available to the public. Teacher-developed games are games that were developed by the teacher of the participants. The majority of games utilized in the studies were developed by the researcher (58%), while 32% of games were commercially developed. Only one publication (S5) utilized a teacher-developed game (5%), and one study (S13) utilized a game that was both researcher and commercially developed (5%) as the game was on a publicly available platform, but the content was created by the researcher.

4.2.2 Gaming Platform

When it comes to the platform utilized for participants to play the games on, computers were the most popular choice with 9 studies (47%) utilizing this platform. Tablets (31%) and iPads (16%) were also popular choices. Nintendo DS Lite (6%) was the only other platform used in the publications.

4.2.3 Game Genre

The genres of the games were categorized into simulation, strategy, action, and role-playing games (Figure 4). The most popular genre of game in the publications was strategy games with 13 studies (68%) using this game genre. 4 studies (21%) used a game from the simulation genre and only 2 studies (11%) used a game from the role-playing genre. No studies used a game from the action genre, likely due to the fact that this genre is not typically associated with serious games for educational purposes.

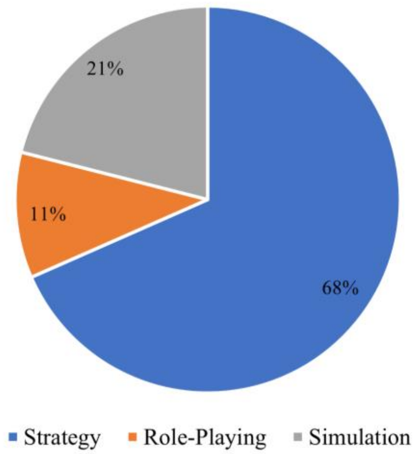


Figure 4. Game Genres

4.3 RQ1b: What type of intervention was utilized?

4.3.1 Research methodologies

A variety of research methodologies were used in the included research studies including qualitative, quantitative, and mixed methods. Figure 5 shows that the majority of studies (69%) were conducted using quantitative methods. 26% of studies used a mixed methods approach, and only 5% used a qualitative approach. Out of the quantitative and mixed methods studies, 56% of studies used a quasi-experimental design while 44% used an experimental design (Figure 6). The one study that utilized a mixed methods approach used a case study design. A cross analysis of study methodology with quantitative and mixed methods studies indicates that the majority of studies used a quantitative method with an experimental design (Figure 7).

The sample size of participants that were used in the studies is categorized into different groups based on their amounts in Figure 8. The majority of studies used a sample size between 50 and 100 students (Figure 8). 24% of studies used a sample size of over 150 students. The duration of the studies is categorized into short term (less than one month), medium term (over 1 month, less than 3 months), and long term (over 1 year). Short term studies were most commonly used as they comprised 70% of studies conducted (Figure 9). A cross analysis of sample size and study duration shows that the majority of studies had between 50-100 participants for a short-term duration (Figure 10).

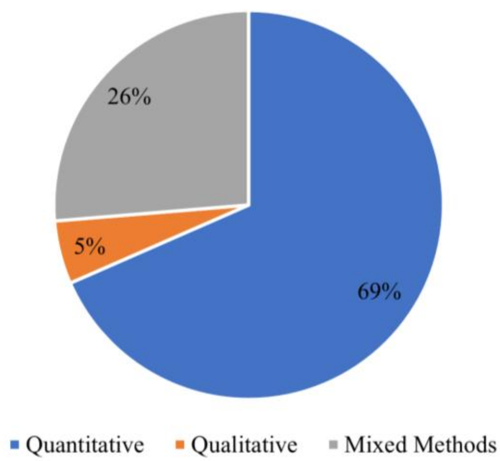


Figure 5. Research Methodologies

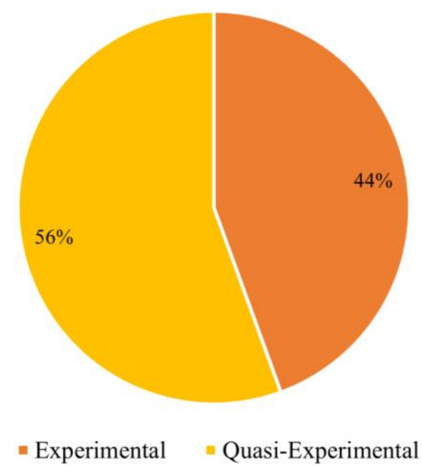


Figure 6. Research Design

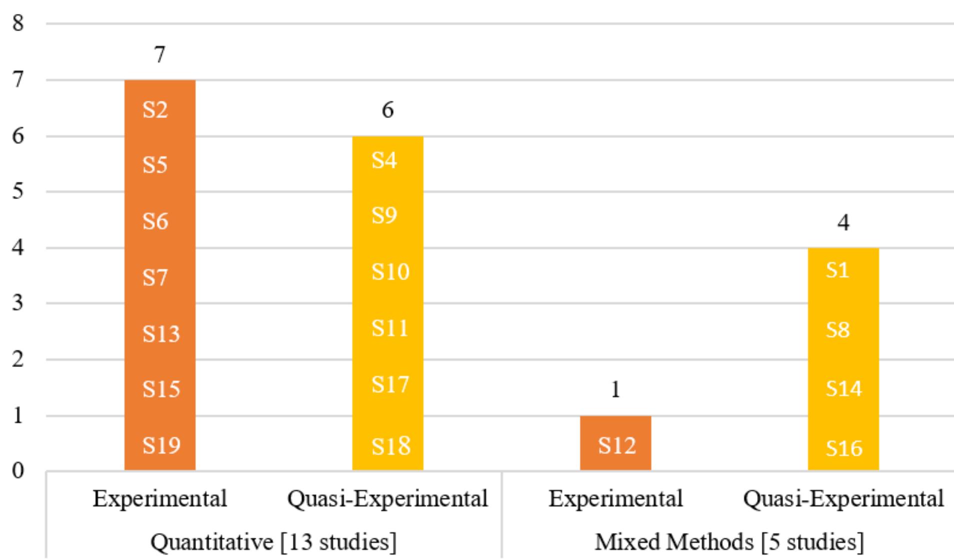
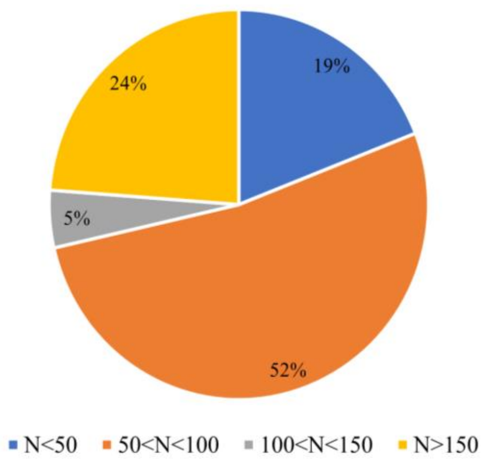


Figure 7. Cross Analysis of Study Methodology and Design for Quantitative and Mixed Methods Studies



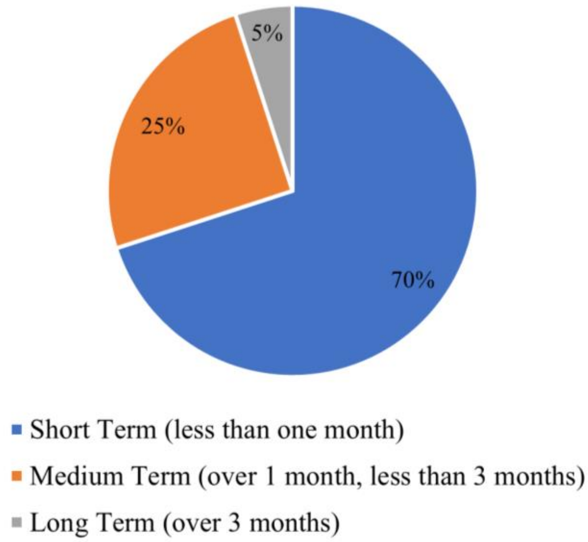


Figure 8. Sample Size of Participants (N)

Figure 9. Study Duration

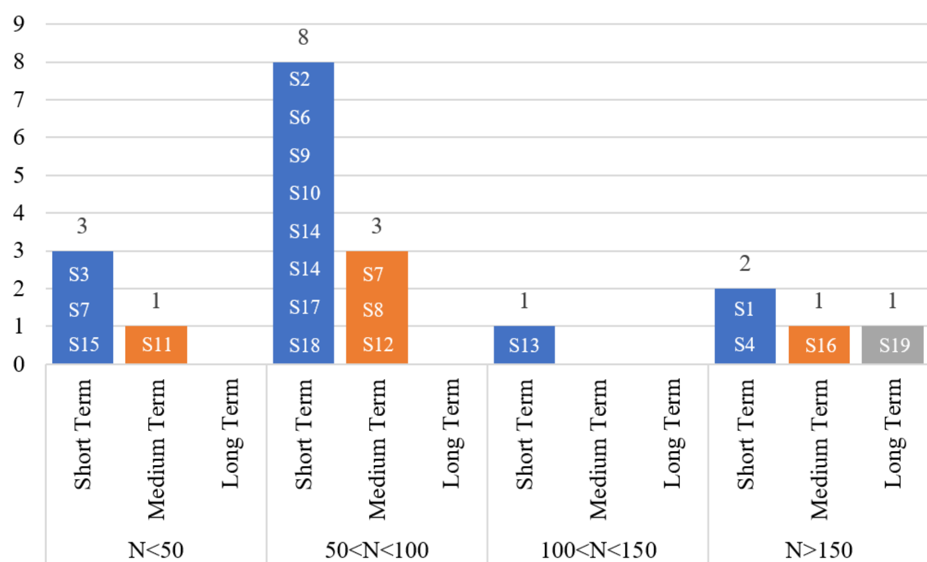


Figure 10. Cross Analysis of Same Size (N) and Study Duration

4.3.2 Study Intervention

Almost every study (95%) utilized a pre- and post-test design (95%). Only one study (S2) utilized a post-test only design. Table 2 summarizes the interventions in each study.

4.4 RQ 2: How does DGBL affect students' motivation and achievement in mathematics?

4.4.1 Dependent Variables

Figure 11 presents the dependent variables used in each study. The majority of studies included in this review investigated the effects of DGBL on both academic achievement and motivation, as 12 (63%) publications included both of these variables. Only 2 (10%) studies looked only at motivation as a dependent variable, while 5 (27%) of studies looked only at achievement as a dependent variable.

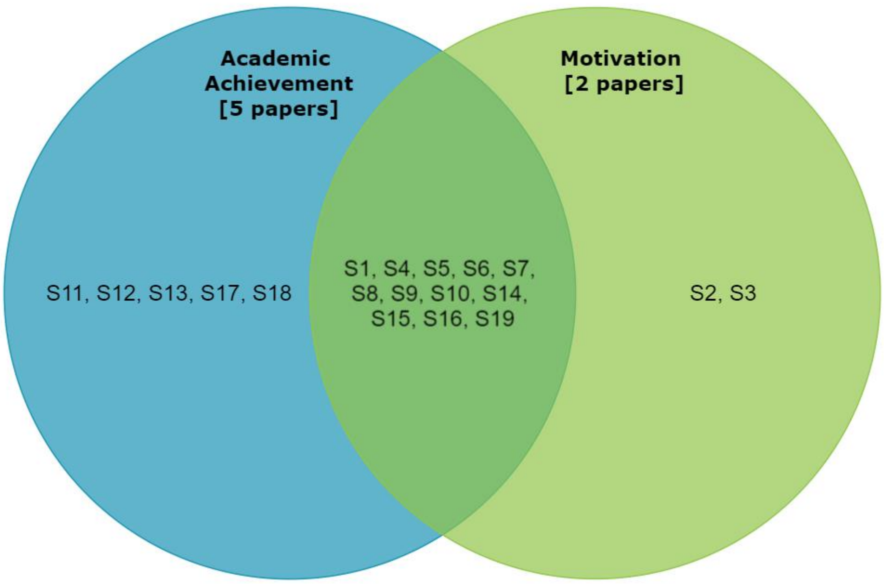


Figure 11. Dependent Variables Used in Studies

4.5 RQ2a: Does DGBL increase student motivation?

4.5.1 Theoretical Framework

Though not every study had a concrete theoretical framework, the two most common theories utilized in this area of research were ARCS Motivation Theory and Flow Theory as they made up a collective 43% of theories (Table 3). Many publications did not frame their study through the lens of a specific motivation theory and instead looked at motivation in more general terms such as engagement, attitude, interest, enjoyment, etc.

4.5.2 Measurements of Motivation

In terms of measuring motivation, the majority of studies (79%) used some form of a survey or questionnaire, while the other 21% used some form of qualitative measurement such as interviews and observations.

4.5.3 Motivation Outcomes

When it comes to the outcomes, the results of the studies were categorized into positive, effect, negative effect, or no significant effect. Some studies such as S10 measured multiple aspects of motivation, therefore the effect of DGBL on each one was included. The majority of outcomes (76%) indicated that DGBL had a significantly positive effect on motivation while only 23% of outcomes indicated no significant effect. Notably, there were no significantly negative effects on motivation in any of the studies. Table 3 shows the results of the effects of DGBL on motivation.

Table 3. Effects of DGBL on Motivation

Reference (Year)	Motivation Framework	Motivation Measurement	Description of Assessment	Effect on Motivation
Ahmad et al. (2018)	ARCS Model of Motivation + Flow theory	Instructional Material Motivational Survey (IMMS)	36-question survey that used a 5-point Likert scale gauging motivation in the subcategories of attention, relevance, confidence, and satisfaction	Positive
Dele-Ajayi et al. (2019)	ARCS Model of Motivation	Attitude towards mathematics questionnaire	10-item questionnaire on a 4-point Likert scale	Positive
Deng et al. (2020)	Engagement	Interviews + Observations	Interviews consisted of 15-20 minute focus-group interviews with students and a 40-50 minute interview with the teacher. Observations included videotapes of 2 regular classes and 6 game classes.	Positive
Es-Sajjade & Paas (2020)	Attitude towards mathematics	Survey adapted from Dutch ‘Attitude towards Mathematics’ scale	17-question survey on a 4-point Likert scale measuring how much students enjoy learning mathematics	No significant effect
Fokides (2018)	Attitude towards mathematics game	Survey on views and attitudes towards game	15 Likert-type questions given only to students in the experimental group	Positive
Gresalfi et al. (2018)	Interest and enjoyment	Survey on interest and enjoyment, Interviews, Observations	Survey consisted of 9 questions on a 4-point Likert scale measuring student enjoyment and engagement. 10-20 minute individual interviews were conducted with 12 experimental group students and 11 control group students. Randomly selected groups were also	Positive

Table 3. Effects of DGBL on Motivation

Reference (Year)	Motivation Framework	Motivation Measurement	Description of Assessment	Effect on Motivation
			videotaped during gameplay.	
Habgood & Ainsworth (2011)	Intrinsic Integration	Pre- and post-content test; challenge level in game; teacher-led reflection	Pre-test was 15-minute timed test from school's computer-based curriculum; post-test was 63-multiple choice questions; challenge level was two specifically constructed levels that directly replicated a portion of outcome test's division problems; Teacher-led reflection consisted of 15 minutes of direct instruction, 10 minutes of collaborative exercises, 10 minutes of exercises in pairs or threes that consisted of 12 divisor-based division problems	Positive
Huang et al. (2014)	ARCS Motivation Theory	ARCS Motivation Scale	Pre- and post-tests for content and mathematics anxiety; ARCS motivation questionnaire; interviews with sample of students and one teacher	Positive
Hung et al. (2014)	Flow Theory Learning motivation for mathematics	Learning motivation scale	Survey with a 5-point Likert scale measuring learning motivation as developed by Fennema and Sherman (1977)	Positive
Hung et al. (2015)	Flow Theory	Questionnaire on flow experience	14-item questionnaire adopted from Hwang et al. (2012) that measured the four dimensions of flow: flow antecedent, flow experience, intrinsic motivation, and extrinsic motivation	- Flow antecedent: Positive - Flow Experience: Positive - Intrinsic Motivation: No significant effect - Extrinsic Motivation: No significant effect
McCarthy et al. (2018)	Engagement in mathematics	Interviews and observations	Teacher interviews were conducted at the end of the intervention where teachers were asked to reflect on how their children responded to the content. Observations were carried out everyday observing student behavior	Positive
Ninaus et al. (2017)	Intrinsic Motivation + Flow Theory	Questionnaire on math interest and math self efficacy. Flow was measured with a modified version of the Flow Short Scale.	3-item questionnaire on math interest and 3-item questionnaire on self-efficacy using a 5-point Likert scale. 10-item questionnaire on flow experience using a 7-point Likert scale.	Positive
O'Rourke et al. (2017)	Student engagement and enjoyment	Semi-structured interviews with students, teachers, and parents	Semi-structured interviews were conducted with 36 students, 8 teachers, and 3 parents regarding student engagement, enjoyment, and performance.	Positive
Yeh et al. (2019)	Interest in mathematics	Questionnaire using items from the PISA and TIMSS 2012	45-item questionnaire measuring attitude, confidence, and initiative	No significant effect

4.6 RQ2b: Does DGBL increase student mathematical achievement?

4.6.1: Achievement Test

Most of the achievement tests used in the studies were either standardized tests (35%) or teacher developed tests (24%). There was also a large number of studies (29%) that did not specify the developer of the test. The other categories included researcher developed (6%) and math expert developed (6%).

When it comes to the specific assessment, almost every study (94%) used a form of a pre- and post-test to measure achievement. The types of assessment varied greatly, ranging from tests as short as 7 questions (S12) to tests as long as 60 questions (S19). These tests involved various kinds of questions such as multiple-choice questions, fill-in-the-blank questions, short-answer questions, matching questions, word problems, and verbal response questions.

4.6.2 Achievement Outcomes

Table 4 presents the outcomes of the effects of DGBL on mathematical achievement. The majority of studies in this review (94%) found positive effects of DGBL on mathematics achievement, and only 6% found no significant effect. No studies found a significantly negative effect of DGBL on achievement.

Table 4. *Effects of DGBL on Achievement*

Reference (Year)	***Test Developer***	***Achievement Assessment***	***Description of Assessment***	***Effect on Achievement***
Ahmad et al. (2018)	Standardized test	Pre- and post-test based on National Math Curriculum for each topic	15-question assessment	Positive
Es-Sajjade & Paas (2020)	Unspecified	Written post-test	15-question assessment with each question worth between 1-8 points for a total of 60 point	Positive

Table 4. *Effects of DGBL on Achievement*

Reference (Year)	***Test Developer***	***Achievement Assessment***	***Description of Assessment***	***Effect on Achievement***
Fokides (2018)	Unspecified	Written pre- and post-test	Tests included mathematical operations, right-wrong, multiple choice, and fill-in-the-blank questions	Positive
Gresalfi et al. (2018)	Standardized test	Pre- and post-test using fraction items from 1990 to 2009 NAEP mathematics and fraction magnitude comparison problems from the 2010 Fraction Battery	Test included 6 questions assessing students' comprehension of symbolic fraction magnitudes, 6 questions assessing magnitudes represented by shaded areas, 2 questions assessing magnitudes represented on a 0–1 number line, and 2 questions assessing students' ability to reason about another students' incorrect answer for a total of 16 points.	No significant effect
Habgood & Ainsworth (2011)	Unspecified	Time-limited computer based test	63-question assessment including 3 interface practice questions, 45 division questions, and 15 conceptual questions	Positive
Huang et al. (2014)	Standardized test	Addition and subtraction test from accredited primary school mathematics textbook	13-item test with 7 comprehension questions and 6 application questions	Positive
Hung et al. (2014)	Teacher developed	Written pre- and post-test developed by experienced teachers	Pret-test containing 9 multiple choice, 11 fill-in-the-blank, and 5 short-answer questions, posttest containing 5 multiple choice, 16 fill-in-the-blank, and 15 short-answer questions	Positive
Hung et al. (2015)	Teacher developed	Written learning achievement tests developed by 3 experienced teachers	100-point test with 30% addition and subtraction with no regrouping, 35% addition problems with regrouping, 35% subtraction problems with regrouping	Positive
Hwa (2018)	Researcher developed	Written achievement tests modified from past teacher-made tests	15 multiple choice questions on selected lessons	Positive
Ke (2019)	Teacher developed	Word problem oriented written pre-and post-test	7 multi-step math context problems, each on a 3-point scale and scored on a grading rubric	Positive
Kim & Ke (2017)	Teacher developed	Written pre- and post-test selected from authentic-application-oriented CCSS practice items	16-item test where students apply basic and advanced fraction knowledge	Positive

Table 4. *Effects of DGBL on Achievement*

Reference (Year)	***Test Developer***	***Achievement Assessment***	***Description of Assessment***	***Effect on Achievement***
McCarthy et al. (2018)	Standardized test	Test of Early Mathematics, Student-Written Mathematics Assessment, and Mathematics Assessment Resource Service (MARS), Student Mathematics Vocabulary Assessment	Test of Early Mathematics: 26-item test measuring students' numbering, number comparisons, calculation, and concepts understanding Student-Written Mathematics Assessment: Untimed written test assessing number and operations and algebraic thinking Mathematics Assessment Resource Service (MARS): Open-response performance-based task measuring number and operations and algebraic thinking Student Mathematics Vocabulary Assessment: Verbal test of mathematics vocabulary word definitions	Positive
Ninaus et al. (2017)	Unspecified	Pre- and post-test embedded into the game	33-question test consisting of 10 estimation tasks, 10 fraction and decimal comparison tasks, and 13 fraction and decimal ordering tasks	Positive
O'Rourke et al. (2017)	Standardized test	Westwood One Minute Test of Basic Number Facts	Norm-referenced 33-item test on basic math functions	Positive
Tazouti et al. (2019)	Unspecified	Mathematics achievement pre- and post-test	Test about theoretical elements of measurements, surfaces and numbers.	Positive
Yang & Chen (2021)	Math expert developed	Written pre- and post-test on basic knowledge	Pre-test included 10 yes-or-no questions and 10 multiple choice questions; Post-test included 10 yes-or-no items, 2 matching questions, and 3 short-answer questions that all tested students' "awareness of ratio and percentage," "conversion of fractions, decimals and percentages," and "application of percentages"	Positive
Yeh et al. (2019)	Standardized test	Standardized achievement written pre- and post-test assessing mathematical ability	Pre-test consisted of 50 questions assessing conceptual understanding (23 questions), calculating (18 questions), and word problem-solving (questions), post-test consisted of 60 questions assessing conceptual understanding (18 questions), calculating (27 questions), and word problem-solving (15 questions)	Positive

5. Conclusion

This systematic review closely examined the effects of digital gamification on students' motivation or achievement through a synthesis of existing literature to understand the effects of gaming technology and to inform future studies to deepen our knowledge of the learning benefits of games for teaching mathematics. This review analyzed the games used, study interventions, and motivation and achievement outcomes of 19 empirical research publications. One takeaway from this review was the evidence that this topic is vastly under researched, as 19 articles produced in over 12 years is a small number of studies. Given the importance of understanding how DGBL affects student outcomes in elementary mathematics, more research should be conducted in this area to better answer this question and guide educators and policymakers towards implementing effective DGBL interventions. Another notable finding was the major gap in literature from countries other than the US and Taiwan. Consistent with other recent literature reviews on DGBL (Bano et al. 2018), the US and Taiwan together made up the overwhelming majority of research on DGBL. This highlights the need for more research on this topic to be conducted in other countries in order to establish how DGBL impacts students across different cultural contexts.

The games utilized in research studies on this topic had various objectives and genres. However, the majority of the games used were researcher-developed, which restricts the opportunity for teachers and students to utilize these games and benefit from their positive outcomes. For elementary educators seeking commercially available empirically backed mathematical games to implement in the classroom, Measure Lands (S1), Motion Math: Hungry Fish (S10), Curious George Math (S14), and Dr. Kawashima’s Brain Training (S16) were games included in this review that had positive effects on both motivation and achievement. While these are concrete options for educators, the small number of readily available games may contribute to teachers' apprehensiveness to implement DGBL into the classroom, which calls for more investment into the development and widespread availability of educational games.

This review found that the majority of studies found positive effects of DGBL on student motivation. When it comes to measures of motivation, many studies utilized in this review did not look at a specific kind of motivation or have a clear theoretical framework for the measurement, therefore their measurement tools were generally self-developed instruments. This may affect the ability to draw concrete conclusions from the results of the studies, therefore it is recommended for research in this area to instead define motivation using an unambiguous framework and utilize a scientific evaluation method to measure motivation. This could help teachers make more informed decisions that are scientifically based when it comes to choosing which games are best for improving their students' motivation.

This review also found mainly positive effects of DGBL on students' mathematical achievement. A wide variety of achievement measurement techniques were used including comparing gain scores of experimental and control groups, comparing post-test scores with pre-test scores as the covariate, or comparing only post-test scores. Several authors have noted that the most preferable method of measurement is the analysis of covariance (ANCOVA) using pre-tests as the covariate, therefore further research on this topic may benefit from using this statistical analysis (Campbell et al., 1963; Dimitrov et al., 2003). Additionally, many studies in this review gave little information on the test developer, which brings into question the validity of the achievement measurement instruments. Objective achievement measurement tools such as standardized tests could provide a more reliable result.

This review highlights the positive effects of DGBL and provides educators with empirical research to help them decide which DGBL interventions would best benefit their classroom. It also provides recommendations and implications for future research on the topic to conduct studies with more rigorous standards of reliability.

6. Limitations and Future Directions

It is important to acknowledge the limitations of the current systematic review in order to guide future research on this topic. First, this review included a very small number of articles which may be attributed to the very narrow selection criteria. Similar to all systematic reviews, this review is also limited by its databases as only two databases were used for extracting articles, opening up the possibility of a publication bias. The use of online databases may have also excluded sources that are not available electronically. Future reviews may utilize more databases, especially those that specialize in education research such as ERIC and EBSCO. Additionally, this review is limited by the search terms which narrow the scope of included articles and could have potentially excluded studies that define digital games through other terms such as computer simulations, mobile applications, etc. A more comprehensive review may include a more exhaustive list of search terms in order to yield more results. This review is also limited by the exclusion criteria of the type of manuscript for each article, as it is possible that theses and dissertations may have added significant value to the conversations about DGBL in early mathematics education. Future research may widen the range of articles included in the review in order to gain a broader perspective on this topic.

Overall, future research may use this review as a guideline to answer more questions regarding DGBL in early education. It may be interesting to look at longitudinal studies in order to gain an understanding of the long-term effects of DGBL on students' motivation and achievement. Moreover, future studies may investigate how DGBL impacts student outcomes in other ways than motivation and achievement such as creativity, memory, well-being, critical thinking, etc.

Appendix A. Study Identification

Study ID	***Citation***
S1	Ahmad, F. H., Malik, M., Siddiqui, S., & Khan, H. (2018). Investigating the Impact of Game-Based Learning in Mathematics Using Tablets Among Primary School Students. *Foundation for Information Technology Educa-tion and Development*.
S2	Dele-Ajayi, O., Strachan, R., Pickard, A. J., & Sanderson, J. J. (2019). Games for teaching mathematics in Nigeria: what happens to pupils' engagement and traditional classroom dynamics?. *IEEE Access*, *7*, 53248-53261.
S3	Deng, L., Wu, S., Chen, Y., & Peng, Z. (2020). Digital game-based learning in a Shanghai primary-school mathematics class: A case study. *Journal of Computer Assisted Learning*, *36*(5), 709-717.
S4	Es-Sajjade, A., & Paas, F. (2020). Educational theories and computer game design: lessons from an experiment in elementary mathematics education. *Educational Technology Research and Development*, *68*(5), 2685-2703.
S5	Fokides, E. (2018). Digital educational games and mathematics. Results of a case study in primary school settings. *Education and Information Technologies*, *23*(2), 851-867.
S6	Gresalfi, M. S., Rittle-Johnson, B., Loehr, A., & Nichols, I. (2018). Design matters: explorations of content and design in fraction games. *Educational Technology Research and Development*, *66*, 579-596.
S7	Habgood, M. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *The Journal of the Learning Sciences*, *20*(2), 169-206.
S8	Huang, Y. M., Huang, S. H., & Wu, T. T. (2014). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Educational Technology Research and Development*, *62*, 187-207.
S9	Hung, C. M., Huang, I., & Hwang, G. J. (2014). Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. *Journal of Computers in Education*, *1*, 151-166.
S10	Hung, C. Y., Sun, J. C. Y., & Yu, P. T. (2015). The benefits of a challenge: student motivation and flow experience in tablet-PC-game-based learning. *Interactive Learning Environments*, *23*(2), 172-190.
S11	Hwa, S. P. (2018). Pedagogical change in mathematics learning: Harnessing the power of digital game-based learning. *Journal of Educational Technology & Society*, *21*(4), 259-276.
S12	Ke, F. (2019). Mathematical problem solving and learning in an architecture-themed epistemic game. Educational Technology Research and Development, 67(5), 1085-1104.
S13	Kim, H., & Ke, F. (2017). Effects of game-based learning in an OpenSim-supported virtual environment on mathematical performance. Interactive Learning Environments, 25(4), 543-557.

S14	McCarthy, E., Tiu, M., & Li, L. (2018). Learning math with curious George and the odd squad: Transmedia in the classroom. *Technology, Knowledge and Learning*, *23*, 223-246.
S15	Ninaus, M., Moeller, K., McMullen, J., & Kiili, K. (2017). Acceptance of game-based learning and intrinsic motivation as predictors for learning success and flow experience. *International Journal of Serious Games*, *4*.
S16	O'Rourke, J., Main, S., & Hill, S. M. (2017). Commercially available digital game technology in the classroom: Improving automaticity in mental-maths in primary-aged students. *Australian Journal of Teacher Education*, *42*(10), 4.
S17	Tazouti, Y., Boulaknadel, S., & Fakhri, Y. (2019). JeuTICE: An arabic serious game to enhance mathematics skills of young children. *International Journal of Emerging Technologies in Learning (iJET)*, *14*(22), 252-265.
S18	Yang, K. H., & Chen, H. H. (2021). What increases learning retention: employing the prediction-observation-explanation learning strategy in digital game-based learning. *Interactive Learning Environments*, 1-16.
S19	Yeh, C. Y., Cheng, H. N., Chen, Z. H., Liao, C. C., & Chan, T. W. (2019). Enhancing achievement and interest in mathematics learning through Math-Island. *Research and Practice in Technology Enhanced Learning*, *14*(1), 1-19.

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