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Examining pedagogical approaches and types of mathematics knowledge in educational games: A meta-analysis and critical review

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ABSTRACT

This meta-analysis systematically reviewed math game studies published between 2010 and 2020 and evaluated them with respect to a) the type of pedogeological foundations inherent in games using Kebritchi and Hirumi's (2008) framework, b) the type of mathematics knowledge they facilitated (Bisanz & LeFevre, 1990; Rittle-Johnson, 2017), and c) their effect on math learning. Only 23 out of 26 studies used games based on a clear pedagogical approach and many studies measured multiple knowledge types. A direct instructional approach was most often used in games to target factual knowledge and resulted in an overall medium sized effect ($g = 0.58$), whereas procedural and conceptual knowledge were used by games using three types of pedagogical approach: experiential, discovery, and constructivist approaches but with mixed effect sizes. Overall, behaviorally oriented pedagogies are still dominant in math games and the effectiveness of each pedagogical approach varies as a function of knowledge type.

1. Introduction

The ever-changing technological landscape is transforming how people live and communicate with each other; as a result, technology has become ubiquitous in the lives of today's children (Prensky, 2001a). Previous studies have shown how connected children are with interactive media (Lenhart, Smith, Anderson, Duggan, & Perrin, 2015; Rideout & Robb, 2019): for instance, it has been found that 72% of teenagers play videogames (Lenhart et al., 2015) and teens spend an average of 7 and half hours a day on entertainment media, not including time spent at school or on homework (Rideout & Robb, 2019). Additionally, a recent social policy report published by the Society for Research on Child Development (Blumberg et al., 2019) found in a survey of children under 8 that usage of interactive games is about 25 min daily, with little usage before age 2. Despite this high level of usage and growing interest among teens, adolescents, and younger children, it appears that educators have yet to take full advantage of learning technologies for Science, Technology, Engineering, and Mathematics subjects.

Yet, the past decade has also seen rapid development and adoption of educational games in classrooms and these educational games have the potential to improve learning and instruction (Clark, Tanner-Smith, & Killingsworth, 2016; F.A.S, 2006; Wouters and van Oostendorp, 2013). Although research has supported the use of games as pedagogical tools (Boyle et al., 2016; Girard, Ecalle, & Magnan, 2013; Outhwaite, Faulder, Gulliford, & Pitchford, 2019), how educators approach learning and delivering curricula via games varies in effectiveness (Olney, Herrington, & Verenikina, 2008). In particular, studies highlight the challenges teachers face in

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trying to find appropriate, valid, and effective games, with many educators selecting inappropriate games that do not align with their pedagogical goals (McManis & Gunnewig, 2012; Ok, Kim, Kang, & Bryant, 2016). Lastly, the vast numbers of educational games available (80,000 +; Hirsh-Pasek et al., 2015) is overwhelming in itself; an overabundance of choice that only serves to hampers educators because they must spend considerable time engaging with each game to understand its suitability and relevance for their classroom (Callaghan & Reich, 2018; Dubé, Kacmaz, Wen, Alam, & Xu, 2020; Larkin, 2015). Therefore, the first step in helping educators to identify suitable and effective games is to understand and evaluate the full potential of educational games and their specific learning outcomes.

Mathematics is considered to be a fundamental educational requirement as it builds foundational cognitive skills that are relevant to many related disciplines of study (e.g., physics, chemistry) and occupations (e.g., engineering, finance). For some time, researchers in mathematics education, policymakers, and the education system as a whole have been concerned with the tools, methods, and approaches used to increase students' engagement in mathematics learning and understanding of mathematical concepts (Malone, 1981). Recently, a widely proposed solution to the problems and challenges in mathematics education is to integrate game-based learning into mathematics teaching and learning (Bray & Tangney, 2017; Clark et al., 2016; Outhwaite et al., 2019). Game-based learning is defined as activities that have a game at their core and have learning as a desired or incidental outcome (Kirriemuir & McFarlane, 2004). Studies have indicated that the engaging nature of such games makes them a promising tool for the development of math skills (Kiili, Ketamo, Koivisto, & Finn, 2014; Outhwaite, Gulliford & Pitchford & 2017). However, due to the lack of empirical evidence on the effectiveness and quality of educational math games, few conclusions can be drawn, (Fabian, Topping, & Barron, 2016; Mayer, 2014; O'Neil, Wainess, & Baker, 2005; Wouters & Van Oostendorp, 2013).

Considering the increased development and implementation of the educational games, there is a need to determine the educational potential of these games in order to justify it (Clark, 2007). How well do educational games support math learning? Given the state of the literature, it is hard to say because studies too often apply different pedagogical approaches, focus on different types of knowledge, and then make overgeneralized conclusions about all math games (Dubé, Alam, Xu, Wen, & Kacmaz, 2019a). In response, this paper conducts a systematic review of math game studies and evaluates the effectiveness and quality of educational math games by categorizing them by their pedagogical approach and the type of math knowledge they report to improve. This is essential step for the meaningful adoption of educational games into the mathematics classroom.

Apart from the previous studies, this meta-analysis adds to the current body of evidence by identifying the influences of pedagogical approaches on math knowledge types as an indicator of games' effectiveness The present meta-analysis contributes to the literature in two ways. First, it provides a recent review of math game research. This is important as the number of studies published on educational games has increased significantly (255% increase from 2011 to 2018, Dubé & Wen, 2021, pp. 1–30) and this necessitates an ongoing evaluation of the evidence. Second, previous reviews of educational games have been criticized for 'lumping' all types of games together in an overly simplistic way (Dubé & Keenan, 2016). Diversity of experience and activity is a fundamental aspect of games and Young et al., 2012 argue that an educational game's effectiveness is strongly influenced by the type of game and its 'fit' with the academic subject being taught. Games are not all the same, this difference may matter, and the present study uses this position to guide a more nuanced investigation of math game effectiveness.

2. Literature review

2.1. *Pedagogical approaches in math games*

Well-designed math games that provide multi-level interactions involving behavioural, cognitive and affective engagement may increase children's interest in and competence for math (Frenzel, Goetz, Pekrun, & Watt., 2010; McEwen & Dubé, 2015; 2016). However, there are many different kinds of educational games with various features and pedagogical foundations, and it is critical to understand which types of math games are more likely to develop and support math knowledge (Clark et al., 2016; Kebritchi & Hirumi, 2008; Dubé et al., 2019a). In the past, studying and grouping all games into a single category has led to mixed results in the games and learning research field (Fabian et al., 2016). Previous studies have investigated the pedagogical practices surrounding the use of educational games by teachers (Kangas et al., 2017). In contrast, few studies have applied a content analysis to the games themselves to determine the pedagogical foundations of the game (e.g., Johnston, Olivas, Steele, Smith, & Bailey, 2018; Kebritchi & Hirumi, 2008). These studies argue that pedagogical classification of educational games is becoming a more common approach for the process of searching, browsing, and categorizing of educational game in game repositories.

Previous literature reviews and meta-analyses have focused on exploring the learning theories (Wu, Chiou, Kao, Hu, & Huang, 2012; Wu, Hsiao, Wu, Lin, & Huang, 2012) or pedagogical foundations (Kebritchi & Hirumi, 2008) of game-based learning. Wu et al.'s (2012) meta-analysis found that only 14% of articles discussed a pedagogical approach. However, they also indicated that the percentage was growing—arguing the use of games with a theoretical or pedagogical perspective has been more common in articles published in the twenty-first century than earlier. Also, a few systematic reviews have focused on identifying the learning theories or pedagogical approaches that may be applied to educational games (Kiili, 2005; Wu, Hsiao, et al., 2012). According to Kebritchi and Hirumi's (2008) review, developers use five main pedagogical foundations in their games, including behaviourism (e.g., in Destination Math stimulus-response conditioning was expected to the eliminate wrong answers to mathematical questions), experiential learning (e.g., the game Biohazard simulated medical emergencies), discovery learning (e.g., the game Gamenomics allowed the player to explore the process of marketing), situated cognition (e.g., in simSchool for classroom management), and constructivism (e.g., in SuperCharged for teaching electromagnetism). This classification system provides valuable insight into how learning theories can serve as a framework for understanding and evaluating different types of educational games.

We argue this classification approach is valid/useful and that a tool/game can be ascribed to a particular approach. This occurs because games are not just a tool, they are an activity. One that has specific rules for how the player's actions are governed (what they can and cannot do) and these rules are represented in a game's mechanics (the moment-to-moment activities of the player). Dubé and Keenan (2016) argue that games teach via their mechanics through a process of procedural rhetoric; by limiting player actions to specific sets of behaviors, the game makes the player interact with the game world and subject of the game in a specific way. For educational games, a game's mechanics are limiting how a player interacts with the subject and this creates a framing of the central academic concept. To be more specific, a math game that demands a player produce answers in a mad-minute like activity is framing math in a similar way as a teacher who gives mad-minute activities to their students. As a result of this, games contain specific activities, and these activities are framings or pedagogical approaches for the player to interact with and understand the academic subject.

Currently, it is unclear whether the same content (e.g., fractions) can be learned more effectively via one approach over another in math (e.g., fractions via a drill and practice approach versus fractions via a discovery-based approach, Amory, Naicker, Vincent, & Adams, 1999). The relation between a games' pedagogical foundation and its ability to improve a specific learning outcome must be assessed to understand and identify which game types are better suited to teach different mathematics content (Kiili, 2005). The insights gained from comparing games based on their pedagogical foundations could allow educators to make informed choices and preliminary decisions before purchasing or committing to using specific games in their classrooms (Dubé et al., 2020). So such a comparison can be done, a way to classify mathematics content is needed.

2.2. *Types of mathematical knowledge in educational games*

Research from the field of mathematical cognition has made progress in identifying a specific set of math skills that are related to success in mathematics (Bisanz & LeFevre, 1990; LeFevre et al., 2010; Rittle-Johnson, Schneider, & Star, 2015). The mental processes that underlie the acquisition of mathematical knowledge are generally categorized in terms of the conceptual complexity involved in different types of mathematical performance and problem-solving. According to Bisanz and LeFevre (1990), understanding the relations among math problems is critical to the development of children's mathematical skills and represents a high level of complexity. Therefore, they distinguish three types of knowledge that play an essential role in mathematics learning: these can be categorized as factual, procedural, and conceptual knowledge that fall along a continuum of basic or fundamental processes to complex cognitive processes, respectively.

At the most basic level of cognitive complexity, *factual knowledge* is information that is memorized about solutions to mathematics problems (e.g., learning the timetables). Such knowledge is declarative in that it is information that we retrieve from our memory with immediate recall (Bisanz & LeFevre, 1990; Miller & Hudson, 2007). Factual knowledge tasks do not require active or external interaction, but rather the absorption of information via repeating the task as many times as possible. At a more complex level of math learning, procedural knowledge involves mental activities, or sequences of operations, to accomplish a goal and solve a problem that can be stored in memory (Rittle-Johnson, Siegler, & Alibali, 2001). In other words, procedural knowledge is used to describe the acquisition and representation of cognitive operations which can be used to facilitate skilled behaviour in the absence of factual knowledge. Pure *procedural knowledge* involves memorizing operations with little understanding of the underlying meaning. For example, the addition of two numbers may be recalled from memory or solved by mental arithmetic procedures acquired by a student. Further, at a higher level of cognitive complexity, *conceptual knowledge* is defined as an implicit and explicit understanding of the principles of a domain that may be generalizable to new problems (Rittle-Johnson et al., 2001). Conceptual knowledge also refers to knowledge of concepts, which are abstract and general principles such as cardinality and numeric magnitude (Rittle-Johnson et al., 2001; 2017) Conceptual knowledge, which can be characterized as deep learning, is about having a fundamental understanding of mathematics that can be applied to novel problems (Bisanz & LeFevre, 1990). Baroody, Feil, and Johnson (2007) argue that conceptual knowledge also entails understanding and interpreting mathematical concepts and the relations between concepts. For example, solving the problem of which fraction is larger than another requires the application of conceptual knowledge relating to relative magnitude (Rittle-Johnson et al., 2001).

Historically, the primary focus of traditional mathematical teaching was on factual and procedural knowledge, such as teaching the body of mathematical knowledge using routines and procedures without connections (Ellis & Berry, 2005). This approach is problematic in that children often showed poor success in later mathematics. Currently, researchers argue that being successful in mathematics requires acquisition of conceptual knowledge, in addition to procedural and factual knowledge (Baroody et al., 2007; Crooks & Alibali, 2014; Rittle-Johnson, 2017), because all three types lead to more flexible problem solving and renders content generalizable to novel situations (Robinson, Osano, & Kotsopoulos, 2019). Further, research on the sequencing of math knowledge development suggest that the causal relations between knowledge types are bidirectional and that all three types develop iteratively with improvements in one type of knowledge supporting improvements in the other type (Rittle-Johnson et al., 2001; 2015). For example, in previous research, prior conceptual knowledge predicted gains in procedural knowledge after the intervention and then in turn predicted gain in conceptual knowledge (Rittle-Johnson et al., 2001). Evidence also suggests that conceptual and procedural knowledge contributes to the development of procedural flexibility (Schneider et al., 2011; Rittle-Johnson 2017). Given the vast usage of games in math teaching and learning, it is essential to understand how educational math games support the developing math knowledge types of children. While it is useful to distinguish mathematical knowledge types; it is necessary to develop all math knowledge types in order to be competent in mathematics.

From the viewpoint of mathematical cognition research, educational math games can be considered effective in the extent to which they develop and facilitate the acquisition of different types of math knowledge. However, games are not all the same and, this difference may matter. Young et al., 2012 argue that an educational game's effectiveness is strongly influenced by the type of game type and its 'fit' with the academic subject being taught. It is possible that various game types may have the differential effects on children' mathematical knowledge development. While studies have examined the ability of games to teach or support math learning overall (Lee et al., 2019), research has not looked at how game types contribute to these three foundational types of mathematical knowledge. Thus, to enhance game-based learning, it is essential to understand the critical relationship between the pedagogical foundations of games and the math knowledge types they aim to improve to understand which instructional events integrated within games have the greatest effect on different math learning outcomes.

3. Purpose

The purpose of this study is to systematically identify, categorize, and compare mathematical game studies to examine whether the different pedagogical approaches found in games (i.e., direct instruction, experiential, discovery learning, situated cognition, constructivist) facilitate different types of mathematical knowledge (i.e., factual, procedural, conceptual) and how effective it is. This will yield valuable information for game designers but also help educators find games that align with their instructional goals. To achieve this, we conducted a systematic review of math game research, classified studies by pedagogical approach and knowledge type, and then compared studies using effect sizes. The following research questions guided the investigation:

1. Which pedagogical approaches are used in mathematics games to support mathematical learning?
2. Which types of mathematics knowledge are promoted by mathematics games?
3. How effective is each pedagogical approach at improving each knowledge type?

4. Method

4.1. Data identification

To address the research questions, a systematic literature search strategy was conducted using various educational reference databases (e.g., PsycINFO, ERIC, Web of Science and SCOPUS). The search process included combinations of the following three primary sets of keywords: a) key words related to game, including "educational game*", "serious game*", "digital game*", "mobile game*", "tablet* game*", "educational app*", "digital app*", "mobile app*" and "learning app*"; b) keywords related to math, including "mathematic*", "math* education", "math* performance", "math achievement" and "math ability"; c) key words related to school aged children, including "kindergarten", "preschool", "elementary school", "primary school" and "K-12". Also, snowballing, forward citing techniques and searches for other articles of interest cited in the papers were also applied to add empirical studies in order to produce a comprehensive data pool. The present systematic review involved math computer games, digital math game or mobile math game studies published in the years 2010–2020. The initial search resulted in 713 articles. Duplicates were removed, and 627 article remained.

4.2. Data screening and selection criteria

In the first round of screening, the abstracts and titles were screened against the pre-determined exclusion criteria such that studies were not included a) if they were published in non-peer reviewed and irrelevant journals (e.g., International Journal of Engineering Education), b) were non-English articles, c) were in the form of dissertation/conference proceedings or annotated bibliography, or d) the participants were non K-12 (such as university students) or were students with special needs. Following exclusion, 238 articles were identified as potentially appropriate. Full-text versions of the remaining 238 studies were retrieved for the next second round of screening.

In the second round, full-text studies were retrieved and further filtered based on the following strict pre-determined inclusion criteria: a) include math learning or achievement related outcomes; b) employed at least one comparison of game versus nongame condition, with studies including more than one game versus nongame condition analyzed as separate individual groups (e.g., Beserra, Nussbaum & Grass. 2017); c) include a sufficient description, explanation or visual content of the game as to determine the pedagogical approaches inherent to the games; d) provide detailed descriptions of the math outcome measures or the math learning goal of the researcher's intention using games as to identify the type of math knowledge being assessed (i.e., factual, procedural, conceptual); and e) report sufficient descriptive data (e.g., pre-post results, group means, standard deviations, *t*-test or F, etc.) to compute the effect size. Due to the strict screening criteria, only 26 studies were selected for analysis after applying all exclusion and inclusion criteria from the 238 articles. (see Appendix A for flow diagram for search characteristics).

4.3. Coding procedure (categorization)

4.3.1. Pedagogical approaches

A directed content analysis approach was used to categorize games in the selected studies based on existing theoretical frameworks from the literature. The directed content analysis approach, used in the present study, is a structured research tool to guide the classification of games by determining the presence of words, concepts, or themes within given data (i.e., text or visual) (Mayring, 2004). Accordingly, researchers can quantify and analyze the presence, meanings and relationships of such certain words, concepts, or themes in research studies (Hsieh & Shannon, 2005; Johnston et al., 2018). The purpose of using a directed content analysis approach in this study was to identify the pedagogical foundations of games by applying the existing categories taken from a theoretically driven framework by examining game' textual and visual contents. The following steps were applied: First, definitions of direct instruction, experiential learning, discovery learning, situated cognition, constructivism, and unclassified approaches and their underlying theoretical assumptions of them were adapted from previous studies (Kebritchi & Hirumi, 2008). The unclassified category was used for content that did not align with any of the five categories. It is important that pedagogical approaches were considered as not mutually exclusive in this study. Having open and closed elements simultaneously in the game context is different from the underlying philosophy of designing game structures. (Arnab et al., 2015; Soller-Adillon, 2019). Educational games, and video games generally, are mostly designed around certain core game mechanics, as a games type is defined by its mechanics and including fundamentally different mechanics is to change the type of game being played. In the more sophisticated analysis of games, this does not apply only to the overall game experience. To be more specific, it is very unlikely to have both constructivist and direct approach applied in a particular game since their game mechanics are fundamentally different from each other due to their pedagogical approach. Grid tables were constructed to define pedagogical approaches, including operationalizations of each pedagogical approach, a list of keywords, concepts as well as key principles aligned with each pedagogical approach. Similar word groups such as “explore” and “exploration” or “real-word” and “real-life” would be considered together under experiential learning theory (see Table 1). In order to build shared understanding, clarifying and developing the definitions and keywords procedure was checked and re-evaluated through constant comparisons. Next, text-based descriptions of the games from the selected studies were initially searched to find explicitly mentioned pedagogical approaches by the researchers. In cases where the pedagogical approach was not explicitly mentioned in these game descriptions, learning theory or pedagogical approach key words, key concepts, game features, design elements, game mechanics or play behaviour (i.e., dragging, dropping … etc.) explanations regarding the game content mentioned in the entirety of the article were used to determine the classification. Following that, a visual content analysis was also conducted by analyzing the presence or absence of some certain game features (i.e., timing feature, types of accuracy feedback, types of information tutorials or hints, the question formats-multiple choice or open ended, game narrative story). Finally, when the pedagogical approaches could not be classified in either textual or visual content, the research team searched the application on the internet and used it as a data source.

Table 1

Operationalization of pedagogical approaches found in educational games (adopted from Kebritchi and Hirumi’s framework, 2008).

Pedagogical Approach	Operationalization and Key Principles	Sample Key Words/Concepts
Direct Instruction/ Drill & Practice	Learning is linked with stimulus-response conditioning, rapid-pace drills, or structured lesson plans that generate student engagement through pacing and immediate feedback. Learning and instruction that entails rote memorization of facts and does not necessarily facilitate creative thought. The presentation of the game follows question, answer, and feedback. Repetitive practice is offered.	drill, feedback, guided, lessons, practice, skills, stimulus-response, paced, reinforcement, reward, speed, rapid recall, repetitive.
Experiential Learning	Learning and teaching in games are based on learning by doing and solving real-life problems through experiencing and interacting with the environment. Learners gain understanding by engaging in simulated actions related to real-life experiences and learn by interacting with the objects in the game. The fundamental basis for experiential learning is the active role of the learner through interaction with the environment.	experience, explore, immerse, recognize, tour, real-life, real word, interact, interaction, exploration, experimentation.
Discovery Learning	Learning occurs as students discover concepts on their own through levels. Discovery learning builds on existing knowledge to discover new things, the learner applies inquiry-based reasoning, performs problem solving, makes the decision, and applies strategy. Students interact with game by exploring and manipulating objects or performing experiments.	apply, build, decision-making, develop, discover, problem-solving, manipulate, strategy.
Situated cognition	Learning is a product of engaging in contexts, activities and culture such that learning occurs in real situations. Students work on exercises or activities that relate to their social and cultural backgrounds. The game allows and encourages students to learn by interacting with others. Situated cognition can occur within game-based learning when learners access the context-specific knowledge by observing and becoming actors within games.	coaching, communicate, contextual, cooperative, social interaction, models, mentoring, observation, role-play, context specific, epistemic.
Constructivist Learning	Learners are actively engaged in their own learning such that knowledge is assumed to be constructed by learners rather than transmitted. Constructivism closely relates to experiential and discovery learning. However, it adds the construction of personal meaning by the learner as a final step.	constructs, creates, knowledge building, meaning, personal.

4.3.2. Types of math knowledge

In parallel with categorizing the pedagogical approaches, the Bisanz and LeFevre (1990) and Rittle-Johnson (2017) definition of mathematics knowledge was adapted and employed to classify games by knowledge types (see Table 2). First, the math learning outcome measures researchers used and aim to assess along with game math tasks explanations, if needed, were analyzed from the studies to identify the types of knowledge. To be clear, the math knowledge being assessed in the studies is not necessarily an indication of the math knowledge being taught in the game. Here, we are looking at the impact of a game's pedagogical approach on various math knowledge types and not on the alignment between the knowledge type targeted in the game and the type assessed by the researcher. One would hope that researchers are developing and using games in their studies where what is practiced and what is measured align. Given that many studies had more than one outcome measurement tests and those authors often identified to capture multiple math knowledge types as being targeted by the game, each math outcome measures in a study were categorized as assessing factual, procedural, or conceptual knowledge or a combination of knowledge types. In cases where standardized assessment tools or benchmark tests with lack of detail were used to assess math learning outcome, three types of knowledge used coding rule applied in the research's intentions and game math tasks descriptions as data source. This was done using descriptions and measures from the methods section and the operationalization of the knowledge types found in Table 2.

4.3.3. Effect size

Means and standard deviations (SD) were used to compute effect sizes for each study. Comprehensive Meta-Analysis Software Version 3.3.070 (CMA; Borenstein, Hedges, Higgins, & Rothstein, 2014) was used to calculate effect size estimates. Some studies had a relatively small sample size, therefore unbiased version of the standardized mean difference proposed by Hedges (1981) was chosen so that Hedges' *g* can be corrected to reduce bias (i.e., $n < 20$; Foster & Shah, 2015). Hedges' *g* was calculated by subtracting the mean of the comparison condition from that of the experimental game condition and then dividing the difference by the pooled average of the two group's standard deviations. Some studies mean and standard deviation results were not available, so Hedges' *g* was estimated from the inferential test results, such as t, F or p value (Lipsey & Wilson, 2001).

The following steps, suggested by Borenstein et al. (2014, p. 104), to calculate and combine ESs were followed.

1) The raw data extracted from studies were mostly provided either in the form of means and SDs or provided in the form of t-values, exact p values and standardized mean differences values, which enabled Hedges' *g* to be calculated in CMA. The studies included in the analyses did not have identical study designs and samples, so different formula for calculating ESs were applied such as pre-post design control group versus single experimental game study design.
2) For subgroup analysis, a study may involve different experimental game groups. For example, Beserra, Nussbaum, and Grass (2017) included two different game design interventions versus a non-game group condition (i.e., a multiple-choice math game group and a fine-grained multiple-choice game group). In such a case, these were treated as two independent groups before determining the estimated summary effect size of the study. For multiple outcome analysis, an article may contain different sub measures for the same math outcome variable, for example, Outhwaite et al. (2017; 2019) used two tests to measure math ability (i.e., math concepts and math curriculum knowledge tests). Thus, different measures in the same study were first calculated as separate effect sizes (Hedges' *g* standardized mean differences) before being combined into a single effect size representing that study (Borenstein et al., 2014).
3) After combining the ESs of all the articles, the overall weighted average ES of the present meta-analysis study were calculated. (Borenstein et al., 2014).
4) A random effects model of was used to calculate the mean effect sizes for a group of studies and the confidence interval of the overall average ES per pedagogical approach (Borenstein et al., 2014). This model assumes that the effect sizes for individual studies differs as a result of sampling error and study design (Borenstein, Hedges, Higgins, & Rothstein, 2011).
5) An important step when conducting meta-analysis is to determine the degree of homogeneity between studies. Heterogeneity tests with critical value refers to the variation in study outcomes between studies. Both Q and I statistics were used to compute heterogeneity analysis to check if the ESs were influenced by the specific variable (e.g., research design).

Table 2

Definition of math knowledge types adapted from Bisanz and LeFevre (1990) and Rittle-Johnson (2017)'s framework.

Types of Math Knowledge	Operationalization
Factual Knowledge	A game's math content or study math outcome measures which involve mostly math fact related problems such as $5 + 2$ and 3×3 in such that children answer these types of problems automatically, without thinking. Factual knowledge consists of memorized information and facts that are accessed only by retrieval, a proccess that involves relatively direct and rapid access to memory representations.
Procedural knowledge	A game's math content or study math outcome measures which encourage problem solving procedures or problem-solving strategies in such that children should not automatically retrieve the answer from memory, rather they need to do mental activities or sequence of activities when solving math problems in games. Procedural knowledge can be inferred from observation of certain physical correlates, such as the way children count their fingers, as well as solution times and accuracy (e.g., Siegler & Shrager, 1984). Also, the nature of the numeral task can require procedural knowledge (e.g., arithmetic tasks that require sequencing, such as associativity, decomposition, count-all).
Conceptual Knowledge	The purpose of the game is to encourage understanding of the underlying concepts or principles of math problems in such that children should interpret concepts and the relations between concepts while solving problems.

Table 3

Descriptive information of the selected studies and summary of the pedagogical approaches and types of math knowledges.

Pedagogical Approaches	Studies	Targeted Math subjects/concepts	Sample Size (Total)	Grade Level	Duration for game intervention groups	Math Knowledge Types		
						Factual	Procedural	Conceptual
Direct Instruction	Shin, Sutherland, Norris, and Soloway (2012)	Arithmetic Skills	41	Grade 2	5 weeks	✓	✓	
	Plass et al. (2013)	Math Fluency	58	Grade 6,7 and 8	15 min	✓		
	Foster and Shah (2015)	Numbers, Arithmetic Skills, Algebra, and geometry	19	Grade 9	3 months, two 50 min sessions per a week	✓		
	Pitchford (2015)	Number Line, Counting, Arithmetic Skills	283	Grade 1,2, and 3	8 weeks, 30–60 min per a day based on their grade level	✓		✓
	Maertens, De Smedt, Sasanguie, Elen, and Reynvoet (2016)	Number Knowledge, Number Line, and Arithmetic Skills	151	Kindergarten (5 years old)	Over 3 weeks, 6 play sessions, 10 min each session.	✓	✓	✓
	Outhwaite et al. (2017)	Numerical Operations and Mathematical Reasoning	133	Kindergarten and Grade 1 (4–7 years old)	Between 6 and 13 weeks	✓		✓
	Beserra et al. (2017)	Arithmetic Skills	83	Grade 2	4–5 weeks, 2 sessions per a week, in total 8 sessions	✓		
	O'Rourke et al. (2017)	Mental Math	236	Grade 4 and 5	Over 10 weeks, each day 20 min.	✓		
	van der Ven et al., 2017	Arithmetic Skills	103	Grade 1	5 weeks	✓		
	Outhwaite et al. (2019)	Numbers, Shape, Space, Measure, and Basic Arithmetic Skills	389	Kindergarten (4–5 years old)	12 weeks, 30 min each day	✓		✓
Experiential Learning	Kebritchi, Hirumi, and Bai (2010)	Algebra	193	Grade 9-10	18 weeks, 30 min each week.	✓	✓	✓
	Bai, Pan, Hirumi, and Kebritchi (2012)	Algebra	437	Grade 8	18 weeks			✓
	Rutherford et al.	Numbers and Arithmetic Skills	13,803	Grade 2, 3, 4 & 5	More than 1 year, 45 min session and twice a week.			✓
	Bakker, van denHeuvel-Panhuizen, and Robitzsch (2015)	Arithmetic Skills: Multiplication	719	Grade 2 and 3	10 weeks	✓	✓	✓
	McLaren, Adams, Mayer, and Forlizzi (2017)	Decimals	153	Grade 6	7 sessions, each of them 45 min			✓
	Papadakis, Kalogiannakis, and Zaranis (2018)	Numbers, Addition, and Subtraction Skills	365	Kindergarten (5 years)	Over 14 weeks, 24 sessions and each of them 30 min.			✓
	Ke (2019)	Ratio and Proportional relationships, Measurements (Angle measure, area, and surface area)	61	Grade 6	6 weeks, 2 sessions per a week. Each session 50 min.		✓	✓
Discovery Learning	Van Den Heuvel-Panhuizen et al. (2013)	Algebra	253	Grade 4,5 and 6	3 weeks, 3 whole sessions.		✓	✓
	Yeh, Cheng, Chen, Liao, and Chan (2019)	Numerical Operations, Quantity and Measure, Geometry, Statistics and Probability	215	Grade 2	2 years		✓	✓
	Brezovszky et al. (2019)	Number Knowledge, Arithmetic Fluency, Pre-Algebra Knowledge	1168	Grade 4,5 and 6	Over 10 weeks	✓	✓	✓
Constructivism	Wang, Chang, Hwang, and Chen (2018)	Speed	107	Grade 6	80 min			✓
	Wiburg, Chamberlin, Valdez, Trujillo, and Stanford (2016)	Ratio, Number Systems, Fractions, and Decimals	741	Grade 5	5 weeks			✓
	Valdez, Trujillo, and Wiburg (2013)	Ratio, Proportion, Scale, and Number Line	460	Grade 6 and 7	8 weeks			✓
Unclassified Approaches	Riconscente (2013)	Fractions, Proportions, and Number Line	122	Grade 4	5-day, 20 min each day			✓
	Chang, Evans, Kim, Norton, and Samur (2015)	Fractions	306	Grade 6,7 and 8	20 min for 18 days which took over 9 weeks			✓
	Schacter et al. (2016)	Number Sense	100	Kindergarten	6 weeks, 3 days a week and each day 10 min.			✓
Total %						46%	13%	73%

6) Forest plots were generated using Forest Plot viewer to display effect size distributions and to identify outliers. Additionally, 95% confidence intervals were computed to provide measure of precision of the mean effect size estimate per study.

Effect sizes were interpreted using Cohen's guidelines of *g* w = 0.2, 0.5 and 0.8 equating to small, medium, and large effects, respectively (Cohen, 1988). Hattie (2009) also proposed that any effect size greater than d=0.4 is educationally important.

5. Results

In this study, we categorized the type of pedagogical approaches based on Kebritchi and Hirumi's (2008) theoretical framework: direct instruction/drill and practice, experiential learning, discovery learning, situated cognition, and constructivist learning. Subsequently, we categorized the studies by math knowledge type: factual, procedural, conceptual (Bisanz & LeFevre, 1990; Rittle-Johnson, 2017). Some of the pedagogical approaches used in educational math games may be better suited to teach some math knowledge types than others (i.e., factual knowledge acquisition using direct instruction games, procedural knowledge via constructivist practices). Therefore, we calculated the range of effect sizes for the game-learning interventions reported in each study based on Hedges' *g* and estimated overall effect sizes for each approach on each individual math knowledge types. The results below are organized to answer our three guiding research questions.

5.1. Which pedagogical approaches are used in mathematics games to support mathematical learning?

A total of 26 studies were included in the meta-analysis; they used games based on almost all of the Kebritchi and Hirumi's (2008) pedagogical approaches and aimed to improve all types of mathematical knowledge (see Table 3). For pedagogical approach, most studies used direct instruction ($n = 10$ or 38.40%) or experiential learning games ($n = 7$ or 26.92%), while fewer studies used discovery ($n = 3$ or11.52%) or constructivist games ($n = 3$ or 11.52%). None of the studies took a situated cognition approach but some studies had games that could not be classified ($n = 3$ or11.52%).

5.2. Which types of mathematics knowledge are promoted by mathematics games?

For math knowledge types in educational games overall, 46% (12) of studies aimed to improve factual knowledge, 23% (6) procedural knowledge, and 73% (19) conceptual knowledge, with many studies (9 or 35%) aiming to improve more than one knowledge type. Of studies that focused on just one knowledge type, 19% (5) focused solely on improving factual knowledge and 46% (12) focused solely on conceptual knowledge, but no studies focused on only procedural knowledge. Furthermore, to analyze and compare the presence of which pedagogical approaches facilitate the acquisition of factual, procedural, and conceptual knowledge, in-depth analysis for each pedagogical approach has been conducted. As can be seen in the table, the types of mathematical knowledge targeted differed alongside a game's pedagogical approach (Table 3).

Direct Instruction. Most of the papers focused on direct instruction via simple drill and practice games. Of the 10 studies, half of the games targeted only factual knowledge ($n = 5$; Plass et al., 2013; Foster & Shah, 2015; Beserra et al., 2017; O'Rourke et al., 2017 and Van der Ven et al., 2017). The other five studies targeted a combination of knowledge types, including factual and procedural knowledge ($n = 1$, Shin et al., 2012); factual and conceptual knowledge ($n = 3$; Pitchford, 2015; Outhwaite et al., 2017; 2019); and all three knowledge types ($n = 1$, Maertens et al., 2016).

Experiential Learning. Of the 26 studies, seven studies used experiential learning games in which players explored and engaged with math problems in a real-life setting. The majority (4) of games targeted only conceptual knowledge (Bai et al., 2012; Rutherford et al., 2014; McLaren et al., 2017 and Papadakis et al., 2018). The other three studies targeted multiple types, including procedural and conceptual (Ke, 2019) and all three types (Kebritchi et al., 2010; Bakker et al., 2015).

Discovery Learning. A total of three studies included discovery learning games. All of them focused on included more than one knowledge type study, while two studies focused on procedural and conceptual knowledge (Van Den Heuvel-Panhuizen et al., 2013; Yeh et al., 2019) and the remaining one study included factual, conceptual and procedural knowledge (Brezovzsky et al., 2019).

Constructivism. Three studies (Valdez et al., 2013; Wang et al., 2018; Wiburg et al., 2016) used constructivist approaches in their games. All of these studies solely targeted conceptual knowledge.

Other/Unclassified Approaches. Three studies did not fit into any of the main pedagogical approaches proposed by Kebritchi and Hirumi (2008). Two of these studies provided explicit descriptions of their pedagogical approaches. Riconscente (2013) mentioned an embodied cognition approach, whereas Schacter (2016) mentioned the Montessori approach. The remaining study (Chang et al., 2015) did not mention a pedagogical approach and did not describe the game in sufficient detail to enable classification. All three of these studies targeted conceptual knowledge.

5.3. How effective is each pedagogical approach at improving each knowledge type?

A central goal of this study is to assess how well different game types (i.e., pedagogical approach) improve different aspects of mathematics (i.e., knowledge type). Therefore, we computed effect sizes for each game and knowledge type separately (cf., calculating an overall average effect size for each study). The following section provides the summary effect sizes by pedagogical approach and knowledge type. A detailed reporting of the effects for each individual study are in Appendix B.

Direct Instruction. Overall, direct instruction games have a medium sized effect on mathematical learning ($n = 10$; $g = 0.510$, 95%

CI [0.25, 0.77], $p < 0.001$, See Fig. 1). For the individual learning outcomes, effects ranged from negative (Symbolic Number Line Estimation $g = -1.069$; Maertens et al., 2016) to positive (Math Curriculum Knowledge $g = 1.945$; Outhwaite et al., 2017; see Appendix B). For each knowledge type (see Table 4), direct instruction games show a medium effect on factual knowledge ($n = 5$; $g = 0.58$), a medium effect on the combination of factual and conceptual ($n = 3$; $g = 0.574$), a small but non-significant effect on the combination of factual and procedural ($n = 1$; $g = 0.278$), and a small non-significant effect on the combination of factual, procedural and conceptual knowledge ($n = 1$; $g = 0.05$, see Table 4). Thus, direct instruction games improve factual knowledge acquisition as well as the combination of factual and conceptual knowledge significantly more than other knowledge types (See Table 4.)

Experiential Learning. Overall, experiential learning games have a medium effect on mathematical learning ($n = 7$; $g = 0.46$, 95% CI [0.22, 0.70], $p < 0.001$, See Fig. 2). For the individual learning outcomes, effects ranged from small (Multiplicative Problem-Solving $g = 0.000$; Bakker et al., 2015) to large (Problem Solving Skills $g = 0.98$; Ke, 2019; see Appendix B). For each knowledge type, experiential learning games show a small to medium effect on conceptual knowledge ($n = 4$; $g = 0.47$), a medium to large effect on the combination of procedural and conceptual knowledge ($n = 1$; $g = 0.67$), and a small to medium effect on the combination of factual, procedural and conceptual knowledge ($n = 2$; $g = 0.67$) (see Table 4). Hence, the greatest effect is seen in experiential games that are facilitating the combination of procedural and conceptual knowledge.

Discovery Learning. Overall, discovery learning games have a small sized effect on overall mathematical learning ($n = 3$; $g = 0.236$, 95% CI [0.012, 0.46], $p < 0.001$, See Fig. 3). For the individual learning outcomes, effects ranged from negative (Pre-Algebra Knowledge $g = -0.599$; Brezovszky et al., 2019) to positive (Algebra $g = 0.544$; Van den Heuvel-Panhuizen et al., 2013; see Appendix B). For knowledge type, discovery learning games show a small effect but non-significant on the combination of factual, conceptual and procedural knowledge ($n = 1$; $g = 0.057$), and a small to medium effect on the combination of procedural and conceptual knowledge ($n = 2$; $g = 0.35$). Results suggested that discovery used games facilitating procedural and conceptual knowledge acquisition significantly more than other knowledge types (See Table 4).

Constructivism. Overall, constructivist learning games targeted conceptual knowledge and produced small effects ($n = 3$; $g = 0.208$, 95% CI [0.02, 0.39], $p < 0.001$, See Fig. 4 and Table 4). For the individual learning outcomes, effects ranged from $g = 0.049$ (Number Line, Ratio, and Proportion Concepts; Valdez et al., 2013) to $g = 0.35$ (Knowledge of Speed Concept; Wang et al., 2018; see Appendix B).

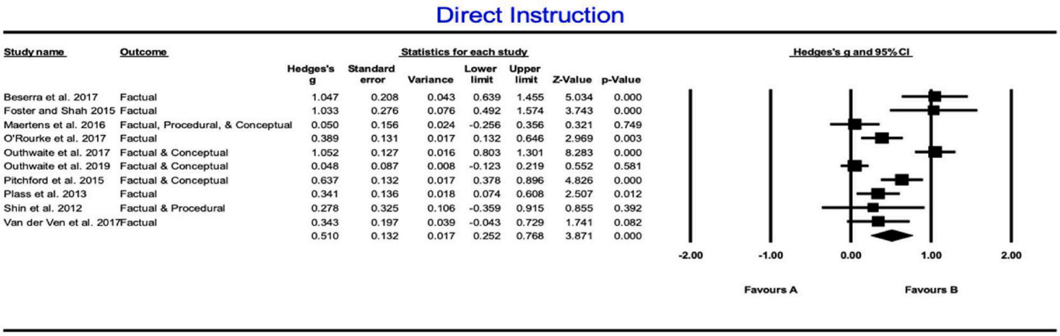
Unclassified Approaches. Games with unclassified or other approaches used various pedagogical approaches but all of them targeted conceptual knowledge. For the individual learning outcomes, effects ranged from small (Math Proficiency $g = 0.056$; Chang et al., 2015; see Fig. 5) to larger (Number Sense $g = 0.74$; Schacter et al., 2016; see Appendix B). Riconscente's (2013) embodied cognition game produced a small but non-significant effect ($g = 0.20$). Chang et al. (2015) used an approach that was not clear and also showed a small effect ($g = 0.32$). In contrast, Schacter et al., 2016 Montessori approach had a large effect ($g = 0.74$). Overall, other/unclassified approaches produced mixed results facilitating conceptual knowledge.

6. Discussion

6.1. R1. Which pedagogical approaches are used in mathematics games to support mathematical learning?

Overall, only 23 out of 26 studies used games based on a clear pedagogical approach. In contrast to Kebritchi and Hirumi's (2008) study, the direct instructional approach was the most common. Direct instruction entails traditional learning and teaching methods where students are exposed to drill and practice routines that include rote memorization of facts and are criticized for not facilitating creativity (Deen, Van den Beemt, & Schouten, 2015). It is not surprising that direct instruction was so common because it is well suited to the design of math games and may be more straightforward to implement for researchers and developers (McEwen & Dubé, 2016).

Direct instruction does not have to be bland or consists purely of rote memorization of facts or procedures; when it also includes opportunities for learners to practice newly learned concepts, apply procedural skills, and problem solve, it can be engaging and effective. In fact, most games can be defined as the repeated enactment of a simple behaviour in service of a goal (i.e., chess involves moving pieces in set routines, Dubé & Keenan, 2016) and they produce high levels of engagement. Previous research shows direct



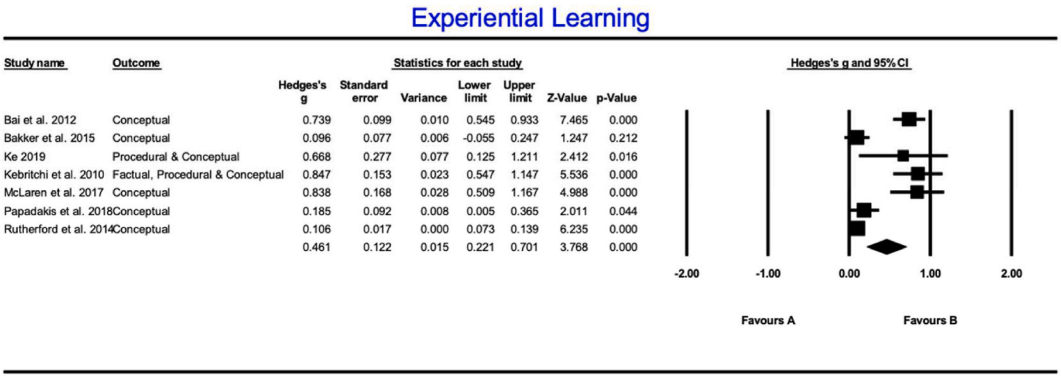
Direct Instruction

Study name	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
Beserra et al. 2017	Factual	1.047	0.208	0.043	0.639	1.455	5.034	0.000
Foster and Shah 2015	Factual	1.033	0.276	0.076	0.492	1.574	3.743	0.000
Maertens et al. 2016	Factual, Procedural, & Conceptual	0.050	0.156	0.024	-0.256	0.356	0.321	0.749
O'Rourke et al. 2017	Factual	0.389	0.131	0.017	0.132	0.646	2.969	0.003
Outhwaite et al. 2017	Factual & Conceptual	1.052	0.127	0.016	0.803	1.301	8.283	0.000
Outhwaite et al. 2019	Factual & Conceptual	0.048	0.087	0.008	-0.123	0.219	0.552	0.581
Pitchford et al. 2015	Factual & Conceptual	0.637	0.132	0.017	0.378	0.896	4.826	0.000
Plass et al. 2013	Factual	0.341	0.136	0.018	0.074	0.608	2.507	0.012
Shin et al. 2012	Factual & Procedural	0.278	0.325	0.106	-0.359	0.915	0.855	0.392
Van der Ven et al. 2017	Factual	0.343	0.197	0.039	-0.043	0.729	1.741	0.082
		0.510	0.132	0.017	0.252	0.768	3.871	0.000

Fig. 1. Effect sizes, statistics and forest plot of direct instruction.

Table 4
Effect sizes, heterogeneity statistics by math knowledge type and pedagogical approach, based on a random model.

Pedagogical Approaches	Types of Math Knowledge	Ns	*g*	95% CI	*p*	I^2%	*Q*
Direct Instruction	Factual	5	0.58	[.30,.87]	0.000	70.042	13.352
	Factual & Procedural	1	0.28	[-.0.36,0.91]	0.39	0.000	0.000
	Factual & Conceptual	3	0.57	[-0.04,1.19]	0.068	95.592	45.372
	Factual, Procedural, & Conceptual	1	0.05	[-0.26,.36]	0.750	0.000	0.000
Experiential Learning	Conceptual	4	0.47	[0.12,.79]	0.011	94.821	57.921
	Procedural & Conceptual	1	0.67	[0.12,1.21]	0.016	0.000	0.000
	Factual, Procedural, & Conceptual	2	0.46	[-0.28,1.12]	0.220	94.798	19.224
Discovery Learning	Factual, Procedural, and Conceptual	1	0.057	[-0.06,0.17]	0.33	0.000	0.000
	Procedural & Conceptual	2	0.355	[0.003,0.47]	0.000	0.000	0.000
Constructivism	Conceptual	3	0.208	[0.02,0.39]	0.026	55.322	4.477
Unclassified/Other	Conceptual	3	0.443	[0.1,0.79]	0.01	9.935	79.870

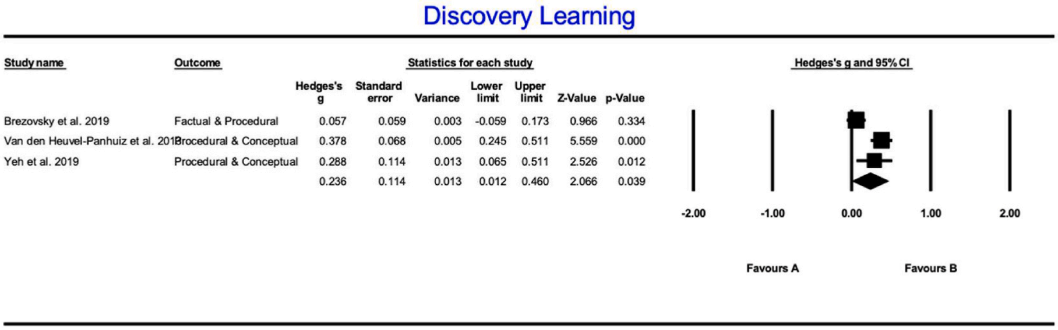

Experiential Learning

Study name	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Bai et al. 2012	Conceptual	0.739	0.099	0.010	0.545	0.933	7.465	0.000
Bakker et al. 2015	Conceptual	0.096	0.077	0.006	-0.055	0.247	1.247	0.212
Ke 2019	Procedural & Conceptual	0.668	0.277	0.077	0.125	1.211	2.412	0.016
Kebritchi et al. 2010	Factual, Procedural & Conceptual	0.847	0.153	0.023	0.547	1.147	5.536	0.000
McLaren et al. 2017	Conceptual	0.838	0.168	0.028	0.509	1.167	4.988	0.000
Papadakis et al. 2018	Conceptual	0.185	0.092	0.008	0.005	0.365	2.011	0.044
Rutherford et al. 2014	Conceptual	0.106	0.017	0.000	0.073	0.139	6.235	0.000
		0.461	0.122	0.015	0.221	0.701	3.768	0.000

Fig. 2. Effect sizes, statistics and forest plot of experiential learning.

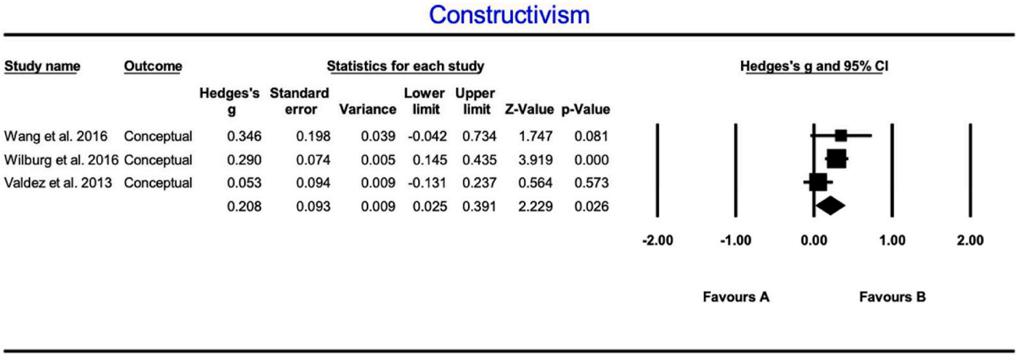
instruction that prompts learners to self-explain their process can improve learning and transfer (Rittle-Johnson, 2006). The present results demonstrate how direct instruction via game-based learning also produce positive learning outcomes, without the need for self-explanation. Interestingly, our findings also suggest that more learner-centered approaches are still underrepresented in math games. In contrast to direct instruction, discovery and constructivism approaches were rarely used and the situated cognition approach was never used. This indicates a lack of math game experiences where the learner explores, experiences, questions, or constructs meaning within an enriched environment.

Thus, math game researchers need to study a greater variety of games and approaches. In fact, several studies in our analysis used the same game in different contexts (e.g., Pitchford, 2015; Outhwaite et al., 2017 & 2019: *Onebillion* app; Bai et al., 2012; Foster & Shah, 2015; Kebritchi et al., 2010: DimensionM). This likely result from researchers selecting a game 'proven' to be effective and then used to further study other aspects of game-based learning (e.g., gender effects, instructional support). Even though our results suggests that games with different pedagogical approaches produce unique patterns of math learning outcomes, more studies are needed. Future studies should focus on how to address this gap and incorporate a broader variety of games into empirical research, not just a few select games that are already proven to work.


Discovery Learning

Study name	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Brezovsky et al. 2019	Factual & Procedural	0.057	0.059	0.003	-0.059	0.173	0.966	0.334
Van den Heuvel-Panhuiz et al. 201	Procedural & Conceptual	0.378	0.068	0.005	0.245	0.511	5.559	0.000
Yeh et al. 2019	Procedural & Conceptual	0.288	0.114	0.013	0.065	0.511	2.526	0.012
		0.236	0.114	0.013	0.012	0.460	2.066	0.039

Fig. 3. Effect sizes, statistics and forest plot of discovery learning.



Constructivism

Study name	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Wang et al. 2016	Conceptual	0.346	0.198	0.039	-0.042	0.734	1.747	0.081
Wilburg et al. 2016	Conceptual	0.290	0.074	0.005	0.145	0.435	3.919	0.000
Valdez et al. 2013	Conceptual	0.053	0.094	0.009	-0.131	0.237	0.564	0.573
		0.208	0.093	0.009	0.025	0.391	2.229	0.026

Fig. 4. Effect sizes, statistics and forest plot of constructivism.

6.2. R2. Which types of mathematics knowledge are promoted by mathematics games?

In the present analysis, the math learning goal of the researcher' using games and math outcome measures were used to classify studies by math knowledge type. This was done because most studies failed to explain the knowledge types targeted in their studies or the measures' explanations were not adequate for classification. Despite working with an established theoretical model, it was difficult to differentiate the types of knowledge that each researcher was meant to target in their explanations as well as the outcome measures that are used to assess math learning. This is a problem common to mathematical cognition research (Crooks & Alibali, 2014). Further, several studies used standardized math tests which are not easily classified by knowledge types. For example, Although Kebritchi et al. (2010) explicitly mentioned the pedagogical approaches used in their game, the authors used standardized tests to assess overall math learning. To provide a clear direction for interpreting the significance and application of findings, it is important for researchers studying educational games to clarify the assumptions that underlie their game interventions as well as the specific knowledge type being targeted. Thus, researchers should choose assessments based on specific learning goals and report on them. It is not enough to know that 'math games work'; we must know how well they work for teaching different types of mathematics.

To this end, our findings show promoting only procedural knowledge was rarely focused on whereas conceptual knowledge was used far more frequently by researchers as an outcome measure that represents students' math ability. Further, many studies measured multiple knowledge types. This in itself suggests a significant preference for games to improve students' understanding of mathematical concepts more broadly instead of focusing on just practicing mathematics facts. This aligns with current best practices in the field that argue successful learning in math requires acquisition of all knowledge types (Baroody et al., 2007; Crooks & Alibali, 2014). Games targeting multiple knowledge types can be seen to support the iterative model of mathematical learning (Rittle-Johnson & Siegler, 1998; Rittle-Johnson et al., 2001), where learners actively move between building conceptual and procedural knowledge. Though a focus on improving multiple knowledge types is important, it is also critical to understand how effective each pedagogical approach is at promoting the different knowledge types.

6.3. R3. How effective is each pedagogical approach at improving each knowledge type?

The current meta-analysis is the first to evaluating the effectiveness of math games with respect to their pedagogical approach and target knowledge type. Although educational games appear to facilitate greater engagement and liking of math (Fabian et al., 2016), analysis of effect sizes in the present study indicates the impact on math performance is rather variable. Overall, the effect sizes of each approach can be organized as: Unclassified approaches (Almost large effect size[1]) > Direct Instruction (Medium effect size) > Experiential Learning (Medium effect size) > Discovery Learning (Small effect size) > Constructivism (Small effect size).

Kebritchi and Hirumi's (2008) previous qualitative study of 24 educational games targeting multiple academic subjects concluded that games with learner-centered approaches are more effective and attractive to learners than games with basic drill and practice approaches. This contrasts with the results from our meta-analysis of 26 studies that suggest the direct instruction approach has the largest effect compared to other theory-driven approaches. This difference may be due to our focus on math and the frequent use of direct instructional approach in math games. Moreover, it may be because two studies used the same game, and this somewhat inflated the overall effect size for the direct instructional approach (Outhwaite et al., 2017; 2019). Regardless, evaluating studies focused on a specific academic subject using effect sizes rather than a qualitative interpretation of effectiveness including games from all subject areas paints a very different picture and highlights the importance of moving beyond making general conclusions on the effectiveness of educational math games overall.

This picture is further clarified when looking at the effect of each pedagogical approach on each knowledge types. The direct instructional approach was most often used to target factual knowledge and resulted in an overall medium sized effect. This may reflect researcher's preference for math games that focuses on mastery of basic concepts in one domain before students learn more advanced

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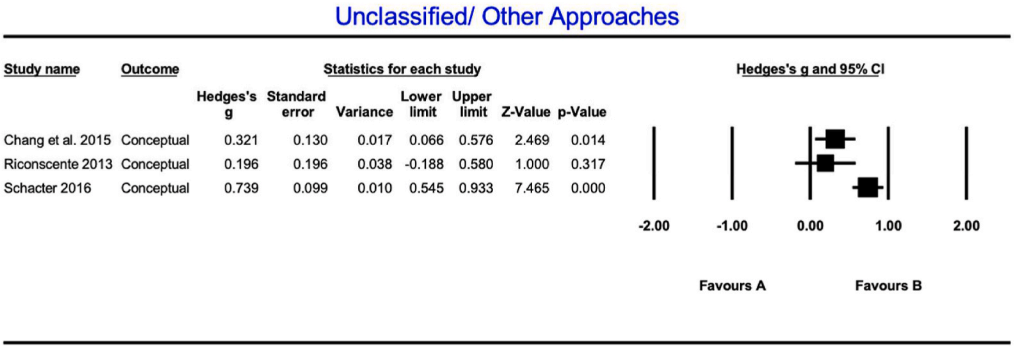
[1] This is not established learning theory or pedagogical approach.



Unclassified/ Other Approaches

Study name	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Chang et al. 2015	Conceptual	0.321	0.130	0.017	0.066	0.576	2.469	0.014
Riconscente 2013	Conceptual	0.196	0.196	0.038	-0.188	0.580	1.000	0.317
Schacter 2016	Conceptual	0.739	0.099	0.010	0.545	0.933	7.465	0.000

Fig. 5. Effect sizes, statistics and forest plot of unclassified/other approaches.

concepts (e.g. Plass et al., 2013). In contrast, procedural and conceptual knowledge were more often facilitated by games using experiential learning, discovery, and constructivist approaches but with mixed effect sizes.

Experiential learning games produced medium effects on procedural and conceptual knowledge together, a large effect on all three knowledge types together, and a small effect when specifically targeting conceptual knowledge. For example, McLaren et al. (2017) used an experiential learning game -Decimal Point-to help middle school students learn decimals concepts via confronting their decimal misconceptions. The simplicity of the game's design, the uncomplicated game mechanics, the straightforward narrative, the lack of competition, and spaced game play were identified by the authors as reasons why the game intervention so outperformed the control group ($g = .83$). In contrast, Bakker et al. (2015), Rutherford et al. (2014) and Papadakis et al. (2018) found either non-significant effects ($g = 0.09$) or small effects ($g = 0.10, 0.18$) of their experiential games on conceptual knowledge. Experiential learning requires real world concepts or examples with associated learning activities and active involvement of learners (Dewey, 1938; Kolb, 1984, Kebricthi & Hirumi, 2008). Applying this approach to target conceptual knowledge alone may be difficult, in part, because conceptual knowledge is inherently "abstract" and there is no clear connection between the concept and real world activities that can be easily substantiated in the game (Ormrod, 1995; Conole, Dyke, Oliver, & Seale, 2004).

Similarly, discovery learning games showed a small effect on improving procedural and conceptual knowledge together while constructivist games had a small effect on improving conceptual knowledge alone. Again, these smaller effects could be explained by the difficulty in substantiating a math concept into gameplay that is to be discovered freely by the player or is connecting to the player's existing understanding of the concept. This is not to say that small effects on conceptual knowledge are not meaningful. In fact, even small improvements on foundational concepts may lead to iterative developments in mathematical knowledge overall (Rittle-Johnson et al., 2001). Future studies could investigate whether the relatively small improvements to conceptual knowledge provided by experiential, discovery, and constructivists games lead to greater subsequent iterative development than the large improvements to factual knowledge provided by direction instruction games. In essence, what matters more; a large effect on isolated factual knowledge now or a smaller effect on connected procedural and conceptual knowledge that grows over time?

7. Limitations

The present study has limitations, and some could be improved on in future works. First, although the studies included in this meta-analysis provide evidence that pedagogical approaches inherent in games influence different math learning outcomes, findings of the study were limited by the small number articles suitable for review. As a result, it was not possible to estimate the average effect of each pedagogical approach on all individual math knowledge types and we could not account for the impact of research design, grade levels, or other possible moderators (i.e., game duration). As more and more game-based studies are being conducted (Dubé & Wen, 2021, pp. 1–30), future reviews will be able to continue this work and address this issue. Second, many studies did not provide clear information on their game's pedagogical approach or on the math learning outcomes they intended to measure. This meant interpretation played a role, through directed content analysis, especially for overlapping pedagogical approaches (experiential learning vs discovery learning vs constructivism). The presence of interpretation in meta-analysis is a common critique of the approach (see Stegenga, 2011), which is often presented as being entirely objective. Similarly, the computation, interpretation, and use of effect sizes in meta-analysis is subject to debate; the most common critiques being that reliance on effect sizes privileges quantifiable data over multi-modal data not amendable to the approach and that it oversimplifies differences amongst studies being compared (see Holman, 2018 for an in-depth review of the critiques). Thus, meta-analysis is but one source of information that can be used to help guide future work and understanding; it should not be framed as superior or purely objective. Fourth, the results indicate that outcomes for specific games varied across studies. This could be attributable to differences among students, or it could be due to differences in how the game was deployed in the classroom. Teachers are not a neutral agent in game-based learning and how they support students use of a math game may affect its utility; perhaps even moderating the pedagogical approach found in the game (e.g., teachers providing reflection prompts during a direct instruction game). Future works will have to consider how teacher supports moderate the effectiveness of the various math game types.

8. Future directions

In a time where math performance by 15-years old students in many western nations is relatively weak compared to several Asian countries (OECD, 2020); educational games are often seen as a viable and effective approach to facilitate student engagement with math learning and enhance performance (Fabian et al., 2016). Future research on educational games would appear to be a timely endeavour; specifically work done that enhances knowledge on the use of experiential, discovery-based, constructivist, and situated cognition games to cultivating different types of mathematical knowledge. Findings from this study also suggest the impact of games on math performance depends on the knowledge type being targeted. This addresses a gap in the literature caused by too few studies looking at how games improve math (Lee et al., 2019) and most previous studies only looking at overall math outcomes (cf., specific math outcomes). Learning, however, is not exclusively about cognitive processes and academic outcomes. How different math game types promote learner motivation, interest, and engagement may also be important, as either moderators or outcomes in themselves (Deci, Koestner, & Ryan, 2001; Hidi, 2006). Future studies should include these other moderators that may also impact game-based math learning.

CRediT author statement

Gulsah Kacmaz: Conceptualization, Methodology, Formal Analyses, Investigation, Writing-Original Draft Preparation Adam K. Dubé: Conceptualization, Validation, Writing -Review, Editing, Supervision.

Disclosure of potential conflicts of interest

There is no potential conflict of interest in the work being described here.

Research involving human participants and/or animals

No ethical approval was required as there were no human participants and/or animals involved.

Informed consent

Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.edurev.2021.100428.

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