Leveraging Technology and Pedagogy: A Multi-Study Examination of Technology, Pedagogy and Teacher Factors in Game-Based Learning Environments

Gulsah Kacmaz

Ph.D. in Educational Psychology

Department of Educational and Counselling Psychology

McGill University

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Abstract

The integration of digital games into education has seen a marked increase in recent years, with a national survey indicating that more than half of K-8 teachers in the US use games in their weekly lessons. Despite its popularity, the effectiveness of this approach remains a matter of debate, with questions surrounding which factors contribute to its success. The quality and types of games, as well as the way in which teachers integrate games into their lessons, are the main factors that affect the effectiveness of game-based learning. These factors have been separately explored in previous studies, while others are still being investigated. To address this gap in the literature, three studies were conducted to provide a comprehensive examination of the various factors involved in effective game-based learning. The first study systematically reviews digital math games, evaluating them based on the pedagogical approach, type of mathematical knowledge promoted, and effect on math learning. The second study validated the Teacher Scaffolding Questionnaire during Game-Based Learning (TSQ-GBL) and examined the impact of antecedent factors. The third study explored the relationship between teachers' knowledge of games and their use of scaffolding strategies, considering the role of teaching experience. The findings from these three studies emphasize the importance of both game factors and teacher factors and can serve as a guide for educators, instructional designers, and researchers to better understand how to design and integrate games into learning environments in a way that promotes meaningful learning and enhances student outcomes.

Resumé

L'intégration des jeux vidéo dans l'éducation a connu une augmentation marquée ces dernières années, avec une enquête nationale indiquant que plus de la moitié des enseignants de la maternelle à la 8e année aux États-Unis utilisent des jeux dans leurs leçons hebdomadaires. Malgré sa popularité, l'efficacité de cette approche reste un sujet de débat, avec des questions entourant les facteurs qui contribuent à son succès. La qualité et les types de jeux, ainsi que la façon dont les enseignants intègrent les jeux dans leurs leçons, sont les principaux facteurs qui affectent l'efficacité de l'apprentissage basé sur les jeux. Ces facteurs ont été explorés séparément dans des études précédentes, tandis que d'autres sont encore en cours d'investigation. Pour combler cette lacune dans la littérature, trois études ont été menées pour fournir un examen complet des différents facteurs impliqués dans l'apprentissage efficace basé sur les jeux. La première étude examine systématiquement les jeux mathématiques numériques, les évaluant en fonction de l'approche pédagogique, du type de connaissances mathématiques promues et de l'effet sur l'apprentissage des mathématiques. La deuxième étude a validé le questionnaire d'échafaudage de l'enseignant lors de l'apprentissage basé sur les jeux (TSQ-GBL) et a examiné l'impact des facteurs antécédents. La troisième étude a exploré la relation entre la connaissance des enseignants des jeux et leur utilisation de stratégies d'échafaudage, en considérant le rôle de l'expérience d'enseignement. Les résultats de ces trois études soulignent l'importance à la fois des facteurs de jeu et des facteurs enseignants et peuvent servir de guide pour les éducateurs, les concepteurs pédagogiques et les chercheurs afin de mieux comprendre comment concevoir et intégrer des jeux dans des environnements d'apprentissage de manière à favoriser un apprentissage significatif et à améliorer les résultats des étudiants.

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Dedication

First and foremost, I would like to dedicate this dissertation to my beloved one, Leo Dogu Ekici, who taught me unconditional love. Next, I would also like to dedicate this dissertation to my advisor, Dr. Adam K. Dubé, who had faith in my success, taught me how to conduct a research project, and guided and supported me about anything and everything during my journey. I would not have achieved this milestone without your constant encouragement, constructive feedback, and unyielding support. You have played a crucial role in my academic and personal growth, and I will always be indebted to you for the profound impact you have had on my life. Finally, to the remarkable single mothers who embody resilience, determination, and strength, this thesis is dedicated to your unwavering commitment to making a difference in the world.

Contribution to Original Knowledge

My doctoral thesis makes several significant contributions to the intersection of technology and pedagogy in the context of game-based learning environments. Specifically, the research presented in this thesis contributes to our understanding of how technology can be leveraged to enhance teachers' pedagogical practices and how teachers' knowledge and pedagogical practices can support students' learning in game-based learning environments.

This thesis makes an original contribution to educational research by conducting a systematic review and meta-analysis in Chapter 3, which examines the effectiveness of different pedagogical approaches and types of mathematics knowledge in educational games. By synthesizing the findings of multiple studies from the literature, Chapter 3 aims to identify the most effective pedagogical strategies and types of mathematics knowledge that can be targeted through educational games, as well as any potential gaps and limitations in existing research related to the pedagogical foundations and types of knowledge that exist in games as factors determining its effectiveness. This facilitates a better understanding of the potential of games as an educational tool. Also, Chapter 3's contributions to original knowledge are a product of the synthesis and evaluation of a wide range of existing research on game-based learning and mathematics education, with the goal of providing insights and guidance for educators and game designers seeking to develop effective educational game interventions for math learning.

Chapter 4 further contributes to the body of knowledge by providing a validated self-report questionnaire for assessing the external scaffolds teachers provide in game-based learning environments. The study establishes the reliability and validity of the Teacher Scaffolding Questionnaire during Game-based Learning (TSQ-GBL), explores which scaffolding supports teachers provide in GBL environments, and details the relationships among teacher scaffolding usage, their use of general game-based pedagogies, and school resources available to them in their school. The study also provides insight into the scaffolding strategies that teachers use in GBL, highlighting the need for teachers to be trained in various scaffolding practices, including cognitive support, to help students navigate the game and engage in the learning process.

Finally, Chapter 5 contributes to the original knowledge in two major ways. First, it examines the relationship between teachers' technological pedagogical content knowledge for game-based learning (TPACK-G) and their use of scaffolding strategies in game-based learning environments, providing new insights into how teachers’ knowledge and confidence in using games may influence their instructional practices. Second, Chapter 5 compares the TPACK-G and TSQ-GBL of junior and senior teachers, providing a better understanding of how teaching experience may affect teachers’ knowledge of and scaffolding during game-based learning. Overall, Chapter 5 provides valuable information that could inform the development of more effective teacher training and professional development programs to support the integration of games in education.

Overall, this doctoral thesis contributes to the original knowledge in educational research by providing new insights into the intersection of technology and pedagogy in game-based learning environments. In other words, this thesis provides valuable contributions to the field of educational research by enhancing our understanding of how technology can be leveraged to support effective pedagogical practices in game-based learning environments by considering both technological and pedagogical factors.

Preface and Contribution of Authors

Three manuscripts and a literature review are presented as chapters in this doctoral thesis. I am the primary author of all manuscripts included in this dissertation. I have had a leading role in all phases of the research reported, including theoretical conceptualization, development, study design, data collection, data analysis, interpretation, and draft writing. I independently wrote the chapters, Dr. Adam K. Dubé supervised, edited, and provided feedback, and he has advised me every step of this process. The earlier version of Chapter 3 was written independently as partial fulfillment of my comprehensive exam. As such, they benefited from the input from my comprehensive exam evaluation committee, which included Dr. Susanne Lajoie and Dr. Alain Breuleux.

Chapter 3

Citation

Kacmaz, G., & Dubé, A. K. (2022). Examining pedagogical approaches and types of mathematics knowledge in educational games: A meta-analysis and critical review. *Educational Research Review*, *35*, 100428. https://doi.org/10.1016/j.edurev.2021.100428

Contributions

The publication titled "Examining Pedagogical Approaches and Types of Mathematics Knowledge in Educational Games: A Meta-analysis and Critical Review" presents the results of a systematic review and meta-analysis conducted on the relevant topic. I conducted the systematic literature review, did content and meta-analysis, and wrote this paper, and Dr. Dubé guided and assisted me in each step of these tasks. This manuscript has been published in *"Educational Research Review."* An earlier version of this paper was prepared in partial fulfilment of my comprehensive exam, for which Drs. Susanne Lajoie and Alain Breuleux provided feedback.

Chapter 4

Citation

Kacmaz, G., & Dubé, A. K. (In preparation). Comparing and Validating the Three-Measurement Models of Teacher Scaffolding Questionnaire during Game-based Learning and Relationship with its Antecedents. *Learning Environments Research.*

Contributions

This manuscript validates a self-report questionnaire for assessing external scaffolding provided by teachers in game-based learning environments. It identifies the need for a multidimensional approach to scaffolding, highlights the importance of cognitive support, and shows differential relationships between scaffolding types and other constructs. I conceptualized the study, developed the scale, did the formal analysis, and wrote the original draft. Dr. Dubé. Dr. Dubé provided funding acquisition, reviewed, edited, supervised, and gave feedback on the whole draft by offering valuable insights in each step. This manuscript is about to be submitted.

Chapter 5

Citation

Kacmaz, G., & Dubé, A. K. (In preparation). Does Teachers' Knowledge of Games Matter in Facilitating Game-based Learning? Investigating the Relationship Between Teachers' TPACK-G and TSQ-GBL. *Computers and Education.*

Contributions

This manuscript further explores the relationship between teachers' knowledge of games and their scaffolding supports usage during game-based learning. The findings were also compared between junior and senior teachers to understand whether teaching experience is a factor that influences their use of scaffolding practices. I conceptualized the research questions and the study, developed the theoretical framework, conducted the data collection and analysis, and independently wrote the draft. Dr. Adam K. Dubé supervised and provided invaluable feedback and edits on the full manuscript during this process. This manuscript is currently being prepared for submission to a journal.

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Abbreviations Used in this Thesis

Abbreviations	Expansions
GBL	Game-Based learning
TSQ-GBL	Teacher Scaffolding Questionnaire during Game-Based Learning
TPACK-G	Teachers Pedagogical, Content, and Knowledge of Games
PA-SR	Perceived Availability of School Resources
GBP-use	Game-based Pedagogies Use
GK	Game Knowledge
GCK	Game Content Knowledge
GPK	Game Pedagogical Knowledge
CS	Cognitive Scaffolding
ES	Emotional Scaffolding
ToR	Transfer of Responsibility Scaffolding

Chapter 1. An Introduction and Overview of Chapters

The digital era created opportunities for online and game applications to augment, enhance, and improve teaching and learning. According to the Federation of American Scientists (FAS, 2006), games are the next great discovery in education because they can engage students to such an extent that they willingly spend several hours learning independently. A 2019 social policy report by the Society for Research on Child Development revealed that children under eight spend an average of 25 minutes using interactive games daily. This increases to an average of 1 hour and 20 minutes per day for children aged eight to eighteen; game use starts early in development and increases until stable patterns emerge during middle childhood (Blumberg et al., 2019). The popularity of games for learning among young learners is attributed to their high technology access and use rates. Felt and Robb's (2016) study revealed that about three-quarters of teenagers in the US own a smartphone, with 24% of them describing themselves as "constantly connected" to the internet and 50% of them admitting to feeling "addicted" to their phone. Although this fact is not directly related to games in education, it is essential to acknowledge the prevalence of technology in modern society and its potential to impact students' learning experiences positively and negatively. Thus, understanding the prevalence of technology and its potential effects on students' attention and engagement with educational games is relevant to the discussion of using games as an effective educational tool. Furthermore, the study by Rikkers et al. (2016) revealed that almost all adolescents aged 11-17 use the internet, with 85.3% engaging in gaming and 92% spending time on online educational activities. Moreover, the increasing attention to games in education is evidenced by the exponential growth of research in this field over the past decade, as Dubé and Wen (2022) noted in their trends paper. These studies highlight the ubiquitous nature of games and the internet in children's lives and present a significant opportunity to enhance teaching and learning.

Despite all this interest in adopting games in classrooms, researchers are consistently challenged by the literature when trying to determine the effectiveness of game-based learning (GBL) due to inconsistent results found across studies (Clark et al., 2016; Connolly et al., 2012; Girard et al., 2013; Wouters et al., 2013; Young et al., 2012). This inconsistency can be attributed to several factors related to the games, such as their design, genre, and difficulty, as well as teacher-related factors, such as their level of expertise, use of effective facilitation and scaffolding strategies, and attitudes toward GBL. As such, there is a need for research that explores the factors influencing the implementation of game technologies and their effectiveness in education. Only then we can unlock the full potential of GBL in enriching students' learning experiences and fostering their academic growth.

Games also have been found as an increasingly popular tools for teaching subject-specific skills and promoting twenty-first-century competencies (Annetta, 2008; Gee, 2008; Shaffer et al., 2005; Spires, 2015). However, not all educational games are equally effective for learning as game-related factors such as game design, genre, and difficulty level, have been identified as one of the critical determinants of GBL effectiveness (Clark et al., 2016). Games that incorporate qualified game features, such as feedback, scaffolding, and active engagement, are more likely to be effective for learning (Callaghan & Reich, 2018; Cayton-Hedges et al., 2015; Dubé et al., 2020). Another way to gain a better understanding of this phenomenon is to examine the pedagogical approaches used in designing these games, as these approaches are grounded in theories and principles that provide a solid basis for creating games that effectively support learning objectives (Kebritchi & Hirumi, 2008). Educators must evaluate and compare games based on their pedagogical foundations and the quality of the content they aim to provide to make informed choices about using games in the classroom. This is crucial because the type of the game either be effective, supportive, or detrimental to their teaching goals. However, further research is necessary to understand the effectiveness of different pedagogical approaches and the types of teaching-specific content as game-related factors.

The success of GBL in classrooms depends not solely on the games but also on teacher-related factors. Teachers are crucial factors in creating and managing learning environments that effectively promote GBL. To ensure the effectiveness of GBL, it is essential for teachers to design and facilitate learning environments that support diverse learners and leverage games as learning tools effectively, as argued by McCall (2011). Engaging and meaningfully designed pedagogical activities, including successful interactions, further support student learning (Chee, 2016). To achieve this, teachers must shift their focus from the games, game systems, and game content to their pedagogical knowledge (Mishra & Koehler, 2006). This involves creating space for games in the curriculum, organizing classroom activities around the use of games, scaffolding students' learning and engagement with GBL activities, and assess student learning (Hébert et al., 2018). Teachers who are more familiar with the games can provide better guidance and support to their students, making the learning experience more efficient and effective (Hsu et al., 2013, 2017). Therefore, teachers must develop their understanding of game mechanics and gameplay to integrate games effectively into their teaching practices. By doing so, teachers can create a more inclusive and engaging learning environment that effectively supports diverse learners and leverages games as powerful learning tools.

The implementation of GBL has been identified as a powerful pedagogical approach that impact student learning outcomes in various ways. Wilson et al. (2018) suggest that student learning outcomes in GBL environments mediated by how teachers implement classroom teaching strategies. However, since GBL is a relatively new pedagogical approach, and many teachers may lack experience in implementing it effectively. Thus, it becomes crucial for teachers need to understand how to align GBL activities with learning objectives, and scaffold and support learning appropriately to achieve the intended learning outcomes (Shute et al., 2015). By providing targeted scaffolding support, teachers can ensure that students stay on track and achieve the intended learning outcomes. However, it is challenging for teachers who lack knowledge of games and have different level of teaching experiences which can influence their ability to use games effectively (Hsu et al., 2021). Therefore, GBL approaches need to be well-planned and carefully organized to engage all students in learning and produce appropriate outcomes (Groff et al., 2010) while providing the necessary scaffolding and taking into consideration different factors to improve the effectiveness of GBL.

Therefore, this thesis aims to comprehensively examine the factors determining the effectiveness of game-based learning, which have been the subject of ongoing debate in the literature. The quality and types of games, as well as how teachers integrate games into their lessons and scaffold learning during game-based learning, teachers' knowledge of games and their teaching experiences have been identified as the main factors that affect the effectiveness of game-based learning in this thesis. While some of these factors have been explored in previous studies separately, others are still being investigated. Therefore, this thesis will address the gap across four chapters: a general literature review (Chapter 2), a systematic literature review and a meta-analysis (Chapter 3), followed by two empirical studies (Chapter 4 and Chapter 5) to provide a comprehensive investigation of the topic.

Chapter 2

This chapter provides a comprehensive review of the literature. In particular it presents an overview of the theoretical background of each factor pertinent to educational games and teachers who use such games in their practice; namely pedagogical foundations of games and types of knowledge that games aim to provide as game-related factors, teachers' scaffolding practices, teachers' knowledge about games, and teaching experiences as teacher-related factors. Previous empirical findings are presented and discussed that inform the studies conducted as part of this dissertation. This chapter also provided an explanation of the overall rationale for how and why the subsequent studies were conducted. A review of fundamental theories underlying the subsequently presented work for games and teachers are presented.

Chapter 3

Chapter 3 includes a meta-analysis and critical review of existing research on educational games and its impact on mathematics learning outcomes. The objectives of the Chapter 3 are listed below.

1. Systematically identify, categorize, and compare mathematical game studies to determine the pedagogical approaches used to support mathematics learning.
2. Examine the different types of mathematical knowledge promoted by mathematics games, including factual, procedural, and conceptual knowledge.
3. Investigate the effectiveness of each pedagogical approach in improving each type of mathematical knowledge.

This chapter identified 39 studies that met the inclusion criteria and analyzed the effectiveness of different pedagogical approaches and types of mathematics knowledge targeted in educational games. The findings showed that educational games were generally effective in improving factual knowledge and that a direct instructional approach was most effective for this purpose. Procedural and conceptual knowledge were targeted by games that used experiential, discovery, and constructivist approaches, but with mixed results. This chapter ends with a conclusion that educational games have the potential to be an effective tool for teaching mathematics, but further research is necessary to understand the specific design elements that contribute to their effectiveness.

Chapter 4

Chapter 4 includes a validation study of a newly developed scale assessing teachers' scaffolding use in GBL environments and investigates the relationship with related constructs to validate it externally. The objectives of Chapter 4 are listed below.

1. Introduce and validate the newly developed self-report scale, the teacher scaffolding questionnaire in game-based learning (TSQ-GBL); establish the reliability and validity of each dimension associated with the TSQ-GBL instrument and compare three different measurement models to determine the best-fit dimension structure through a robust and systematic approach.
2. Investigate the relationship between the role of available school resources and teachers' general game-based pedagogy use as antecedents of scaffolding usage in GBL environments.
3. Identify the most used types of scaffolding supports during game-based learning.

This chapter compared three measurement models for the TSQ-GBL to determine the best-fit dimension structure. A multidimensional model with three dimensions (cognitive, transfer of responsibility, and emotional scaffolding) approach was superior to the other models. The study found that different types of scaffolding in game-based learning (GBL) have varying relationships with related constructs: game-based pedagogy usage and availability of school resources. The study also found that teachers tend to use the transfer of responsibility scaffold the most in GBL environments, emphasizing student autonomy and self-directed learning. They also use recruitment, direction, and reduction scaffolds more frequently than cognitive scaffolding. This chapter ends with a conclusion that a need for teacher education and training in various scaffolding practices, including cognitive support, to promote student learning in GBL environments. Future research should assess the effectiveness of different scaffolding strategies.

Chapter 5

Chapter 5 includes a cross-sectional survey and correlational study design to understand of the relationship between teachers' TPACK-G and TSQ-GBL, validates the structural relationship between TPACK-G and TSQ-GBL, as well as determines the differences between junior and senior teachers in terms of their TPACK-G and TSQ-GBL. This chapter analyzes whether these differences are related to teachers' use of different types of scaffolding supports in GBL environments. The research objectives guiding the study are:

1. To confirm the TPACK-G and TSQ-GBL instruments and measurement models used in the study are valid.
2. To compare the TPACK-G and TSQ-GBL of junior and senior teachers to determine if there are differences in their use of scaffoldings and knowledge related to game-based learning.
3. To explore the relationship between junior and senior teachers' self-reported TPACK-G and their use of TSQ-GBL(s) to better understand how teachers' knowledge and confidence in using games may influence their instructional practices in game-based learning environments.

Chapter 5's study is motivated by the need to better understand how teachers' knowledge as well as their teaching experience in using games may influence their usage of scaffolding practices in GBL environments. The findings from the study could have implications for teacher training and professional development programs by identifying ways to support the integration of games in education effectively. This study will also inform further research for the design and implementation of game-based learning interventions in the classroom.

References

Annetta, L. A. (2008). Video games in education: Why they should be used and how they are being used. *Theory Into Practice, 47*(3), 229–239. https://doi.org/10.1080/00405840802153940

Blumberg, F. C., Deater-Deckard, K., Calvert, S. L., Flynn, R. M., Green, C. S., Arnold, D., et al. (2019). Digital games as a context for children's cognitive development: Research recommendations and policy considerations. *Social Policy Report, 32*(1), 1–33. http://dx.doi.org/10.1002/sop2.3.

Callaghan, M. N., & Reich, S. M. (2018). Are educational preschool apps designed to teach? An analysis of the app market. *Learning, Media and Technology, 43*(3), 280-293. ttps://doi.org/10.1080/17439884.2018.1498355

Cayton-Hodges, G. A., Feng, G., & Pan, X. (2015). Tablet-based math assessment: What can we learn from math apps? *Journal of Educational Technology & Society, 18*(2), 3-20. http://www.jstor.org/stable/jeductechsoci.18.2.3

Chee, Y. S (2016). *Games-To-Teach or Games-To-Learn: Unlocking the Power of Digital Game-Based Learning Through Performan*ce. Singapore: Springer Singapore.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86*(1), 79–122. https://doi.org/10.3102/0034654315582065

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education, 59*(2), 661-686. https://doi.org/10.1016/j.compedu.2012.03.004

Dubé, A. K., & Wen, R. (2022). Identification and evaluation of technology trends in K-12 education from 2011 to 2021. *Education and Information Technologies, 27*(2), 1929-1958. https://doi.org/10.1007/s10639-021-10689-8

Dubé, A. K., Kacmaz, G., Wen, R., Alam, S. S., & Xu, C. (2020). Identifying quality educational apps: Lessons from 'top' mathematics apps in the Apple App store. *Education and Information Technologies, 25*, 5389-5404. https://doi.org/10.1007/s10639-020-10234-z

Federation of Academic Scientists. (2016). *Harnessing the power of video games for learning.* Retrieved March 30, 2023, from https://www.informalscience.org/sites/default/files/Summit_on_Educational_Games.pd

Felt, L. J. & Robb, M. B. (2016). *Technology addiction: Concern, controversy, and finding balance.* San Francisco, CA: Common Sense Media

Gee, J. P. (2008). Learning and Games. In *The Ecology of Games: Connecting Youth, Games, and Learning*. MIT Press. doi: 10.1162/dmal.9780262693646.vii

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29*(3), 207-219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Groff, J. S., Howells, C., & Cranmer, S. (2010). *The impact of console games in the classroom: Evidence from schools in Scotland* (pp. 1–94). https://www.nfer.ac.uk/media/1788/futl25.pdf

Hébert, C., Jenson, J., & Fong, K. (2018). Challenges with measuring learning through digital gameplay in K-12 classrooms. *Media and Communication, 6*(2), 112–125. https://doi.org/10.17645/mac.v6i2.1366

Hsu, C.-Y., Liang, J.-C., Chai, C.-S., & Tsai, C.-C. (2013). Exploring preschool teachers' technological pedagogical content knowledge of educational games. *Journal of Educational Computing Research, 49*(4), 461–479. https://doi.org/10.2190/EC.49.4.c

Hsu, C.-Y., Liang, J.-C., Chuang, T.-Y., Chai, C.-S., & Tsai, C.-C. (2021). Probing in-service elementary school teachers' perceptions of TPACK for games, attitudes towards games, and actual teaching usage: a study of their structural models and teaching experiences. *Educational Studies, 47*(6), 734–750. https://doi.org/10.1080/03055698.2020.1729099

Hsu, C.-Y., Tsai, M.-J., Chang, Y.-H., & Liang, J.-C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Educational Technology & Society, 20*(1), 134–143. https://www.jstor.org/stable/jeductechsoci.20.1.134

Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*(4), 1729–1743. https://doi.org/10.1016/j.compedu.2008.05.004

Mccall, J. (2011). *Gaming the Past: Using Video Games to Teach Secondary History*. Routledge, Taylor & Francis Group.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Rikkers, W., Lawrence, D., Hafekost, J., & Zubrick, S. R. (2016). Internet use and electronic gaming by children and adolescents with emotional and behavioural problems in Australia – results from the second Child and Adolescent Survey of Mental Health and Wellbeing. *BMC Public Health, 16,* 1-16. https://doi.org/10.1186/s12889-016-3058-1

Shaffer, D. W., Squire, K. R., Halverson, R., & Gee, J. P. (2005). Video games and the future of learning. *Phi Delta Kappan, 87*(2), 105-111. https://doi.org/10.1177/003172170508700205

Shute, V. J., D'Mello, S., Baker, R., Cho, K., Bosch, N., Ocumpaugh, J., Ventura., Matthew & Almeda, V. (2015). Modeling how incoming knowledge, persistence, affective states, and in-game progress influence student learning from an educational game. *Computers & Education, 86,* 224-235. https://doi.org/10.1016/j.compedu.2015.08.001

Spires, H. A. (2015). Digital game-based learning. *Journal of Adolescent & Adult Literacy, 59*(2), 125–130. https://doi.org/10.1002/jaal.424

Wilson, C. D., Reichsman, F., Mutch-Jones, K., Gardner, A., Marchi, L., Kowalski, S., Lord, T., & Dorsey, C. (2018). Teacher implementation and the impact of game-based science curriculum materials. *Journal of Science Education and Technology, 27,* 285–305. https://doi.org/10.1007/s10956-017-9724-y

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wouters, P., Van Nimwegen, C., Van Oostendorp, H., & Van Der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*(2), 249. https://doi.org/10.1037/a0031311

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–89. DOI: 10.3102/0034654312436980

Chapter 2. Comprehensive Review of Relevant Literature

Educational institutions have increasingly adopted modern learning strategies, such as game-based learning to assist learners in developing skills while having fun (Connolly et al., 2012, Girard et al., 2013; Ke, 2009). Game-based learning (GBL) employs digital games, video games, simulations, virtual worlds, board games, and card games to facilitate learning and skill-building (Tobias et al., 2013). This approach encourages collaboration, problem-solving, creativity, critical thinking, increasing knowledge and understanding (Sung & Hwang, 2013). Moreover, it allows students to interact with one another and the environment to gain in-depth understanding and a meaningful learning experience. With the balanced combination of technology and pedagogy, GBL has the potential to transform the way we teach and learn and create a more dynamic and engaging educational experience for learners of all ages. Given this, the purpose of this literature review is to provide a comprehensive overview of the key factors that influence the effectiveness of game-based learning in educational contexts. Therefore, the review will cover various game-related factors, such as the pedagogical foundations of games, the types of knowledge that games aim to provide, and their impact on learning outcomes. Additionally, the review will explore teacher- and pedagogy-related factors that can impact the successful implementation of GBL, such as teachers' scaffolding usages in GBL environments, their knowledge of games, game' content, and game' pedagogical knowledge, as well as their teaching experiences.

Games can be an effective tool for learning due to their user-friendly interface, making them accessible to learners of all ages (Troussas et al., 2020), and players can accelerate the game and switch between tasks to practice the skills they have learned, making the learning process more efficient. Engaging visuals also help to keep learners attentive and focused on the game, leading to a more enjoyable learning experience (Ge & Ifenthaler, 2018). Additionally, games with narrative stories can introduce characters and concepts, helping students remain engaged and focused throughout the game, making learning interactive (Breien & Wasson, 2020). Social interaction is another key benefit of games for learning, allowing players to interact, collaborate, and compete while sharing their learning experiences (Oksanen et al., 2017). Overall, games offer a range of features that support effective learning and make them a valuable tool for educators to consider.

In addition to these game design related factors, incorporating educational games into the classroom is crucial as it aids in visualizing complex concepts that may be challenging to grasp through traditional teaching methods (Wu & Anderson, 2015). Specifically, these approaches are helpful in the STEM curriculum that encompasses numerous facts and concepts that students need to comprehend and apply in their daily lives. By allowing students to interact with game mechanics in a virtual world and achieve set goals, educational games provide an enjoyable and immersive experience that enhances their understanding of the learning objectives. Furthermore, interaction and involvement in problem-solving in the virtual world offer a meaningful gaming experience (Ball et al., 2020, Wu & Anderson, 2015), which helps sustain interest and promote a growth mindset (Fisher, 2014). Given these potential benefits, an increasing number of educators and instructional designers are developing and utilizing games for use in K-12 to achieve various learning outcomes.

Considering the increased development and implementation of educational games, researchers have argued that there is a need to determine the educational potential of these games (Clark, 2007). However, it is hard to say how well educational games support learning because studies too often apply different pedagogical approaches and focus on different types of knowledge, leading to overgeneralized conclusions. (Dubé et al., 2019). Additionally, factors related to the design of a game, such as game mechanisms, goals, narratives, and the interaction between the player and the game through various controls (e.g., keyboard, joystick, motion-sensing), are frequently overlooked in the context of learning. To understand how well games support or facilitate learning, it is important to consider not only the common or overlooked design elements of games, but also the underlying pedagogical foundations of the games and the types of knowledge they aim to provide, as these factors can also influence ones' learning experience. Thus, taking a more comprehensive approach to game design could potentially lead to the development of more effective educational games that better support learning outcomes and create better learning experiences for students, ultimately helping educators to create better learning experiences.

Game-related Factors

Pedagogical Foundations in Games

When it comes to education, the key focus for any teacher is to ensure that the learner has understood the material presented. Teachers may use various pedagogical approaches, such as direct instruction, problem-centered learning, inquiry-based learning, and game-based learning. The approach employed by educators is often influenced by the individual needs of the students, including their level of understanding. The use of these pedagogical approaches can have numerous benefits, including enhancing the learner's comprehension of the content.

One possible reason for the growing use of games in education is their ability to engage learners in a way that traditional instructional methods may not achieve. Games have been designed to incorporate various pedagogical approaches, leading to improved learning outcomes (Kebritchi & Hirumi, 2008). The unique aspect of game-based learning lies in its ability to create an immersive experience that captures learners' attention and provides a dynamic learning environment (Jabbar & Felicia, 2015). This, in turn, can enhance the learner's comprehension of the content and provide more enjoyable learning experiences. Specifically, Tokarieva et al. (2019) found that games provide a more captivating and interactive experience that enhances learning. Additionally, as highlighted in the study by Yang (2012), games can encourage problem-solving and critical thinking skills through collaboration, idea-sharing, and skill-sharing among players. Furthermore, according to Tay et al. (2022), pedagogical approaches such as experiential and discovery-based learning implemented in games provide learners authentic content with the essential resources and tools. Therefore, the use of games in education has proven to be a successful and engaging alternative to traditional instructional methods.

Previous reviews of educational games have been criticized for 'lumping' all types of games together in an overly simplistic way (Dubé & Keenan, 2016). Only a few studies have explored the underlying learning theories and pedagogical foundations of games as a game effectiveness factor. For instance, Kebritchi (2008) identified five main pedagogical foundations used in 24 educational games, including behaviorism, experiential learning, discovery learning, situated cognition, and constructivism. However, the study found that only 18 of the games used established instructional strategies or learning theories, and only seven of these were based on pedagogical approaches that promote inquiry and active involvement by learners. Moreover, Wu et al. (2012) found that only 14% of articles discussed pedagogical approaches in their meta-analysis, but this percentage has been increasing in more recent literature. The study recommends the use of instructional supports, such as game procedure explanations and feedback, to facilitate game-based learning. In conclusion, taking a more comprehensive approach to game design can lead to the development of more effective educational games that support learning outcomes and create better learning experiences for students.

Apart from games, the Kebritchi and Hirumi (2008) conceptual framework was used to identify the pedagogical foundations in virtual reality (VR) educational applications. Experiential learning was the most common pedagogy, followed by discovery learning, constructivism, and situated cognition. Most of the applications analyzed were learner-centered, and even those employing direct instruction were in a VR environment offering visual and kinesthetic support. Other pedagogies, such as discovery learning, were also present but not as prevalent. Together, these studies show that the practice of pedagogical classification of educational games is becoming a common approach for the process of categorizing and evaluating educational games to determine the effective pedagogical approaches that improve learning. This classification system provides valuable insight into how learning theories can serve as a framework for understanding and evaluating different types of educational games.

In short, it is important for game developers to ground their designs on established learning and instructional theories and report how related instructional events and experiences are integrated with gameplay. This will enable researchers to determine what factors have the greatest effect on learner motivation and achievement and inform future game designs.

Knowledge Types in Games

Educational games are designed to provide learners with various types of knowledge that are essential for their learning experience. These types of knowledge include factual knowledge, procedural knowledge, and reflective knowledge. Factual knowledge involves learning facts and information to achieve a specific goal or complete a task within the game (Anderson, 2005; Perini et al., 2018). For example, a game that teaches players about different historical events or scientific facts. Procedural knowledge involves learning how to perform specific tasks or skills required to progress in the game, such as using tools in Minecraft. Reflective knowledge is a crucial element of many educational games, including math games, where players are encouraged to think critically about the choosing different strategies they make and reflect on the potential outcomes. These examples are just a few of the many ways educational games can help players acquire knowledge and skills in a fun and engaging way (Papastergiou, 2009).

Taking mathematics as an example, three types of knowledge have been identified that are essential for success in mathematics: factual, procedural, and conceptual knowledges (Bisanz & LeFevre, 1990; LeFevre et al., 2010; Rittle-Johnson et al., 2015). Factual knowledge refers to memorized information, such as multiplication tables or formulae (Bisanz & LeFevre, 1990; Miller & Hudson, 2007). Procedural knowledge involves mental activities, like following a set of steps to solve a problem and is often used to solve routine mathematical problems (Rittle-Johnson et al., 2001). Conceptual knowledge, on the other hand, involves a deep understanding of principles and concepts, and allows for flexible problem solving and generalizable content (Rittle-Johnson et al., 2001). Traditionally, mathematical teaching has focused primarily on developing factual and procedural knowledge, but research suggests that conceptual knowledge is also necessary for success in mathematics (Baroody et al., 2007; Crooks & Alibali, 2014; Rittle-Johnson, 2017). Given that educational math games can be effective in developing different types of math knowledge, but their effectiveness depends on the type of game, and it's fit with the academic subject being taught (Young et al., 2012).

Critically, to enhance game-based learning, it is necessary to understand the relationship between game pedagogy and the knowledge types they aim to improve. Varied pedagogical approaches can be employed to teach different knowledge types. However, the effectiveness of the learning experience will depend on the appropriateness of the pedagogical approaches used in games (Lamb et al., 2018). For instance, in a factual knowledge math game, an effective approach may be direct instruction. For a procedural knowledge math game, the constructivist approach might be the most effective (Pan & Ke, 2023). To enhance the learning experience for players, it is important to ensure that game design incorporates pedagogical approaches and suitable types of knowledge they aim to teach. If the knowledge type is unsuited for the game's content, and the knowledge is essential for success in the game, players will be unable to acquire the necessary knowledge to continue with the game. Therefore, understanding the relationship between game pedagogy and the knowledge types they aim to improve is essential.

In addition to the pedagogical approaches and types of knowledge included within games, scaffolding is an instructional approach used by teachers that supports learners external to the games. Scaffolding is crucial to enhance game-based learning as it helps learners to develop their skills and knowledge gradually. This approach is particularly effective in games that involve complex problem-solving or require the application of procedural knowledge or conceptual knowledge. In the following section, the different ways scaffolding can be implemented in game-based learning will be explored.

Teacher/ Pedagogy Related Factors

Scaffolding Learning as an Effective Instructional Support

Theoretical Background

Scaffolding is an instructional strategy that is widely recognized as a valuable tool for supporting student success, as it can help students overcome challenges or obstacles that might impede their learning progress and help them develop the skills and confidence they need to succeed. Therefore, having recognized the importance of scaffolding as an instructional strategy, it is useful to understand the underlying theory behind it.

Over the past three decades, the concept of scaffolding and its broad meanings has received a great deal of attention, primarily in educational research, learning sciences and child development. Numerous journals have published special issues on scaffolding, for example, *Educational Psychologist* 40(4), *Instructional Science* 33, and *Educational Technology Research and Development* 56(1). Historically, the underlying theory behind scaffolding draws primarily on the ideas of Vygotsky (1978) and constructivist theories of learning. Vygotsky (1978) proposed the notion of a zone of proximal development (ZPD) which is important to consider when discussing successful scaffolding and operationalizing it. Vygotsky's idea of the ZPD provided the first foundation for the concept of scaffolding. In 1962, the ZPD was mentioned in the English Translation of *Thinking and Speech* (Vygotsky 1987; Wertsch, 1985). Yet, the implications of Vygotsky's ZPD did not become evident until "*Mind in Society*" was published in 1978.

Vygotsky (1978) defined the phrase *zone of proximal development* "*to denote the distance between student's actual developmental level and their level of potential development that can occur via problem*-solving with parental assistance or collaboration with more capable peers" (p.86). According to Vygotsky (1978), this means that learning is enhanced when children engage in interaction and collaboration with more knowledgeable peers and adults within their learning environment. From this perspective, scaffolded instruction directed at the ZPD provides a mechanism for learners to achieve their learning potential.

The term scaffolding was first applied to educational contexts by Wood, Bruner, and Ross (1976), who highlighted the importance of social interaction with more capable individuals in one's cognitive development. More precisely, "more capable" individuals refer to those who possess more knowledge and skills on the task that the less advanced learners cannot accomplish by themselves. It is with these unequal levels of expertise that the more advanced individuals can facilitate the cognitive development of the less advanced learners (Driscoll, 1994). Eventually, the responsibility for performing the task shifts from the more advanced other to the student as the student gains mastery and can complete the task without the support. Based on Wood et al., (1976) research with young children, an ideal and effective scaffolding in learning should involve six important functions:

1. Recruitment: The first task of the tutor is to recruit learner interest in relation to the task and to adhere to the learning objectives.
2. Reduction of degrees of freedom: The tutor's role consists of reducing and simplifying the complexity of the task to make it more manageable and achievable so that it is within the learner's current range of ability.
3. Direction maintenance: An effective tutor should sustain the learner's motivation to pursue the goal of the activity to achieve it and maintain directions by making it worthwhile for the learner to risk taking the next step.
4. Marking critical features: The tutor's role involves highlighting a task's critical features using different types of tools. This step clarifies the current performance, and the ideal desired performance.
5. Frustration control: The tutor's role is to reduce frustration and risks without creating too much dependency on the tutor.
6. Demonstration: The tutor's role is to model or imitate the task, which involves the idealization of the act to be performed, and the presentation of complete tasks that are already partially executed by the tutee and the goals of the activity are clearly defined.

Cazden (1983) extended scaffolding beyond describing parent-child interactions to analyzing teacher-student interactions in the classroom. In addition to Wood et al.'s (1976) study with children, Bruner (1985,) further indicated that teachers play a critical role in "scaffolding" the learning task to make learners internalize external knowledge and convert the support into their conscious control.

Although Vygotsky (1978; 1986), Wood et al. (1976), and Bruner (1985) addressed the concept of scaffolding from a psychological perspective and child development perspective, the different forms and applications of scaffolding have been adopted into education and learning sciences as well. However, many educators and learning scientists have reflected on Wood et al.'s (1976) original assertions about scaffolding. Collins et al. (1989) viewed scaffolding as an essential component of cognitive apprenticeship, which shifts the focus from traditional apprenticeship's mastery of physical skills to the development of learners' cognitive and metacognitive abilities. Cognitive apprenticeship theory suggests breaking down a learning task into various parts to guide learners through it and enable them to solve complex problems beyond their individual capabilities. Task decomposition is adaptive to a learner's needs and allows them to gradually become more independent and competent by removing or fading out the support as they complete the task on their own (Choi & Hannafin, 1995; Palincsar & Brown, 1984).

In the 2000s, the rapid creation and innovative educational practices and technological developments resulted in various forms of scaffolding applications in educational settings. Consequently, the definition and the concept of scaffolding became very broad, complex, and unclear in meaning and has been defined from several perspectives (Pea, 2004; Reiser 2004; Quintana et al., 2004; Sherin et al., 2004). To improve learning appropriately with the use of new technologies, such as digital games, in today's classrooms, it is important to understand and distinguish between different forms and types of scaffolding.

Scaffolding Forms

There has been an extensive body of research on scaffolding in different forms and settings. Before 2000, studies on scaffolding in face-to-face instruction were prevalent, focusing mainly on expert-novice interactions, scaffolding strategies, and the characteristics of an effective expert scaffold provider (Sharma & Hannafin, 2007). With the increasing role of computers in teaching and learning over the past two decades, scaffolding has been incorporated into this context to address the challenges of complex problem-solving tasks for learners using cognitive tools. This has led to a change in the way researchers define scaffolding.

To design effective scaffolds that support learners' cognitive development, the primary and leading studies in the scaffolding research field have been identified and classified based on their applied settings. Thus, a scoping review of literature was undertaken to identify highly recognized "scaffolding" research studies. Search terms included related keywords about "scaffold*" AND OR "technology" AND "teacher*" OR "peer" OR "educator*" AND "learning" in three databases: Web of Science, PsycINFO and ERIC will be limited by "English" and "peer-reviewed journal." The exclusion criteria are duplications, dissertation/conference proceedings, annotated bibliography, books, non-target students (such as university students or students with special needs). Exclusion criteria was applied when scanning abstracts and titles. Specific attention paid to find the articles that has been published in highly peer-reviewed journals. Among the 28 primary studies identified as the most cited and adapted scaffolding studies (see Table 1), 14 relied on computers, 14 adopted human scaffolds, and only seven adopted peer scaffolding (e.g., Lajoie et al., 2001; Puntambekar & Kolodner, 2005). These primary and fundamental studies demonstrate that new technologies have led researchers to focus on studying computer-based scaffolds to facilitate learning, with less emphasis on teacher-based scaffolds in recent years. This could be explained by the fact that as scaffolds are applied in computers, the instructor's role has become less of a focus. Furthermore, the scaffolding metaphor has been expanded with the emergence of powerful technologies, moving away from the original concept.

Table 1

Forms of Scaffolding Studies Found in the Primary and Leading Scaffolding Studies

Study	One-to-one (Teacher) scaffolding	Peer scaffolding	Computer-based scaffolding
Palincsar and Brown (1984)		✓	
Hmelo and Day (1999)			✓
Davis and Linn (2000)			✓
Lajoie et al. (2001)			✓
Saye and Brush (2002)			✓
Cho and Jonassen (2002)			✓
Maloch (2002)	✓		
Pedersen and Liu (2002)			✓
Kolodner et al. (2003)		✓	
Hakkarainen (2004)		✓	
Sandoval and Reiser (2004)			✓
Puntambekar and Kolodner (2005)			✓
Azevedo and Hadwin (2005)			✓
Rubens et al. (2005)		✓	
Gillies and Boyle (2006)	✓		

Oh and Jonassen (2007)		✓	
Mertzman (2008)	✓		
Raphael et al. (2008)	✓		
Li and Lim (2008)			✓
Gijlers et al. (2009)			✓
Pentimonti and Jutice (2010)	✓		
Pifarre and Cobos (2010)		✓	
Lee et al. (2010)			✓
Belland (2010)			✓
Jadallah et al. (2011)	✓		
Van de Pol et al. (2011)	✓		
Van Aalst and Truong (2011)		✓	
Belland et al. (2011)			✓

One-to-One scaffolding. Scaffolding can be implemented in the context of one-on-one tutoring (Wood et al., 1976), where a tutor works with a single student. One-to-one scaffolding is generally considered the ideal form of scaffolding because it can be customized to meet the individual needs of each student (Maloch, 2002; van de Pol et al., 2010). In this form of scaffolding, the teacher's role is to dynamically assess the student's current level and provide the appropriate level of support, gradually fading it as the student progresses (Belland, 2013; van de Pol et al., 2010). As a result, one-to-one scaffolding is generally considered ideal because it is highly contingent on the student's needs (Belland et al., 2015). A recent meta-analysis showed that one-to-one scaffolding tends to lead to the highest effect sizes, with an average effect size of 0.79, compared to step-based intelligent tutoring systems, which had an average effect size of

0.76 (VanLehn, 2011). However, delivering individualized scaffolding support presents pragmatic challenges in large K-12 classrooms, where it can be difficult to monitor and meet the individual learning needs of each student, particularly in complex and dynamic technology-based learning environments (van de Pol et al., 2010). While individualized scaffolding delivery appears to be an ideal form of scaffolding support based on the literature, it may not always be feasible in large classroom settings.

Peer Scaffolding. Scaffolding can also be implemented within the classroom when students work in groups (Gaskins et al., 1997). While scaffolding's original definition involves assistance from a more capable individual (Wood et al., 1976), other authors have argued that peers can also provide scaffolding to each other (Gillies, 2008; Palinscar & Brown, 1984). Peer-based scaffolding is considered a cost-effective way to support all students in classrooms (Belland, 2013), as it has the potential advantage of allowing learners with different abilities to help each other with learning tasks. Moreover, empirical studies have indicated that peer scaffolding has a positive impact on cognitive outcomes (Pifarre & Cobos, 2010) and is helpful for students with low self-regulation (Helle et al., 2007). However, it is also possible that peers may not be able to provide effective scaffolding to each other if they have similar abilities (King, 1998), thereby hindering their ability to move each other towards higher-order thinking (Angelova et al., 2006). Nonetheless, for peer scaffolding to be effective, students need clear guidelines, such as asking thought-provoking questions and frameworks for evaluating their own work and that of others (Gillies, 2008).

Computer-based Scaffolding. More recently, "scaffolding" has been applied to computers. This type of scaffolding has emerged as a solution for teachers to help and share the burden of scaffolding in typical K-12 classrooms, because teachers cannot one-to-one scaffold all students in a classroom (Hawkins & Pea, 1987; Stone, 1998). Computers offer a nice alternative and can provide constant scaffolding that caters to student learning needs (Chen et al., 2003). Throughout the literature, computer-based scaffolding has been organized to display several strategies for helping learners understand a task, decompose complex and open-ended tasks, and acquire strategies (Quintana et al., 2004; Reiser, 2004). Furthermore, computer-based scaffolding in classroom settings could be used as an effective support to facilitate learner's problem-solving (Reiser, 2004) and assist learners in generating solutions to complex and ill-structured problems (Hannafin et al.,1999; Quintana et al., 2004). Additionally, this form of scaffolding is advantageous when teacher-student ratios, geography, or other factors inhibit a high level of student-teacher interaction (Belland & Drake, 2013). However, several studies have reported that computer-based scaffolding is ineffective without one-on-one scaffolding provided by a capable expert (McNeill & Krajcik, 2009; Tabak, 2004).

Apparently, "scaffolding" has become a broadened concept in the field (Belland 2015; Puntambekar & Kolodner, 2005; Tabak, 2004). The common issue among diverse scaffolding studies is that researchers use the same term but apply it in different settings and with different types. Most authors clearly state in their studies that the common goal of each scaffolding form is to provide temporary support and help learners solve problems, carry out tasks, or achieve goals that they cannot accomplish on their own. Although the earlier and original definition of traditional scaffolds involves a more knowledgeable person, such as a teacher or tutor, authors commonly agree that it is challenging to apply customized scaffolding that supports each individual learner in today's large classrooms. One possible reason is that teachers in typical large classes tend to have difficulty monitoring each student's progress and understanding each individual's needs (Puntambekar & Kolodner, 2005). For example, teachers cannot provide sufficient support suited to each learner's specific needs. Therefore, future empirical findings are needed to address how to enhance learning with a combination of different scaffolds using new and complex technologies (e.g., digital games) in classrooms and to research what types of scaffolding are effective based on theoretically grounded learning.

Scaffolding Types

The increasing advancements in technology have led to a variety of scaffolding applications in educational settings. Although the definition of scaffolding is clear in different settings, the types of scaffolding techniques used in the literature are still unclear. Researchers and theorists have attempted to describe and classify scaffolding techniques embedded in different forms to explain how scaffolding facilitates learning. To understand the aim of scaffolding, it is important to identify and explain the types of scaffolding used in these studies. Table 2 below summarizes several classifications of scaffolding strategies and their applied disciplines to make it visually clear.

Table 2

Types of Scaffolding Found in Literature

Authors & Types of scaffolding	**Descriptions**	**Disciplines applied**
Silliman and Wilkinson (1994)		
Supportive scaffolds	Providing learners with opportunities to explore information that are necessary for learning.	Language and literacy learning (e.g., Saxena, 2010; Silliman et al., 2000), Math learning (e.g., Spencer-Smith & Hardman, 2014)
Directive scaffolds	Providing directional learning support that facilitates the learner in navigating through the learning material or the problem-solving process.	
Jackson et al. (1998)		

Supportive scaffolds	Offering support throughout the learning process as a form of advice or support to aid students while helping them to complete the task. It serves such purposes as guiding, coaching, and modelling.	Science learning (e.g., Yu et al., 2013)
Reflective scaffolds	Helping learners to plan, predict, and evaluate their learning by solving or conceptualizing the task by using forms and prompts.	
Intrinsic scaffolds	Helping help learners to reduce the complexity of the learning material as a form of visual support (e.g., maps and models) so that learners can focus on the learning task without worrying about the interpretation of extraneous information.	
Hannafin et al. (1999)		
Conceptual scaffolds	Providing support to learners with content or contextual information pertinent to the learning task or complex problem, such as explicit hints, structural maps, prompts, guides, or content trees. It is a guidance about what knowledge to consider.	Computer literacy (e.g., Su & Klein, 2010)
Metacognitive scaffolds	Helping learners' plan and manage of their individual learning process. This type of scaffolds can appear as generic reminders that encourage learners to evaluate and reflect on their learning progress or propose self-regulatory strategies. It is a guidance about how to think during learning.	
Procedural scaffolds	Helping learners to achieve the learning goal by pointing at or emphasizing helpful resources and tools such as use of balloon or pop-up window. It is guidance about how to utilize available resources and tools.	
Strategic scaffolds	Supporting learners in making strategic decisions at key points in the learning process by directing students to other helpful learning information and providing expert advice and learner centered help in the formats of start-up questions, write-up structures, and so forth. It is a (guidance about alternative approaches that might assist decision making.	
Azevedo et al., (2004; 2008)		
Adaptive & Dynamic scaffolding	Providing support systems or tools that are flexible which can adjust to meet individual student needs and abilities during the learning process. This type of scaffolding requires a teacher or tutor to continuously diagnose a student's	Computer Science (Moleenar et al., 2012) Problem solving

	understanding and provide timely support to address any knowledge gaps or difficulties they may encounter.	(Margulieux & Catrambone, 2021)
Fixed scaffolding	Providing predetermined set of support structures or tools that are provided to students to assist their learning within a particular learning environment which are static and not adaptable to individual student needs or abilities, meaning that all students are provided with the same level of support regardless of their prior knowledge or learning goals	
Reiser (2004)		
Scaffolding for structuring the task	Structuring the task with scaffolding refers to simplify the task. If the student is able to accomplish the task without simplified the task, then the scaffolding was never needed.	Science (e.g., Smith & Reiser, 2005)
Scaffolding for problematizing the task	Problematizing task with scaffolding points out or highlights important concepts learners to which should pay particular attention. Ultimately, this type of scaffolding will lead to skill gain through problematization.	
Neitzel & Stright (2004)		
Cognitive Scaffolding	Providing students with learning strategies linked with task simplification, demonstration, and marking of critical features	Problem Solving (e.g., Leerkes et al., 2011; Mermelshtine & Barnes, 2016; Stright, Herr, & Neitzel, 2009)
Transfer of Responsibility	Providing supports about recruitment and attention maintenance and may foster agency and autonomy.	
Emotional Support	Manifesting through controlling frustration and warm and sensitive instruct	

Scaffolding and Games

Scaffolding can be provided through human guidance or computer-based learning environments (Lajoie, 2005; O'Rourke et al., 2015). Human-guided scaffolding is similar to a cognitive apprenticeship, where novices learn from experts who direct them towards learning goals (Lajoie, 2005). Educators with both curriculum and content knowledge and pedagogy experience are best suited to provide effective scaffolding (Lajoie, 2005). In contrast, intelligent tutoring systems provide scaffolding based on what a student knows and needs to know without the need for human input (Lajoie, 2005; O'Rourke et al., 2015).

Intelligent tutoring systems have been found to be effective in improving learning outcomes (Bennett, 2002; Lajoie, 2005; Koedinger & Aleven, 2016; Kulik & Fletcher, 2016). Kulik and Fletcher's (2016) meta-analysis of 50 controlled evaluations of intelligent computer tutoring systems found an average increase in test scores of 0.66 standard deviations, reflecting a moderate to large effect size from the 50th to the 75th percentile of performance. However, the effect was more significant on tests developed locally concerning local curricula, highlighting the importance of teacher input in curriculum development for optimal performance outcomes (Kulik & Fletcher, 2016).

Several game-based learning studies have investigated the effects of scaffolding in educational learning environments. Teacher-based scaffolding may be provided at different phases of learning, as investigated by Foster and Shah (2015). Their study showed that effective teacher-based scaffolding support may be designed and tailored to fit with the inquiry, communication, construction, and expression phases of learning. In-game scaffolding support has also been found to be effective in improving mathematics learning achievement (Yang et al., 2017). Yang et al. (2017) investigated the effectiveness of progressive prompting on math achievement, flow, and self-efficacy among second-grade Taiwanese students. Participants were randomly assigned to either an experimental condition incorporating progressive prompting into a math learning game or a control condition where they completed the learning game without scaffolding support. The findings showed that students who used the game-based learning approach with the progressive prompting strategy showed significantly better learning achievements than those who used the conventional game-based learning approach (Yang et al., 2017). Ustunel and Tokel's (2018) qualitative investigation provided essential insights into some specific processes associated with teacher-based scaffolding support, showing how scaffolding can facilitate the development of scientific arguments.

Assessing students' knowledge and competencies is a significant challenge for educators who utilizes games to support learning (Shute et al., 2021). Traditional assessment methods (e.g., multiple-choice tests) may not adequately capture the dynamic nature of game-based learning. Stealth assessment techniques, like evidence-centered design (ECD), offer a potential solution by integrating assessments into the gameplay and providing ongoing data on student competencies and knowledge (Shute & Ke, 2012). This approach might have implications for educators by giving real-time data on students' competencies and areas of need, which ultimately allows for providing targeted and appropriate scaffolding types. With the help of stealth assessment, teachers can tailor their support to individual students, providing hints, sharing resources, or demonstrating game play strategies to help them overcome challenges and master complex concepts. However, it remains unknown whether teachers are applying scaffolding techniques to support game-based learning, and if so, what types of supports they use. Therefore, research is needed to identify the scaffolding techniques used by teachers and how they can be tailored to effectively support game-based learning before deciding on the appropriate scaffolding types.

Balancing built-in and teacher-based scaffolding has been suggested to provide optimal educational outcomes (Bennett, 2002; Lajoie, 2005; Reiser & Tabak, 2014). Although game-based learning environments may provide support within a game, external scaffolding provides an opportunity for a caring response that positively affects student motivation (Pea, 2004). However, research into scaffolding lacks a clearly defined measurement instrument to capture the different means of teacher-based scaffoldings reported in the research, such as feedback, hints, instructing, explaining, modelling, and questioning (van de Pol et al., 2010). Therefore, further studies are necessary to assess and understand the usage of scaffolding practices provided by teachers in game-based learning environments (van de Pol et al., 2010).

Teachers' Knowledge of Games and Level of Expertise in GBL

The theoretical framework of Technological Pedagogical Content Knowledge (TPACK) has been developed in the last decade to explain the integration of information and communications technology (ICT). Essentially, TPACK expands upon Shulman's concept of Pedagogical Content Knowledge (PCK) by including knowledge about technology (Shulman, 1986). Later, Mishra and Koehler (2016) proposed that in the current technological era, teachers must develop knowledge about technology, such as Technological Knowledge (TK), as well as Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and TPACK in using technologies in classroom settings to explore educators' knowledge about games and their relationships with other related outcomes.

Effective implementation of game-based learning (GBL) requires teachers to have a thorough understanding of games and their potential as educational tools. This includes teachers' levels of familiarity with games and their knowledge about games in GBL environments (Hsu et al., 2013). In response to this, there has been some movement to refine the TPACK framework to highlight the knowledge needed for game-based instruction (Hsu et al., 2013, 2015). Hence the TPACK-G framework was proposed by Huang et al., (2013) as an extension of the Technological Pedagogical Content Knowledge (TPACK; Mishra & Koehler 2006) framework to assess teachers' knowledge of games instead of technology in general. The Technological Pedagogical Content Knowledge—Games (TPACK-G) framework provides a comprehensive approach to examining teachers' levels of familiarity with games and knowledge about GBL environments (Hsu et al., 2013) and it contains three components: technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) related to games, which form the basis of teachers' TPACK for GBL.

Regarding teachers' familiarity with games, research has shown that many teachers lack sufficient experience and expertise in using games for educational purposes (Hsu et al., 2017; 2020; 2021). This lack of game familiarity can be one factor that impedes the effective implementation of GBL. Teachers need to be able to identify suitable games for their specific teaching purposes, understand how to integrate games into the curriculum, and be able to evaluate their effectiveness in promoting student learning. Therefore, teachers need to develop their TK about games, which can be achieved through professional development programs and collaboration with game designers (Hsu et al., 2015). Moreover, teachers' PK is crucial for effective GBL. Teachers need to understand the pedagogical principles that underpin game-based instruction, such as the importance of scaffolding, feedback, and motivation (Nousiainen et al., 2018). Teachers should also be aware of the potential challenges associated with GBL, such as managing student behavior, addressing individual differences in student learning, and ensuring that learning outcomes are aligned with curriculum standards. Finally, teachers' CK is also critical for effective GBL. Teachers must identify the specific learning goals and objectives they want to achieve through game-based instruction and ensure that the game aligns with the relevant curriculum standards (Hsu et al., 2021). Teachers should also have a deep understanding of the subject matter and be able to facilitate student learning through game-based activities.

Recent studies (Hsu et al., 2017; Li & Huang, 2016) have revealed that teachers' perceptions and confidence in using games in the classroom may be also influenced by their teaching experience. Further, different attitudes and perceptions towards integrating GBL were found across various career stages of elementary school teachers, indicating a significant factor in inhibiting, encouraging, and motivating GBL integration (Hayak, Avidov-Ungor, 2020). Hsu et al. (2017) also found that teachers with less than ten years of teaching experience perceived higher self-efficacy in their game knowledge, game content knowledge, game pedagogical knowledge, and game pedagogical content knowledge than their senior colleagues. Conversely, senior teachers tended to perceive the curriculum as inflexible and believed that gaming had negative impacts on learning, whereas junior teachers were more likely to identify a lack of resources as a barrier to game-based teaching (Baek, 2008).

Conclusion

In conclusion, effective game-based learning has the potential to enhance student engagement and motivation in the classroom. However, not all educational games are equally effective in supporting learning outcomes. To determine the educational potential of these games, this current review argues that it is crucial to consider not only the common or overlooked design elements of games but also the underlying pedagogical foundations of the games and the types of knowledge they aim to provide. Therefore, taking this more comprehensive approach towards game design could potentially lead to the development of more effective educational games that better support learning outcomes and create immersive learning experiences for students. Ultimately, this could help educators create a more meaningful and enjoyable learning experiences.

Despite the potential benefits of games, selecting or incorporating well-designed games into instruction is not enough for effective GBL. It also relies on the ability of teachers to scaffold student learning by adjusting support levels based on individual needs or using various types of scaffolds. Moreover, it is not yet clear whether teachers who have knowledge about games, game content, and game pedagogies are able to effectively support students' learning by applying scaffolding practices in GBL. This review further discusses potential factors that may affect teachers' use of scaffolding, such as their tendency to use scaffolds, the amount and type of scaffolding they use, which may depend on their level of knowledge with games and their teaching experience. By exploring the relationship between teachers' knowledge of games, their teaching experiences and usage of scaffolding practices, the effectiveness of GBL can be improved, and students' learning experiences can be enhanced. Therefore, it is necessary to conduct more research to explore the relationship between teachers' technological pedagogical content knowledge for game-based learning, their teaching experiences, and their use of scaffolding practices in game-based learning to improve the effectiveness of GBL by integrating TPACK-G framework and scaffolding theory.

References

Abdul Jabbar, A. I., & Felicia, P. (2015). Gameplay engagement and learning in game-based learning: A systematic review. *Review of Educational Research, 85*(4), 740-779. https://doi.org/10.3102/0034654315577210

Anderson, L. W. (2005). Objectives, evaluation, and the improvement of education. Studies in Educational Evaluation, 31(2-3), 102-113. https://doi.org/10.1016/j.stueduc.2005.05.004

Angelova, M., Gunawardena, D., & Volk, D. (2006). Peer teaching and learning: Co-constructing language in a dual language first grade. *Language and Education, 20*(3), 173–190. https://doi.org/10.1080/09500780608668722

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology*, *29*(3), 344-370. https://doi.org/10.1016/j.cedpsych.2003.09.002

Azevedo, R., & Hadwin, A. F. (2005). Scaffolding self-regulated learning and metacognition – implications for the design of computer-based scaffolds. *Instructional Science, 33*(5–6), 367–379. https://doi.org/10.1007/s11251-005-1272-9

Azevedo, R., Moos, D. C., Greene, J. A., Winters, F. I., & Cromley, J. G. (2008). Why is externally facilitated regulated learning more effective than self-regulated learning with hypermedia? *Educational Technology Research and Development*, *56*, 45-72. https://doi.org/10.1007/s11423-007-9067-0

Baek, Y. K. (2008). What hinders teachers in using computer and video games in the classroom? Exploring factors inhibiting the uptake of computer and video games. *Cyberpsychology & Behavior, 11*(6), 665–671. https://doi.org/10.1089/cpb.2008.0127

Ball, C., Huang, K.-T., Cotten, S. R., & Rikard, R. V. (2020). Gaming the SySTEM: The relationship between video games and the digital and STEM divides. *Games and Culture, 15*(5), 501-528. https://doi.org/10.1177/1555412018812513

Baroody, A. J., Feil, Y., & Johnson, A. R. (2007). An alternative reconceptualization of procedural and conceptual knowledge. *Journal for Research in Mathematics Education, 38*(2), 115–131. https://doi.org/10.2307/30034952

Belland, B. R. (2010). Portraits of middle school students constructing evidence-based arguments during problem-based learning: the impact of computer-based scaffolds. *Educational Technology Research and Development, 58*(3), 285–309. https://doi.org/10.1007/s11423-009-9139-4

Belland, B. R. (2013). Scaffolding: Definition, current debates, and Future Directions. *Handbook of Research on Educational Communications and Technology*, 505–518. https://doi.org/10.1007/978-1-4614-3185-5_39

Belland, B. R., & Drake, J. (2013). Toward a framework on how affordances and motives can drive different uses of scaffolds: theory, evidence, and design implications. *Educational Technology Research and Development, 61*(6), 903–925. https://doi.org/10.1007/s11423-013-9313-6

Belland, B. R., Burdo, R., & Gu, J. (2015). A blended professional development program to help a teacher learn to provide one-to-one scaffolding. *Journal of Science Teacher Education, 26*(3), 263–289. https://doi.org/10.1007/s10972-015-9419-2

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2011). Problem-based learning and argumentation: testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instructional Science, 39*(5), 667–694. https://doi.org/10.1007/s11251-010-9148-z

Bennett, F. (2002). The Future of Computer Technology in K-12 Education. *Phi Delta Kappan, 83*(8), 621–625. https://doi.org/10.1177/003172170208300811

Bizans, J., & LeFevre, J. (1990). Strategic and nonstrategic processing in the development of mathematical cognition. In D. F. Bjorklund (Ed.), *Children's Strategies: Contemporary Views of Cognitive Development* (pp. 213-244). New Jersey, New York: Lawrence Erlbaum Associates.

Breien, F. S., & Wasson, B. (2020). Narrative categorization in digital game-based learning: Engagement, motivation & learning. *British Journal of Educational Technology, 52*(1), 91–111. https://doi.org/10.1111/bjet.13004

Bruner, J. (1985). Child's Talk: Learning to Use Language. *Child Language Teaching and Therapy*, *1*(1), 111–114. https://doi.org/10.1177/026565908500100113

Cazden, C. B. (1983). Peekaboo as an instructional model: Discourse development at home and at school. *The Sociogenesis of Language and Human Conduct*, 33–58. https://doi.org/10.1007/978-1-4899-1525-2_3

Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning, 19*(3), 347–359. https://doi.org/10.1046/j.0266-4909.2003.00036.x

Cho, K.-L., & Jonassen, D. H. (2002). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research and Development, 50(*3), 5–22. https://doi.org/10.1007/bf02505022

Choi, J.-I, & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational Technology Research and Development, 43(*2), 53–69. https://doi.org/10.1007/bf02300472

Clark, R. E. (2007). Learning from serious games? Arguments, evidence, and research suggestions. *Educational Technology, 47(*3), 56–59. https://www.jstor.org/stable/44429512

Crooks, N. M., & Alibali, M. W. (2014). Defining and measuring conceptual knowledge in mathematics. *Developmental Review, 34*(4), 344–377. https://doi.org/10.1016/j.dr.2014.10.001

Davis, E. A., & Linn, M. C. (2000). Scaffolding students' knowledge integration: prompts for reflection in KIE. *International Journal of Science Education, 22*(8), 819–837. https://doi.org/10.1080/095006900412293

Driscoll, M. P. (1994). *Psychology of learning for instruction.* Allyn & Bacon.

Dubé, A. K., & Keenan, A. (2016). Are games a viable home numeracy practice? In B. Blevins-Knabe & A. M. B. Austin (Eds.), *Early childhood mathematics skill development in the home environment* (pp. 165–184). Springer. https://doi.org/10.1007/978-3-319-43974-7_10

Dubé, A. K., Alam, S. S., Xu, C., Wen, R., & Kacmaz, G. (2019). Tablets as elementary mathematics education tools: Are they effective and why. *Mathematical learning and cognition in early childhood: Integrating interdisciplinary research into practice*, 223-248.

Fisher, C. (2017) *Designing games for children: Developmental, usability, and design considerations for making games for kids*. New York: Focal Press.

Foster, A., & Shah, M. (2015). The play curricular activity reflection discussion model for game-based learning. *Journal of Research on Technology in Education, 47*(2), 71–88. https://doi.org/10.1080/15391523.2015.967551

Gaskins, I. W., Rauch, S., Gensemer, E., Cunicelli, E., et al. (1997). Scaffolding the development of intelligence among children who are delayed in learning to read. In K. Hogan & M. Pressley (Eds.), *Scaffolding student learning: Instructional approaches and issues* (pp. 43–73). Brookline Books.

Ge, X. & Ifenthaler, D. (2018). Designing Engaging Educational Games and Assessing Engagement in Game-Based Learning. In I. Management Association (Ed.), *Gamification in Education: Breakthroughs in Research and Practice* (pp. 1-19). IGI Global. https://doi.org/10.4018/978-1-5225-5198-0.ch001

Gillies, R. M. (2008). The effects of cooperative learning on junior high school students' behaviours, discourse and learning during a science-based learning activity. *School Psychology International, 29*(3), 328–347. https://doi.org/10.1177/0143034308093673

Gillies, R. M., & Boyle, M. (2006). Ten australian elementary teachers' discourse and reported pedagogical practices during cooperative learning. *Elementary School Journal, 106*(5), 429–452. https://doi.org/10.1086/505439

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29*(3), 207-219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Hakkarainen, K. (2004). Pursuit of explanation within a computer-supported classroom. *International Journal of Science Education, 26*(8), 979–996. https://doi.org/10.1080/1468181032000354

Hannafin, M., Land, S., & Oliver, K. (1999). Open-ended learning environments: Foundations, methods, and models. In C. M. Reigeluth (Ed.), *Instructional design theories and models: Volume II. A new paradigm of instructional theory* (pp. 115–140). Mahwah, NJ: Erlbaum.

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching, 24*(4), 291–307. https://doi.org/10.1002/tea.3660240404

Helle, L., Tynjälä, P., Olkinuora, E., & Lonka, K. (2007). 'Ain't nothin' like the real thing'. Motivation and study processes on a work-based project course in information systems design. *British Journal of Educational Psychology, 77*(2), 397–411. https://doi.org/10.1348/000709906x105986

Hmelo, C., & Day, R. (1999). Contextualized questioning to scaffold learning from simulations. *Computers & Education, 32*(2), 151–164. https://doi.org/10.1016/s0360-1315(98)00062-1

Hsu, C. Y., Liang, J. C., & Su, Y. C. (2015). The role of the TPACK in game-based teaching: Does instructional sequence matter? *The Asia-Pacific Education Researcher, 24*, 463-470. https://doi.org/10.1007/s40299-014-0221-2

Hsu, C. Y., Liang, J. C., & Tsai, M. J. (2020). Probing the structural relationships between teachers' beliefs about game-based teaching and their perceptions of technological pedagogical and content knowledge of games. *Technology, Pedagogy and Education, 29(*3), 297-309. https://doi.org/10.1080/1475939X.2020.1752296

Hsu, C.-Y., Liang, J.-C., Chai, C.-S., & Tsai, C.-C. (2013). Exploring preschool teachers' technological pedagogical content knowledge of educational games. *Journal of Educational Computing Research, 49*(4), 461–479. https://doi.org/10.2190/EC.49.4.c

Hsu, C.-Y., Liang, J.-C., Chuang, T.-Y., Chai, C.-S., & Tsai, C.-C. (2021). Probing in-service elementary school teachers' perceptions of TPACK for games, attitudes towards games, and actual teaching usage: a study of their structural models and teaching experiences. *Educational Studies, 47*(6), 734–750. https://doi.org/10.1080/03055698.2020.1729099

Hsu, C.-Y., Tsai, M.-J., Chang, Y.-H., & Liang, J.-C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Educational Technology & Society, 20(*1), 134–143. https://www.jstor.org/stable/jeductechsoci.20.1.134

Jackson, S. L., Krajcik, J., & Soloway, E. (1998). The design of guided learning-adaptable scaffolding in interactive learning environments. In C.-M. Karat, A. Lund, J. Coutaz, & J. Karat (Eds.), *Proceedings of CHI 98: Human factors in computing systems* (pp. 187–194). Reading, MA: Addison-Wesley

Jadallah, M., Anderson, R. A., Nguyen-Jahiel, K., Miller, B. W., Kim, I.-H, Kuo, L.-J, Dong, T., & Wu, X. (2011). Influence of a teacher's scaffolding moves during child-led small-group discussions. *American Educational Research Journal, 48*(1), 194–230. https://doi.org/10.3102/0002831210371498

Kapp, K. M. (2012). *The gamification of learning and instruction: Game-based methods and strategies for training and education*. San Francisco: Pfeiffer.

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. Ferdig (Ed.), *Handbook of Research on Effective Electronic Gaming in Education* (pp. 1–32). New York: IGI Global.

Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*, 1729–1743. https://doi.org/10.1016/j.compedu.2008.05.004

King, A. (1998). Transactive peer tutoring: Distributing cognition and metacognition. *Educational Psychology Review, 10*(1), 57–74. https://doi.org/10.1023/a:1022858115001

Koedinger, K. R., & Aleven, V. (2016). An interview reflection on "Intelligent tutoring goes to school in the big city." *International Journal of Artificial Intelligence in Education, 26*(1), 13–24. https://doi.org/10.1007/s40593-015-0082-8

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: putting learning by design(tm) into practice. *The Journal of the Learning Sciences, 12*(4), 495–547. https://doi.org/10.1207/s15327809jls1204_2

Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of intelligent tutoring systems: A meta-analytic review. *Review of Educational Research, 86*(1), 42–78. https://doi.org/10.3102/0034654315581420

Lajoie, S. P. (2005). Extending the Scaffolding Metaphor. *Instructional Science, 33*(5–6), 541–557. https://doi.org/10.1007/s11251-005-1279-2

Lajoie, S. P., Guerrera, C., Munsie, S. D, & Lavigne, N. C. (2001). Constructing knowledge in the context of BioWorld. *Instructional Science, 29*(2), 155–186. https://doi.org/10.1023/a:1003996000775

Lamb, R., Antonenko, P., Etopio, E., & Seccia, A. (2018). Comparison of virtual reality and hands on activities in science education via functional near infrared spectroscopy. *Computers & Education, 124*, 14-26. https://doi.org/10.1016/j.compedu.2018.05.014

Lee, H.-S., Linn, M. C., Varma, K., & Liu, O. L. (2010). How do technology-enhanced inquiry science units impact classroom learning? *Journal of Research in Science Teaching, 47*(1), 71–90. https://doi.org/10.1002/tea.20304

Leerkes, E. M., Blankson, A. N., O'Brien, M., Calkins, S. D., & Marcovitch, S. (2011). The relation of maternal emotional and cognitive support during problem-solving to pre-academic skills in preschoolers. *Infant and Child Development,20,* 353–370. doi:10.1002/icd.728

LeFevre, J.-A., Fast, L., Skwarchuk, S.-L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., & Penner-Wilger, M. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development, 81*(6), 1753–1767. https://doi.org/10.1111/j.1467-8624.2010.01508.x

Li, D. D., & Lim, C. P. (2008). Scaffolding online historical inquiry tasks: A case study of two secondary school classrooms. *Computers & Education, 50*(4), 1394–1410. https://doi.org/10.1016/j.compedu.2006.12.013

Maloch, B. (2002). Scaffolding student talk: One teacher's role in literature discussion groups. *Reading Research Quarterly, 37*(1), 94–112. https://doi.org/10.1598/RRQ.37.1.4

Margulieux, L. E., & Catrambone, R. (2021). Scaffolding problem solving with learners' own self explanations of subgoals. *Journal of Computing in Higher Education, 33,* 499-523. https://doi.org/10.1007/s12528-021-09275-1

McNeill, K. L., & Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain-specific and domain-general knowledge in writing arguments to explain phenomena. *The Journal of the Learning Sciences, 18*(3), 416–460. https://doi.org/10.1080/10508400903013488

Mermelshtine, R., & Barnes, J. (2016). Maternal responsive–didactic caregiving in play interactions with 10-month-olds and cognitive development at 18 months. *Infant and Child Development,25*(3), 296–316. doi: 10.1002/icd.1961

Mertzman, T. (2008). Individualising scaffolding: teachers' literacy interruptions of ethnic minority students and students from low socioeconomic backgrounds. *Journal of Research in Reading, 31*(2), 183–202. https://doi.org/10.1111/j.1467-9817.2007.00356.x

Miller, S. P., & Hudson, P. J. (2007). Using evidence-based practices to build mathematics competence related to conceptual, procedural, and declarative knowledge. *Learning Disabilities Research & Practice, 22*(1), 47–57. https://doi.org/10.1111/j.1540-5826.2007.00230.x

Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Molenaar, I., Roda, C., van Boxtel, C., & Sleegers, P. (2012). Dynamic scaffolding of socially regulated learning in a computer-based learning environment. *Computers & Education*, *59*(2), 515-523. https://doi.org/10.1016/j.compedu.2011.12.006

Neitzel, C., & Stright, A. D. (2004). Parenting behaviours during child problem solving: The roles of child temperament, mother education and personality, and the problem-solving context. *International Journal of Behavioral Development,28*(2), 166–179. doi:10.1080/01650250344000370

Nousiainen, T., Kangas, M., Rikala, J., & Vesisenaho, M. (2018). Teacher competencies in game-based pedagogy. *Teaching and Teacher Education, 74*, 85-97. https://doi.org/10.1016/j.tate.2018.04.012

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning sciences*, *13*(3), 273-304. https://doi.org/10.1207/s15327809jls1303_2

Reiser, B. J., & Tabak, I. (2014). Scaffolding. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 44-62). Cambridge University Press.https://doi.org/10.1017/CBO9781139519526.005

Saxena, M. (2010). Reconceptualising teachers' directive and supportive scaffolding in bilingual classrooms within the neo-Vygotskyan approach. *Journal of Applied Linguistics & Professional Practice*, *7*(2), 163-184.

Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development, 50*(3), 77–96. https://doi.org/10.1007/bf02505026

Sharma, P., & Hannafin, M. J. (2007). Scaffolding in technology-enhanced learning environments. *Interactive Learning Environments, 15*(1), 27–46. https://doi.org/10.1080/10494820600996972

Sherin, B., Reiser, B. J., & Edelson, D. (2004). Scaffolding analysis: Extending the scaffolding metaphor to learning artifacts. *The Journal of the Learning Sciences, 13*(3), 387–421. https://doi.org/10.1207/s15327809jls1303_5

Shute, V. J., & Ke, F. (2012). Games, learning, and assessment. In *Assessment in Game-Based Learning* (pp. 43–58). New York: Springer.

Shute, V., Rahimi, S., Smith, G., Ke, F., Almond, R., Dai, C. P., Kuba, R., Liu, Z., Yang, X., & Sun, C. (2021). Maximizing learning without sacrificing the fun: Stealth assessment, adaptivity and learning supports in educational games. *Journal of Computer Assisted Learning*, *37*(1), 127-141. https://doi.org/10.1111/jcal.12473

Silliman, E. R., Bahr, R., Beasman, J., & Wilkinson, L. C. (2000). Scaffolds for learning to read in an inclusion classroom. *Language, Speech, and Hearing Services in Schools*, *31*(3), 265-279.

Silliman, E., & Wilkinson, L. C. (1994). Discourse scaffolds for classroom intervention. In *Language Learning Disabilities in School-Age Children and Adolescents*, ed. G. Wallach and K. Butler. New York: Pearson Higher Education.

Smith, B. K., & Reiser, B. J. (2005). Explaining behavior through observational investigation and theory articulation. *The Journal of the Learning Sciences, 14*(3), 315-360. https://doi.org/10.1207/s15327809jls1403_1

Spencer-Smith, G., & Hardman, J. (2014). The impact of computer and mathematics software usage on performance of school leavers in the Western Cape Province of South Africa: a comparative analysis. *International Journal of Education and Development using ICT*, *10*(1).

Stone, C. A. (1998). The metaphor of scaffolding: Its utility for the field of learning disabilities. *Journal of Learning Disabilities, 31*(4), 344-364. https://doi.org/10.1177/002221949803100404

Stright, A. D., Herr, M. Y., & Neitzel, C. (2009). Maternal scaffolding of children's problem solving and children's adjustment in kindergarten: Hmong families in the United States. *Journal of Educational Psychology,101*(1), 207–218. doi: 10.1037/a0013154

Su, Y., & Klein, J. (2010). Using scaffolds in problem-based hypermedia. *Journal of Educational Multimedia and Hypermedia*, *19*(3), 327-347.

Tabak, I. (2004). Synergy: A complement to emerging patterns of distributed scaffolding. *The Journal of the Learning Sciences, 13*(3), 305–335. https://doi.org/10.1207/s15327809jls1303_3

Tay, J., Goh, Y. M., Safiena, S., & Bound, H. (2022). Designing digital game-based learning for professional upskilling: A systematic literature review. *Computers & Education,* 104518. https://doi.org/10.1016/j.compedu.2022.104518

Tobias, S., Fletcher, J. D., & Wind, A. P. (2014). Game-based learning. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (pp. 485–503). New York, NY: Springer.

Tokarieva, A. V., Volkova, N. P., Harkusha, I. V., & Soloviev, V. N. (2019). Educational digital games: models and implementation. *Educational Dimension, 1*, 5-26. https://doi.org/10.31812/educdim.v53i1.3872

Troussas, C., Krouska, A., & Sgouropoulou, C. (2020). Collaboration and fuzzy-modeled personalization for mobile game-based learning in higher education. *Computers & Education*, *144,* 103698. https://doi.org/10.1016/j.compedu.2019.103698

Ustunel, H. H., & Tokel, S. T. (2018). Distributed scaffolding: Synergy in technology-enhanced learning environments. *Technology, Knowledge, and Learning, 23*(1), 129–160. https://doi.org/10.1007/s10758-017-9299-y

van Aalst, J., & Truong, M. S. (2011). Promoting knowledge creation discourse in an asian primary five classrooms: Results from an inquiry into life cycles. *International Journal of Science Education, 33*(4), 487–515. https://doi.org/10.1080/09500691003649656 van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review, 22*(3), 271–296. https://doi.org/10.1007/s10648-010-9127-6

van de Pol, J., Volman, M., & Beishuizen, J. (2011). Patterns of contingent teaching in teacher–student interaction. *Learning and Instruction, 21*(1), 46–57. https://doi.org/10.1016/j.learninstruc.2009.10.004

Vygotsky, L. S. (1978). *Mind in society: Development of higher psychological processes.* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.) Cambridge, MA: Harvard University Press.

Vygotsky, L.S. (1987). Thinking and speech. In The *collected works of L.S. Vygotsky. Problem Of General Psychology* (Vol.1, pp.37–285) (translated by Norris Minick). NewYork, London: Plenum Press.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind.* Cambridge, MA: Harvard University Press.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. Journal of Child Psychology and Psychiatry, 17(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching, 38*(7), 821-842. https://doi.org/10.1002/tea.1033

Wu, W. H., Hsiao, H. C., Wu, P. L., Lin, C. H., & Huang, S. H. (2012). Investigating the learning-theory foundations of game-based learning: A meta-analysis. *Journal of*

Computer Assisted Learning, 28(3), 265–279. https://doi.org/10.1111/j.1365-2729.2011.00437.x

Wu, Y.-T., & Anderson, O. R. (2015). Technology-enhanced stem (science, technology, engineering, and mathematics) education. *Journal of Computers in Education, 2*(3), 245–249. https://doi.org/10.1007/s40692-015-0041-2

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–89. https://doi.org/10.3102/0034654312436980

Yu, F. Y., Tsai, H. C., & Wu, H. L. (2013). Effects of online procedural scaffolds and the timing of scaffolding provision on elementary Taiwanese students' question-generation in a science class. Australasian Journal of Educational Technology, 29(3). https://doi.org/10.14742/ajet.197

Yu, Z., Gao, M., & Wang, L. (2021). The effect of educational games on learning outcomes, student motivation, engagement and satisfaction. *Journal of Educational Computing Research, 59*(3), 522–546. https://doi.org/10.1177/0735633120969214

Bridging Text

Chapter 2 provided a comprehensive literature review for determining the relative factors that influence the effectiveness of game-based learning. First, the review provided an overview of various game-related factors, such as a game's pedagogical foundations, game knowledge types, and game impact on learning outcomes. Additionally, the review explored teacher- and pedagogy-related factors that can impact the successful implementation of GBL, such as teachers' scaffolding usages in GBL environments, their knowledge of games, game content, and game pedagogical knowledge, as well as their teaching experiences. Furthermore, the review discusses the fundamental theories underlying the subsequent works presented in each section or explains the rationale behind the approaches presented in the studies by providing literature findings.

The studies presented in this thesis aim to elucidate the various factors underlying the effectiveness of game-based learning. Specifically, three studies were conducted to explore game- and teacher-related factors and provide an overall understanding of the effective implementation of game-based learning. In Chapter 3, the impact of a game's pedagogical foundations on game-based learning outcomes is explored, explicitly investigating whether different pedagogical approaches impact the different types of knowledge provided by games. This is an essential consideration as a game's pedagogical approach may influence the pedagogical strategies teachers use to facilitate learning. Thus, a systematic review and meta-analysis approach was employed in Chapter 3 to understand the impact of the pedagogical foundations of games on learning outcomes.

Chapter 3. Manuscript 1

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 pedagogical 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.

Keywords: Pedagogical approaches, Math knowledge, Effectiveness, Math games, Meta-analysis

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 et al., 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 et al., 2016; FAS, 2006; Wouters & van Oostendorp, 2013). Although research has supported the use of games as pedagogical tools (Boyle et al., 2016; Girard et al., 2013; Outhwaite et al., 2019), how educators approach learning and delivering curricula via games varies in effectiveness (Olney et al., 2008). In particular, studies highlight the challenges teachers face in 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 et al., 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 hamper educators because they must spend considerable time engaging with each game to understand its suitability and relevance for their classroom (Callaghan & Reich, 2018; Dubé, et al., 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 et al., 2014; Outhwaite et al., 2017). However, due to the lack of empirical evidence on the effectiveness and quality of educational math games, few conclusions can be drawn, (Fabian et al., 2016; Mayer, 2014; O'Neil et al., 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 et al., 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, 2022, 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.

Literature review

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 et al., 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 et al., 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 et al., 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 limit 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 et al., 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.

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 et al., 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 et al., 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 et al., 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.

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?

Method

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) keywords 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) keywords 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 games or mobile math game studies published in the years 2010–2020. The initial search resulted in 713 articles. Duplicates were removed, and 627 articles remained.

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 et al., 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 the flow diagram for search characteristics).

Coding Procedure (Categorization)

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 (Adapted 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.

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.

Table 2

Definition of Math Knowledge Types Adapted from Bizans 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 process 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.

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 et al., 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 groups' 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 *SD*s 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 et al. (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 et al., 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).
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.

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 Saleway (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	✓		✓
	Mertens, De Smedy, Sasangue, Bles, and Reynvoer (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	✓		✓
	Beser 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	✓		✓
	Kebritchi, Hirumi, and Bai (2010)	Algebra	193	Grade 9-10	18 weeks, 30 min each week	✓	✓	✓
	Bai, Pan, Hirumi, and Rebritchi (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, Kalogiamakis, 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-Fanhuizen 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		✓	✓
	Brevazky 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	Ricorsente (2013)	Fractions, Proportions, and Number Line	122	Grade 4	5-day, 20 min each day			✓
Approaches	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%

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.

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 Kebritchi and Hirumi's (2008) pedagogical approaches and aimed to improve all types of mathematical knowledge (see Table 3). For the 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 or 11.52%) 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%).

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, an 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.

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 A.

Direct Instruction

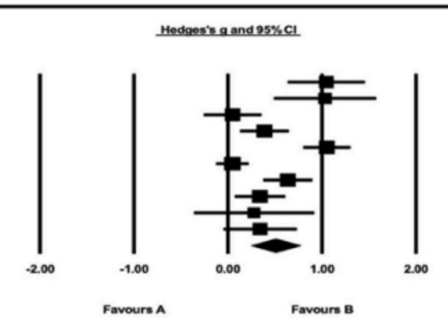
Overall, direct instruction games have a medium sized effect on mathematical learning (n = 10; g = 0.510, 95% CI [0.25, 0.77], p < 0.001, See Fig. 1). For the individual learning outcomes, effects ranged from negative (Symbolic Number Line Estimation g = − 1.069; Maertens et al., 2016) to positive (Math Curriculum Knowledge g = 1.945; Outhwaite et al., 2017; see Appendix A). 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).

Figure 1

Effect Sizes, Statistics, and Forest Plot of Direct Instruction

Direct Instruction

Study name	Outcome	Statistics for each study						
		Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
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



Experiential Learning

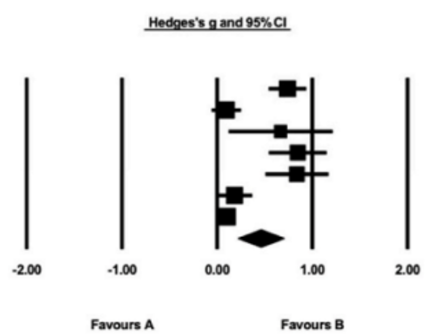
Overall, experiential learning games have a medium effect on mathematical learning (n = 7; g = 0.46, 95% CI [0.22, 0.70], $p < 0.001$, See Fig. 2). For the individual learning outcomes, effects ranged from small (Multiplicative Problem-Solving g = 0.000; Bakker et al., 2015) to large (Problem-Solving Skills g = 0.98; Ke, 2019; see Appendix A). 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.

Figure 2

Effect Sizes, Statistics, and Forest Plot of Experiential Learning

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



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 A). 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).

Figure 3

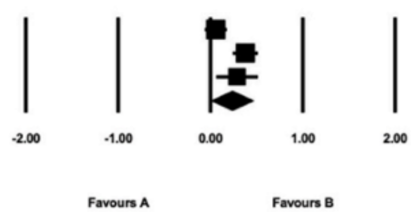
Effect Sizes, Statistics, and Forest Plot of Discovery Learning

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

Statistics for each study

Hedges's g and 95% CI



Constructivism

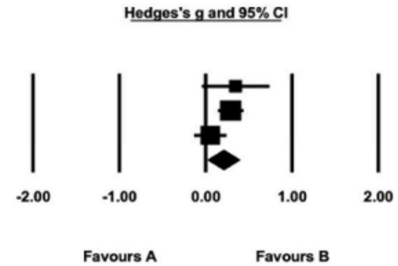
Overall, constructivist learning games targeted conceptual knowledge and produced small effects (n = 3; g = 0.208, 95% CI [0.02, 0.39], $p < 0.001$, See Fig. 4 and Table 4). For the individual learning outcomes, effects ranged from g = 0.049 (Number Line, Ratio, and Proportion Concepts; Valdez et al.,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

Figure 4

Effect Sizes, Statistics, and Forest Plot of Constructivism

Constructivism

Study name	Outcome	Statistics for each study						
		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



Unclassified Approaches

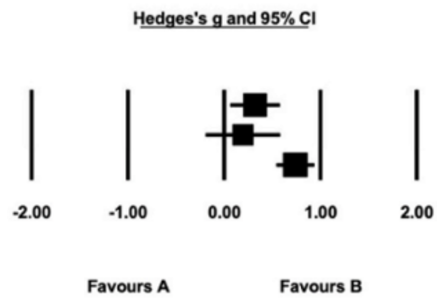
Games with unclassified or other approaches used various pedagogical approaches but all of them targeted conceptual knowledge. For the individual learning outcomes, effects ranged from small (Math Proficiency *g* = 0.056; Chang et al., 2015; see Fig. 5) to larger (Number Sense *g* = 0.74; Schacter et al., 2016; see Appendix A). 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.

Figure 5

Effect Sizes, Statistics, and Forest Plot of Unclassified/Other Approaches

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



Discussion

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 consist 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 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.

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]	< .001	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
	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]	0.026	0.000	0.000
	Conceptual	3	0.208	[0.02,0.39]	0.026	9.935	79.870
	Conceptual	3	0.443	[0.1,0.79]	0.01		

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.

How Effective is Each Pedagogical Approach at Improving Each Knowledge Type?

The current meta-analysis is the first to evaluate 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 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 et al., 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?

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, 2022, 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.

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 et al., 2001; Hidi, 2006). Future studies should include these other moderators that may also impact game-based math learning.

References

Amory, A., Naicker, K., Vincent, J., & Adams, C. (1999). The use of computer games as an educational tool: Identification of appropriate game types and game elements. *British Journal of Educational Technology, 30*(4), 311–321. https://doi.org/10.1111/1467-8535.00121

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., De Freitas, S., Louchart, S., et al. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology, 46*(2), 391–411. https://doi.org/10.1111/bjet.12113

Bai, H., Pan, W., Hirumi, A., & Kebritchi, M. (2012). Assessing the effectiveness of a 3-D instructional game on improving mathematics achievement and motivation of middle school students. *British Journal of Educational Technology, 43(*6), 993–1003. https://doi.org/10.1111/j.1467-8535.2011.01269.x

Bakker, M., van den Heuvel-Panhuizen, M., & Robitzsch, A. (2015). Effects of playing mathematics computer games on primary school students' multiplicative reasoning ability. *Contemporary Educational Psychology, 40,* 55–71. https://doi.org/10.1016/j.cedpsych.2014.09.001

Baroody, A. J., Feil, Y., & Johnson, A. R. (2007). An alternative reconceptualization of procedural and conceptual knowledge. *Journal for Research in Mathematics Education,* 115–131. https://doi.org/10.2307/30034952

Beserra, V., Nussbaum, M., & Grass, A. (2017). Using a fine-grained multiple-choice response format in educational drill-and-practice video games. *Interactive Learning Environments, 25*(6), 717–732. https://doi.org/10.1080/10494820.2016.1172244

Bisanz, J., & LeFevre, J. A. (1990). Strategic and nonstrategic processing in the development of mathematical cognition. In D. F. Bjorklund (Ed.), *Children's strategies: Contemporary views of cognitive development* (pp. 213–244). Hillsdale: Lawrence Erlbaum Associates, Inc.

Blumberg, F. C., Deater-Deckard, K., Calvert, S. L., Flynn, R. M., Green, C. S., Arnold, D., et al. (2019). Digital games as a context for children's cognitive development: Research recommendations and policy considerations. *Social Policy Report, 32*(1), 1–33. https://doi.org/10.1002/sop2.3

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein. (2011). Introduction to meta-analysis. John Wiley & Sons.

Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2014). Comprehensive meta-analysis (version 3). Englewood, NJ: Biostat.

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., et al. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education, 94,* 178–192. https://doi.org/10.1016/j.compedu.2015.11.003

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research–A systematic review of recent trends. *Computers & Education, 114,* 255–273. https://doi.org/10.1016/j.compedu.2017.07.004

Brezovszky, B., McMullen, J., Veermans, K., Hannula-Sormunen, M. M., Rodríguez-Aflecht, G., Pongsakdi, N., et al. (2019). Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge. *Computers & Education, 128,* 63–74. https://doi.org/10.1016/j.compedu.2018.09.011

Callaghan, M. N., & Reich, S. M. (2018). Are educational preschool apps designed to teach? An analysis of the app market. *Learning, Media and Technology, 43*(3), 280–293. https://doi.org/10.1080/17439884.2018.1498355

Chang, M., Evans, M. A., Kim, S., Norton, A., & Samur, Y. (2015). Differential effects of learning games on mathematics proficiency. *Educational Media International, 52* (1), 47–57. https://doi.org/10.1080/09523987.2015.1005427

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86*(1), 79–122. DOI: 10.3102/0034654315582065

Clark, R. E. (2007). Learning from serious games? Arguments, evidence, and research suggestions. *Educational Technology, 47*(3), 56–59. https://www.jstor.org/stable/44429512

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Routledge.

Conole, G., Dyke, M., Oliver, M., & Seale, J. (2004). Mapping pedagogy and tools for effective learning design. *Computers & Education, 43*(1–2), 17–33. https://doi.org/10.1016/j.compedu.2003.12.018

Crooks, N. M., & Alibali, M. W. (2014). Defining and measuring conceptual knowledge in mathematics. *Developmental Review, 34(*4), 344–377. https://doi.org/10.1016/j.dr.2014.10.001

Deci, E. L., Koestner, R., & Ryan, R. M. (2001). Extrinsic rewards and intrinsic motivation in education: Reconsidered once again. *Review of Educational Research, 71* (1), 1–27. https://doi.org/10.3102/00346543071001001

Deen, M., Van den Beemt, A., & Schouten, B. (2015). The differences between problem-based and drill and practice games on motivations to learn. *International Journal of Gaming and Computer-Mediated Simulations, 7*(3), 44–59.

Dewey, J. (1938). *Experience and education.* New York: Simon and Schuster.

Dubé, A. K., & Keenan, A. (2016). Are games a viable home numeracy practice? In B. Blevins-Knabe & A. M. B. Austin (Eds.), *Early childhood mathematics skill development in the home environment* (pp. 165–184). Springer.

Dubé, A. K., & Wen, R. (2022). Identification and evaluation of technology trends in K-12 education from 2011 to 2021. *Education and Information Technologies, 27*(2), 1929-1958. https://doi.org/10.1007/s10639-021-10689-8

Dubé, A. K., Alam, S. S., Xu, C., Wen, R., & Kacmaz, G. (2019a). Tablets as elementary mathematics education tools: Are they effective and why? *Mathematical learning and cognition in early childhood: Integrating interdisciplinary research into practice*, (pp. 223–248). Cham: Springer.

Dubé, A. K., Kacmaz, G., Wen, R., Alam, S. S., & Xu, C. (2020). Identifying quality educational apps: Lessons from 'top' mathematics apps in the Apple App store. *Education and Information Technologies*, *25*, 5389-5404. https://doi.org/10.1007/s10639-020-10234-z

Ellis, M. W., & Berry, R. Q., III (2005). The paradigm shifts in mathematics education: Explanations and implications of reforming conceptions of teaching and learning. *Mathematics Educator,* 15(1).

Fabian, K., Topping, K. J., & Barron, I. G. (2016). Mobile technology and mathematics: Effects on students' attitudes, engagement, and achievement. *Journal of Computers in Education, 3*(1), 77–104. https://doi.org/10.1007/s40692-015-0048-8

Federation of Academic Scientists. (2016). *Harnessing the power of video games for learning*. Retrieved March 30, 2023, from https://www.informalscience.org/sites/default/files/Summit_on_Educational_Games.pd

Foster, A., & Shah, M. (2015). The play curricular activity reflection discussion model for game-based learning. *Journal of Research on Technology in Education, 47*(2), 71–88. https://doi.org/10.1080/15391523.2015.967551

Frenzel, A. C., Goetz, T., Pekrun, R., & Watt, H. M. (2010). Development of mathematics interest in adolescence: Influences of gender, family, and school context. *Journal of Research on Adolescence, 20(*2), 507–537. https://doi.org/10.1111/j.1532-7795.2010.00645.x

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: How effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29*(3), 207–219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Hattie, J. (2009). *Visible learning: A synthesis of over meta-analyses relating to achievement.* London: Routledge.

Hedges, L. V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational Statistics, 6,* 107–112. https://doi.org/10.3102/10769986006002107

Hidi, S. (2006). Interest: A unique motivational variable. *Educational Research Review, 1*(2), 69–82. https://doi.org/10.1016/j.edurev.2006.09.001

Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in "educational" apps: Lessons from the science of learning. *Psychological Science in the Public Interest, 16*(1), 3–34. https://doi.org/10.1177/1529100615569721

Holman, B. (2018). In defense of meta-analysis. Synthese, 196(8), 3189–3211. https://doi.org/10.1007/s11229-018-1690-2

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277–1288. https://doi.org/10.1177/10497323052766

Johnston, E., Olivas, G., Steele, P., Smith, C., & Bailey, L. (2018). Exploring pedagogical foundations of existing virtual reality educational applications: A content analysis study. *Journal of Educational Technology Systems, 46*(4), 414–439. https://doi.org/10.1177/0047239517745560

Ke, F. (2019). Mathematical problem solving and learning in an architecture-themed epistemic game. *Educational Technology Research & Development, 67*(5), 1085–1104. https://doi.org/10.1007/s11423-018-09643-2

Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51,* 1729–1743. https://doi.org/10.1016/j.compedu.2008.05.004

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education, 55*(2), 427–443. https://doi.org/10.1016/j.compedu.2010.02.007

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education, 8*(1), 13–24. https://doi.org/10.1016/j.iheduc.2004.12.001

Kiili, K., Ketamo, H., Koivisto, A., & Finn, E. (2014). Studying the user experience of a tablet-based math game. *International Journal of Game-Based Learning (IJGBL), 4*(1), 60–77. http://doi.org/10.4018/IJGBL.2014010104

Kirriemuir, J., & McFarlane, A. (2004). *Literature review in games and learning*. Futurelab. Retrieved March 30, 2023, from http://www.futurelab.org.uk/resources/documents/lit_reviews/Games_Review.pdf.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development.* Englewood Cliffs, NJ: Prentice-Hall.

Larkin, K. (2015). "An app! An app! My kingdom for an app": An 18-month quest to determine whether apps support mathematical knowledge building. *Digital games and mathematics learning: Potential, promises and pitfalls*, 251-276.

Lee, J., Andrade, S., Negotie, A., Li, C., Aruliah, R., Wood, E., & June. (2019). Do math apps "teach" numeracy skills to young children? In *paper presented at the 2019 the Mathematical Cognition and Learning Society Conference, Ottawa.*

LeFevre, J. A., Fast, L., Skwarchuk, S. L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., et al. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development, 81*(6), 1753–1767. https://doi.org/10.1111/j.1467-8624.2010.01508.x

Lenhart, A., Smith, A., Anderson, M., Duggan, M., & Perrin, A. (2015). *Teens, technology and friendships.* Pew Research Center. Retrieved March 30, 2023, from http://www.pewinternet.org/2015/08/06/teens-technology-and-friendships/.

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis*. SAGE publications, Inc.

Maertens, B., De Smedt, B., Sasanguie, D., Elen, J., & Reynvoet, B. (2016). Enhancing arithmetic in pre-schoolers with comparison or number line estimation training: Does it matter? *Learning and Instruction, 46,* 1–11. https://doi.org/10.1016/j.learninstruc.2016.08.004

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science, 5*(4), 333–369. https://doi.org/10.1016/S0364-0213(81)80017-1

Mayer, R. E. (2014). *Computer games for learning: An evidence-based approach*. MIT Press.

Mayring, P. (2004). Qualitative content analysis. *A Companion to Qualitative Research*, *1*(2), 159–176.

McEwen, R. N., & Dubé, A. K. (2015). Engaging or distracting: children's tablet computer use in education. *Journal of Educational Technology & Society, 18*(4), 9.

McEwen, R., & Dubé, A. K. (2016). Intuitive or idiomatic: An interdisciplinary study of child-tablet computer interaction. *Journal of the Association for Information Science and Technology, 67*(5), 1169–1181. https://doi.org/10.1002/asi.23470

McLaren, B. M., Adams, D. M., Mayer, R. E., & Forlizzi, J. (2017). A computer-based game that promotes mathematics learning more than a conventional approach. *International Journal of Game-Based Learning (IJGBL), 7*(1), 36–56. http://doi.org/10.4018/IJGBL.2017010103

McManis, L. D., & Gunnewig, S. B. (2012). Finding the education in educational technology with early learners. *Young Children, 67*(3), 14–24.

Miller, S. P., & Hudson, P. J. (2007). Using evidence-based practices to build mathematics competence related to conceptual, procedural, and declarative knowledge. *Learning*

Disabilities Research & Practice, 22(1), 47–57. https://doi.org/10.1111/j.1540-5826.2007.00230.x

O'Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: Evidence from the computer games literature. *Curriculum Journal, 16*(4), 455–474. https://doi.org/10.1080/09585170500384529

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), 50–70. http://dx.doi.org/10.14221/ajte.2017v42n10.4

OECD (2020). *OECD Economic Outlook Volume Issue 1: Preliminary Version.* Retrieved September 15, 2020, from https://www.oecd.org/economy/greece-economic-snapshot/.

Ok, M. W., Kim, M. K., Kang, E. Y., & Bryant, B. R. (2016). How to find good apps: An evaluation rubric for instructional apps for teaching students with learning disabilities. *Intervention in School and Clinic, 51*(4), 244–252. https://doi.org/10.1177/105345121558917

Olney, I., Herrington, J. & Verenikina, I. (2008) *iPods in early childhood: Mobile technologies and storytelling.* In: Proceedings ASCILITE 2008 - Hello! Where are you in the Landscape of Educational Technology? Melbourne, Australia pp. 696-700.

Ormrod, J. E. (1995). *Educational psychology: Principles and applications.* Merrill.

Outhwaite, L. A., Faulder, M., Gulliford, A., & Pitchford, N. J. (2019). Raising early achievement in math with interactive apps: A randomized control trial. *Journal of Educational Psychology, 111(*2), 284. https://doi.org/10.1037/edu0000286

Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2017). Closing the gap: Efficacy of a tablet intervention to support the development of early mathematical skills in UK primary school children. *Computers & Education, 108,* 43–58. https://doi.org/10.1016/j.compedu.2017.01.011

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018). The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece. *Education and Information Technologies, 23*(5), 1849–1871. https://doi.org/10.1007/s10639-018-9693-7

Pitchford, N. J. (2015). Development of early mathematical skills with a tablet intervention: A randomized control trial in Malawi. *Frontiers in Psychology, 6,* 485. https://doi.org/10.3389/fpsyg.2015.00485

Plass, J. L., O'Keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., et al. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology, 105*(4), 1050. https://doi.org/10.1037/a0032688

Prensky, M. (2001). Digital Natives, Digital Immigrants Part 1. *On the Horizon, (9)*5,1-6. https://doi.org/10.1108/10748120110424816

Riconscente, M. M. (2013). Results from a controlled study of the iPad fractions game Motion Math. *Games and Culture, 8*(4), 186–214. https://doi.org/10.1177/15554120134968

Rideout, V., & Robb, M. B. (2019). *The Common sense census: Media use by tweens and teens, 2019.* San Francisco: Common Sense Media. Retrieved March 30, 2023, from https://www. commonsensemedia.org/sites/default/files/uploads/research/2019-census-8-to-18-key-findings-updated.pdf.

Rittle-Johnson, B. (2006). Promoting transfer: effects of self-explanation and direct instruction. *Child Development, 77,* 1–15. doi:10.1111/j.1467-8624.2006.00852.x.

Rittle-Johnson, B., & Siegler, R. S. (1998). The relation between conceptual and procedural knowledge in learning mathematics: A review. In C. Donlan (Ed.), *The development of mathematical skills* (pp. 75–110). London: Psychology Press.

Rittle-Johnson, B., Schneider, M., & Star, J. R. (2015). Not a one-way street: Bidirectional relations between procedural and conceptual knowledge of mathematics. *Educational Psychology Review, 27*(4), 587–597. https://doi.org/10.1007/s10648-015-9302-x

Rittle-Johnson, B., Siegler, R. S., & Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: an iterative process. *Journal of Educational Psychology, 93,* 346–362. doi:10.1037//0022-0663.93.2.346.

Rittle-Johnson, B. (2017). Developing mathematics knowledge. *Child Development Perspectives, 11*(3), 184-190. https://doi.org/10.1111/cdep.12229

Rutherford, T., Farkas, G., Duncan, G., Burchinal, M., Kibrick, M., Graham, J., et al. (2014). A randomized trial of an elementary school mathematics software intervention: Spatial-temporal math. *Journal of Research on Educational Effectiveness, 7*(4), 358–383. https://doi.org/10.1080/19345747.2013.856978

Schacter, J., Shih, J., Allen, C. M., DeVaul, L., Adkins, A. B., Ito, T., et al. (2016). Math shelf: A randomized trial of a prekindergarten tablet number sense curriculum. *Early Education & Development, 27*(1), 74–88. https://doi.org/10.1080/10409289.2015.1057462

Shin, N., Sutherland, L. M., Norris, C. A., & Soloway, E. (2012). Effects of game technology on elementary student learning in mathematics. *British Journal of Educational Technology, 43*(4), 540–560. https://doi.org/10.1111/j.1467-8535.2011.01197.x

Stegenga, J. (2011). Is meta-analysis the platinum standard of evidence? *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences, 42*(4), 497-507. https://doi.org/10.1016/j.shpsc.2011.07.003

Valdez, A., Trujillo, K., & Wiburg, K. (2013). Math Snacks: Using animations and games to fill the gaps in mathematics. *Journal of Curriculum and Teaching, 2*(2), 154–161. http://dx.doi.org/10.5430/jct.v2n2p154

van den Heuvel-Panhuizen, M., Kolovou, A., & Robitzsch, A. (2013). Primary school students' strategies in early algebra problem solving supported by an online game. *Educational Studies in Mathematics, 84*(3), 281–307. https://doi.org/10.1007/s10649-013-9483-5

van der Ven, F., Segers, E., Takashima, A., & Verhoeven, L. (2017). Effects of a tablet game intervention on simple addition and subtraction fluency in first graders. *Computers in Human Behavior, 72,* 200–207. https://doi.org/10.1016/j.chb.2017.02.031

Wang, S. Y., Chang, S. C., Hwang, G. J., & Chen, P. Y. (2018). A microworld-based role-playing game development approach to engaging students in interactive, enjoyable, and effective mathematics learning. *Interactive Learning Environments, 26*(3), 411–423. https://doi.org/10.1080/10494820.2017.1337038

Wiburg, K., Chamberlin, B., Valdez, A., Trujillo, K., & Stanford, T. (2016). Impact of Math Snacks games on students' conceptual understanding. *Journal of Computers in*

Mathematics and Science Teaching, 35(2), 173–193. https://eric.ed.gov/?id=EJ1095367

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60* (1), 412–425. https://doi.org/10.1016/j.compedu.2012.07.018

Wu, W. H., Chiou, W. B., Kao, H. Y., Hu, C. H. A., & Huang, S. H. (2012). Re-exploring game-assisted learning research: The perspective of learning theoretical bases. *Computers & Education, 59*(4), 1153–1161. https://doi.org/10.1016/j.compedu.2012.05.003

Wu, W. H., Hsiao, H. C., Wu, P. L., Lin, C. H., & Huang, S. H. (2012). Investigating the learning-theory foundations of game-based learning: A meta-analysis. *Journal of Computer Assisted Learning, 28*(3), 265–279. https://doi.org/10.1111/j.1365-2729.2011.00437.x

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. https://doi.org/10.1186/s41039-019-0100-9

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., et al. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–89. https://doi.org/10.3102/0034654312436980

Bridging Text

In Chapter 3, I conducted a meta-analysis that systematically reviewed math game studies published between 2010 and 2020. The goal was to evaluate their pedagogical approach and effectiveness in teaching different types of mathematics knowledge. The analysis addressed various unanswered questions about using games in math education, such as the pedagogical approaches used in mathematics games to support mathematical learning, the types of mathematics knowledge promoted by mathematics games, and how effective each pedagogical approach is at improving each knowledge type. The findings revealed that the choice of pedagogical approach used in math games is critical for promoting mathematical learning. By analyzing the design of games, we can better understand how to create effective game-based learning environments. Furthermore, I discussed some future directions for research in game-based learning, emphasizing the significant role teachers play in this context. The way teachers support their students in using games can influence the game's usefulness and potentially impact the pedagogical approach within the game. Therefore, future research should investigate how teacher scaffolding affects the effectiveness of different types of games. However, an important aspect neglected in this chapter is measuring teachers' scaffolding practices provided in GBL.

In Chapter 4, I introduce a novel self-report questionnaire that measures teacher scaffolding usage in GBL environments and validate this measure both internally and externally with related constructs. Additionally, this study examines how teachers' use of scaffolds is affected by two antecedent factors: the perceived availability of school resources and teachers general use of game-based pedagogies. Drawing on the fundamental theory of scaffolding provided by Wood et al. (1976), I aim to streamline the categorization of common scaffolding practices by comparing different models and proposing a new classification system based on more recent scaffolding studies. The chapter concludes with recommendations for future studies on measuring scaffolding usage in GBL environments. By offering a valuable instrument to evaluate GBL practices, this significant methodological contribution has practical implications for educators.

Taken together, these studies highlight the importance of considering both game and teacher factors in designing effective game-based learning experiences. While games with a clear pedagogical approach can be effective in promoting learning outcomes, the role of the teacher in scaffolding learning during gameplay is also crucial. By understanding how game and teacher factors interact, educators and game designers can create more effective game-based learning experiences that maximize learning outcomes for students.

Chapter 4. Manuscript 2

Comparing and Validating the Three-Measurement Models of Teacher Scaffolding Questionnaire during Game-based Learning and Relationship with its Antecedents

Kacmaz, G., & Dubé, A. K. (In preparation). Comparing and Validating the Three-Measurement Models of Teacher Scaffolding Questionnaire during Game-based Learning and Relationship with its Antecedents. *Learning Environments Research.*

Abstract

While previous studies of teacher (e.g., gender, teaching experience) and affective factors (e.g., attitudes, beliefs) provide essential information on the successful integration of games into classrooms, little is known about how teachers scaffold learning during gameplay in game-based learning environments. Thus, this pilot cross-sectional study developed and tested a teacher scaffolding questionnaire during game-based learning (TSQ-GBL) and further examines whether the perceived availability of school resources (PA-SR) and general game-based pedagogies use (GBP-use) affects teachers' scaffolding use. 180 K-12 in-service teachers were recruited to 1) validate the TSQ-GBL measure and b) explore the relationship (i.e., direct and indirect effects) between the TSQ-GBL, PA-SR, and GBP-use. The results supported a 3-discrete dimension measurement model, including cognitive, transfer of responsibility, and emotional scaffolding types. Findings also revealed that GBP use has a direct effect, whereas PA-SR indirectly affects the use of scaffolds and their types in game-based learning environments.

Keywords: Teacher Scaffolding, Game-Based Learning, Self-Report Measure, Teachers

Interest in research on games is continuously growing. While the majority of previous studies of teacher (e.g., gender, teaching experience) and affective factors (e.g., acceptance, attitudes, beliefs) provide essential information on the successful integration of games into classrooms, the role that teachers play and how they facilitate learning during game-based learning (GBL) has received minimal attention and still remains an unexplored area of research (Girard et al., 2013; Hanghøj & Brund, 2011; Ke, 2009; Tzuo et al., 2012; Watson et al., 2011).

In the context of game-based learning, teachers have significant roles in enhancing learning and motivation and designing the game-based learning processes. These perspectives have been highlighted in numerous studies that present pedagogical frameworks specifically aimed at integrating games into classroom settings. For instance, Sørensen (2011) introduces the concept of educational design, encompassing learning objectives, subject-related content selection, planning, and organizing learning processes within game-based learning. Another example is the Play Curricular activity Reflection Discussion (PCaRD) presented by Foster and Shah (2015), which emphasizes the teacher's role as an agent connecting game-based learning to the curriculum. Additionally, research conducted by Kangas et al. (2016) has identified teachers' pedagogical activities across various game-based learning processes, including planning, orientation, during the gaming sessions, and after the game-play sessions. Despite the significance of teachers in game-based learning, there is a lack of understanding about the specific facilitation strategies that teachers employ to support learning during game-based activities.

Some of the biggest challenges teachers face implementing games into lessons is making connections between the knowledge learned in the game and the knowledge taught in the class, as well as guiding the learning process and gameplay experience (Clark et al., 2011; Eastwood &

Sadler, 2013; Habgood & Ainsworth, 2011; Van Eck, 2006). For example, if the gameplay intended to convey the underlying academic skill is too unfamiliar for a student, it may obfuscate the intended skill and disengage the learner. In such a case, an instructional approach for overcoming this difficulty is supplementing external scaffolding by teachers to build connections and keep the student interested and engaged (Barzilai & Blau, 2014; Charsky & Ressler, 2011; Chen & Law, 2016; Haataja et al., 2019; Pata et al., 2005). This highlights teachers' critical role in GBL environments, as integrating external scaffolding might be the key to improving students' subject knowledge and gameplay experience.

In the literature, game-based learning (GBL) is defined as activities with a game at their core and learning as a desired or incidental outcome (Kirriemuir & McFarlane, 2004). Teachers play various roles in GBL environments (Kangas et al., 2017), such as playmakers (i.e., communicating tasks, roles, goals, and dynamics of the game), evaluators (i.e., analyzing students' understanding and experiences of the gameplay), tutors (i.e., supporting students during gameplay in one-o-one), and instructors (i.e., planning and communicating learning goals). Additionally, teachers can serve as facilitators by structuring the game task, reducing complexities, making thinking strategies explicit, and directing student's attention to the learning outcomes in GBL environments (Barzilai & Blau, 2014; Haataja et al., 2019; Rienties et al., 2012; Watson et al., 2011). As a result, students can progress more deeply, have more control over their problem-solving learning process, and meet learning objectives with the help of scaffolding (Barzilai & Blau, 2014; Rienties et al., 2012; Waiyakoon et al., 2015). Overall, GBL is a powerful tool that allows teachers to take various roles and use scaffolds to support students in achieving their learning objectives.

Furthermore, teachers can positively influence students' attitudes and their persistence in learning by providing guidance and asking questions and allowing students to share their knowledge and experiences during GBL (Barzilai & Blau, 2014; Chen & Law, 2016; Muhonen et al., 2016; Rienties et al., 2012). Teachers can also act as facilitators by providing different types of scaffolding, such as helping them learn to control the game, directing learning and gameplay, demonstrating various gameplay strategies, drawing students' attention to important events, encouraging them to engage in the discussion, and providing various resources and instant feedback (Haruehansawasin & Kiattikomol, 2018). Further, according to the observational study Sun et al. (2021) conducted, teachers can provide whole class scaffolding that enables the congruity between students' gameplay experience and conceptual understanding of subject knowledge. This study revealed that teacher scaffolding can help students become familiar with the gameplay and take greater control over their problem-solving while learning more from it (Sun et al., 2021). However, incorporating scaffolding in gameplay also risks "*negatively influence[ing] students' views of learning and enjoyment in the game*." (Barzilai & Blau, 2014). For this reason, it is important to identify the range and efficacy of teacher scaffolding types in GBL environments so that students' learning, engagement, and gameplay are positively affected (Barzilai & Blau, 2014; Chen & Law, 2016; Pata et al., 2005; Rienties et al., 2012).

Theoretical Background

Teacher Scaffoldings in Game-based Learning Environments

Studies have shown that games can be an effective tool for motivating students to learn in new ways (Kiili et al., 2014; Outhwaite et al., 2017). However, despite their potential, many teachers find it challenging to incorporate them into their classrooms. These difficulties include technology, time management, behavioural regulation, emotional control, and aligning games with the curriculum (Bell & Gresalfi, 2017, Chen & Law, 2016; Vandercruysse et al., 2013; Watson et al., 2011). Likewise, possessing insufficient knowledge of games and little previous experience in using game-based pedagogies are other crucial factors contributing to teachers' difficulty in implementing GBL (Hsu et al., 2013; Nousiainen et al., 2018; Shah & Foster 2015; Silseth 2012). In such cases, games can either empower or hinder the teacher's role in encouraging students to explore, triggering and maintaining their interest, and helping them learn independently. Consider the example of a student playing Minecraft in the classroom; the teacher may not understand the educational potential of the game and thus might not be able to create effective lesson plans that incorporate the game's mechanics and objectives or simply use it as a distraction, instead of utilizing its potential for problem-solving and collaboration. Thus, using common scaffolds found in other teaching scenarios can help make games more effective in the classroom, rather than expecting teachers to adapt their teaching practices to fit the games (Hanghøj & Brund, 2011). This approach can be more efficient since there are many games available in the market (Dubé et al., 2020).

A theory-driven approach is needed to organize and classify different methods of instruction in GBL environments, and scaffolding can be used as a framework. The concept of scaffolding in education is often attributed to Wood, Bruner, and Ross (1976), which refers to a situation where a teacher provides support to students to complete a task or solve a problem that they are unable to do alone but is within their potential to learn (Vygotsky, 1978). Although the work of Wood et al. (1976) specifically focused on learning support provided by a more capable individual in one-on-one sessions with young children using building blocks, they still identified the effective features of scaffolding that enhance learning in three ways: it keeps learners motivated, it provides appropriate assistance to reduce uncertainty, and it guides the play toward the goal. Additionally, it highlights critical information or breaks down complex problems so learners can identify the concepts needed to complete the tasks.

Further, when the scaffolding provided is systematic and matches the learners' mental models, new concepts can be more easily internalized and integrated into existing knowledge structures (Bruner, 1985). In GBL environments, supplementing games with external and proper scaffolds can help students establish a link between what they have achieved in the game and what they learned in school (Barzilai & Blau, 2014; Charsky & Ressler, 2008; Rienties et al., 2012). Thus, identifying the appropriate scaffold to facilitate learning and create engaging learning experiences, as well as taking into account the learner's perspective, are critical for teachers (Becker, 2007).

Types of Scaffolding

Various types of scaffolding across various disciplines and learning environments have been defined and conceptualized in the scaffolding literature. Previous studies employed the approach developed by Wood and Middleton (1975) and Wood et al. (1978) to assess students' areas of sensitivity to instruction. These studies adhere to the more traditional definition of scaffolding. Wood et al.'s (1976) research on young children shows that an ideal and well-designed scaffolded lesson should contain six features (Anghileri, 2016). They are as follows: ***Recruitment.*** The first task of the instructor is to recruit learner interest concerning the goals of the task/activity and to adhere to the learning objectives with greater clarity. ***Reduction of degrees of freedom***. The instructor's role consists of reducing and simplifying the complexity of the task to make it more manageable and achievable. ***Direction maintenance.*** The instructor should sustain the learner's motivation to pursue the goal of the activity to achieve it and maintain direction by making it worthwhile for the learner to risk taking the next step. ***Marking critical features.*** The instructor's role involves highlighting a task's critical features using different tools. ***Frustration control.*** The instructor's role is also to reduce frustration and risks without creating too much dependency on the instructor**.** ***Demonstration.*** The instructor's role is to model or imitate the task, which involves the idealization of the act to be performed or the presentation of the complete task that is already partially executed by the learner. While there is an agreement in the literature on the importance of these six features/scaffold types, how they are realized in a GBL environment has yet to be articulated.

Another approach views scaffolding as a multidimensional concept and groups scaffolding behaviours into three major components: cognitive support, emotional support, and transfer of responsibility (Hughes, 2015; Leerkes et al., 2011; Mermelshtine & Barnes, 2016; Neitzel & Stright, 2003, 2004; Stright, Herr, & Neitzel, 2009). Each dimension plays a distinct role in a student's scaffolding experience. Cognitive support can provide students with learning strategies linked with task simplification, demonstration, and marking of critical features. Emotional support is manifest through controlling frustration and warm and sensitive instruction. Transfer of responsibility is associated with recruitment and attention maintenance and may foster agency and autonomy (Neitzel & Stright, 2004). Although Wood et al. (1976) did not explicitly discuss these three dimensions, it can be argued that each scaffolding behaviour described as part of the process corresponds to one of the dimensions. In Table 1, we have combined these approaches and provided theoretical and operationalized definitions for each scaffold in the context of a GBL environment.

Table 1

Usage of Teacher Scaffolding during Game-based Learning Questionnaire (TSQ-GBL)

Dimensions/ Groups of Scaffolding	Scaffolding Types	Definition (Based on Wood et al.,' scaffolding theory (1976))	Operationalization	Item example(s)
Cognitive Scaffold(s)	Reduction	To reduce and simplify the complex task by reducing the number of constituent acts required to reach a solution.	To reduce the gameplay task difficulty by breaking the skill down into parts to make it achievable and manageable.	(1) Simplifying the gameplay by showing or prompting each component step-by-step. (2) Helping students to provide additional time to master in complex levels.
	Marking	To use a variety of means marks or accentuates certain features of the task that are relevant.	To highlight/mark the key concepts or point out important events that exist in the game.	(1) Highlighting/marking important game design/features relevant about gameplay. (2) Highlighting /marking the key learning concepts or tasks.
	Demonstration	To demonstrate, model, or imitate the ideal solutions to a task.	To model or demonstrate the game play or explain explicitly the learning concepts/goals in the game.	(1) Demonstrating how to play the game. (2) Explaining explicitly the learning concepts in the game.
Transfer of Responsibility Scaffold(s)	Recruitment	To recruit or enlist the learner's interest and adherence to the activity/task's requirements with greater clarity.	To introduce information about the game or to explain the game goals to recruit students' attention to initiate the task.	(1) Focusing on students' attention on the game's learning goals. (2) Focusing students' attention on the game itself (e.g., describe game rules).
	Direction	To keep children in pursuit of a particular objective, keep the child in the field, and keep or sustain him motivated.	To keep students on task, encourage them to complete the gameplay, focus students' attention on learning content, or provide relevant clues.	(1) Providing reminder prompts to help keep students on task. (2) Asking questions to help students focus on their learning process.

Emotional Scaffold(s)	Control	To reduce frustration and risks without creating too much dependency on the instructor.	To help familiarize them with the game and reduce students' frustration while taking control of the gameplay.	(1) Providing gameplay suggestions or strategies (e.g., helping stop the game). (2) Providing emotional support or strategies.

In general, having different types of knowledge or skills to be learned in different learning environments, disciplines, subjects, and even sub-topics might require different scaffolds. Moreover, using various forms of scaffolding may have different effects on students' learning outcomes and gameplay experiences, such as activating and developing students' interests, influencing students' emotions, and improving knowledge acquisition and content understanding in the GBL environments (Abdul Jabbar & Felicia, 2015; Quintana et al., 2004, Sun et al., 2021). Research indicates that students who receive marking critical features, for example, outperformed those who receive demonstrations and those who do not (Kao et al., 2017). Thus, providing a full explanation or highlighting important concepts may have diverse effects on learning outcomes. This finding confirms that more study is needed to explore and identify the types and ranges of different scaffold(s) teachers use in GBL environments.

Most research on external scaffolding in various learning environments is based on qualitative descriptions from narrative, observational, or occasionally single-case studies, whereas quantitative data are less common (Fleer, 1992; Tabak & Kyza, 2018; Van de Pol, J et al., 2010). Existing research indicates that teachers' scaffolding is directly linked to effective teachers' teaching practices, teaching quality, student learning outcomes, and engagement.

Specifically, the scarcity of quantitative studies on understanding teachers' roles in GBL environments is likely due to a lack of established and validated scales. As a result, the focus of this study is to develop and validate a new self-report scale intended to measure teachers' scaffolding usage in GBL environments to take the first snapshot of teachers' roles using games in classrooms.

Antecedents Associated with Teacher Scaffolding Use in GBLe(s)

Several other factors at the teacher and school level serve as barriers to incorporating technologies effectively in the classrooms (Inan & Lowther, 2010). As such, studying game-based learning must also consider teacher(s) and school-level factors. (Nousiainen et al., 2018). For example, only 8 % of K-18 teachers received training on game technology integration (Takeuchi & Vaala, 2014). This finding shows that teachers without formal training are not exposed to the broader range of instructional or scaffolding strategies that can enhance and facilitate learning in GBL.

One of the major obstacles is the need for teachers to have more competency in using various game-based pedagogies. Game-based pedagogy approaches refer to the use of games and play in education to enhance learning and engagement. These approaches differ in the use of different types of games. ***The educational games*** approach involves using games specifically designed for educational purposes, such as learning a new language or practicing math skills. The **e*ntertainment games*** approach involves using games that are not specifically designed for educational purposes but can still be used to enhance learning. For example, a teacher might use a popular video game to teach about historical events or cultural norms. The d***esigning or making games*** approach involves teachers or students designing and creating their own games to support learning. These approaches aim to create a more engaging and interactive learning environment while allowing students to learn through play. Previous research shows that experienced educators play a crucial role in making game-based learning effective, regardless of the approach used (Nousiainen et al., 2018). Hence, more knowledge is needed to determine whether game-based pedagogies use influences the way that teachers scaffold learning during gameplay.

Another significant barrier that hinders teachers' successful integration of technology in the classroom is the scarcity or inadequacy of school resources and infrastructure (i.e., hardware, software, ed tech training, Dawson & Rakes, 2003; Gil-Flores et al., 2017; Ozgur, 2020), which could be a similar scenario for game-based learning environments. Previous studies revealed that teachers' use of technology is impeded by factors such as a lack of physical/ technological resources and a lack of technical support (Becker, 1994; Gil-Flores et al., 2017), but it is unknown if the availability of school resources perceived by teachers (PA-SR) affects their ability to use scaffolding techniques to facilitate learning in GBL environments. It is crucial to investigate the relationship between the availability of school resources, teachers' experience with game-based pedagogies, and their scaffolding use in GBL environments. This will reveal whether teachers with more resources and experience in game-based pedagogy enact scaffolding practices differently than those with fewer resources and less experience, thus providing a deeper understanding of how to support teachers in effectively implementing GBL in the classroom.

Purpose

Based on the gaps in the literature, this current study aimed to introduce a newly developed self-report teacher scaffolding questionnaire in game-based learning (TSQ-GBL) and establish reliability and validity evidence for each dimension associated with the TSQ-GBL instrument by comparing three different measurement models to determine the best-fit dimension structure through a robust and systematic approach. Construct validity evidence for the subscales of each model is evaluated through testing for internal consistency as well as convergent and discriminant validity evidence that are collectively used to evaluate the appropriateness of the use of the TSQ-GBL. Measurement model fitness criteria are additionally applied to test which dimension model best fits and explains TSQ-GBL. In addition to the validation of these models through confirmatory analytic work to ensure the model fits criteria, further structural path relationships are established for additional criterion validity by investigating the relationship between the role of the available school resources and teacher's general game-based pedagogy use as antecedents of scaffolding usage in GBL environments. In line with the research purpose, the following research questions guided this instrument development and validation study:

1. Are the measures used in this study reliable and valid for measuring K – 12 teachers' self-reported teacher scaffolding use during game-based learning, game-based pedagogy use, and perceived availability of school resources?
    1.1. More specifically, are the measurement models of *"Teacher Scaffolding"* produced by the TSQ-GBL supported via reliability, internal consistency, convergent validity, multicollinearity, and discriminant validity?
    1.2. Does a 6-(recruitment, reduction, direction, marking, control, and demonstration scaffolding), 3-(cognitive scaffolding, transfer of responsibility scaffolding, and emotional scaffolding), or 1- (teacher scaffolding) dimension model of TSQ-GBL best fit the data?
2. Which types of scaffolding supports do K-12 teachers use the most during game-based learning?

3. What are the unique effects of GBP-use and PA-SR on the usage of each scaffolding type of the TSQ-GBL?

Method

Participants

Participants were recruited using an online recruitment tool (Prolific), and eligibility criteria were: 1) employment as a K-12 educator of any subject and grade and 2) resident of a North American or majority native English-speaking European country**.** A power analysis was conducted using an a priori sample size online calculator (Soper, 2018) and based on assumptions, the required sample size was 177. A total of 211 were eligible, but only 187 completed the study and seven were excluded due to missing attention checks. 180 participants were included in this study, which also fits the literature recommendations (Soper, 2021; Westland, 2010). A summary of both primary and secondary school teachers' demographic characteristics is shown in Table 2.

Table 2

Demographic Characteristics of K-12 Teachers

	Primary School Teachers (N = 100)				Secondary School Teachers (N =80)				Total (N=180)			
	N	%	*M*	*SD*	*N*	%	*M*	*SD*	*N*	%	*M*	*SD*
Age			39.37	9.54			38.35	8.16			38.9	8.94
Gender												
Male	23	23.0 %			43	53.8 %			66	36.7 %		
Female	77	77.0 %			37	46.3 %			114	63.3 %		
Highest Level of Education												
≤ Bachelor's Degree	61	61.0%			42	52.15%			103	57.2%		
≥ Master's Degree	39	39.0%			38	47.5%			77	42.8%		
Employment Status												
Full-time teacher	71	71.0%			64	80.0%			135	75.0%		
Part-time teacher	22	22.0%			14	17.5%			36	20.0%		
Others (e.g., teaching assistants…etc.)	7	7.0%			2	2.5%			9	5.0%		
Teaching Years			11.38	7.11			11.09	6.98			11.3	7.04
Teaching Country												
Canada	6	6.0%			4	5.0%			10	5.6%		
United States	26	26.0%			35	43.8%			61	33.9%		
United Kingdom	68	68.0%			41	51.2%			109	60.6%		
Primary Subject												
Language, Literacy or Primary Subjects	42	42.0%			21	26.3%			63	35.0%		
Science, Math, or Technology Subjects	44	44.0%			37	46.3%			81	45.0%		
Social Studies, Arts, or Music Subjects	10	10.0%			17	21.3%			27	15.0%		
Others (e.g., Special Education, Business, Careers…etc.	4	4.0%			5	6.3%			9	5.0%		

Procedure

The Research Ethics Committee of McGill University approved the study before data collection. Participants completed all measures online via Qualtrics. They first provided informed consent before moving on to a questionnaire that included five sections a) demographics, b) perceived availability of school resources, c) game-based pedagogies usage, and d) teacher scaffolding use during game-based learning. Eight attentional check questions were included to identify participants who did not read the instructions or questions properly (Tourangeau et al., 2000), also known as careless respondents (Meade & Craig, 2012) or insufficient effort respondents (Shamon & Berning, 2019). Careless respondents, ones who failed or missed two or more attention check questions out of eight, were excluded. The reasoning behind this is that if participants are not paying attention or following instructions, the data they provide may not be reliable or valid. Thus, their data were not included in the analysis.

Measures

Demographics

Participants were asked to provide basic information, including age, gender, educational background, current employment status, teaching experience, teaching country, primary subjects taught, and the educational level where they work. Demographic data is used to characterize the sample and is reported above in Table 2.

Perceived Availability of School Resources (PA-SR)

Items for assessing the perceived availability of school resources were adapted from previous studies (Gil-Flores et al., 2017). Three items assessed the level of available a) hardware, b) software, and c) amount of educational technology training offered at the participants' school. A sample item is "*what best describes the level of educational technology training offered by your school?*" The items were assessed on a 5-point scale from 1 (Very under-resourced) to 5 (Very highly resourced).

Game-based Pedagogy Use (GBP-use)

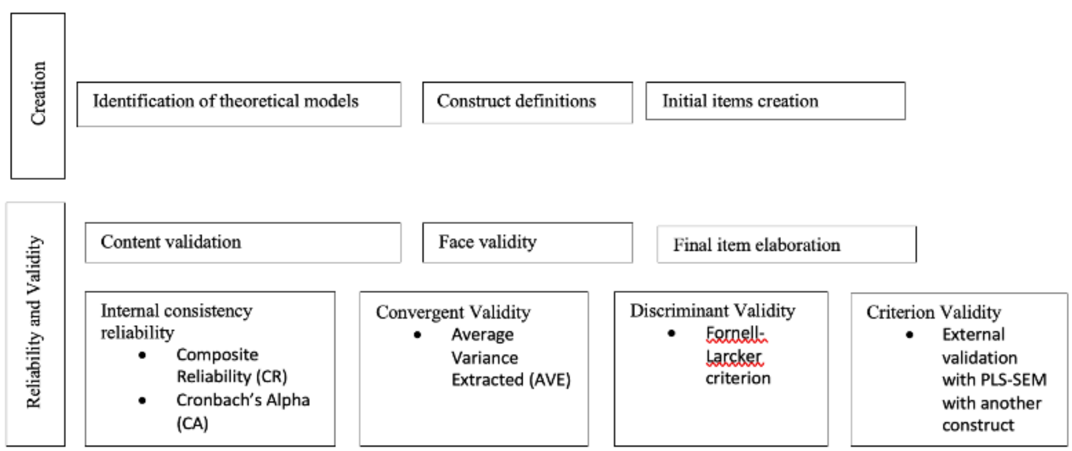
Three items assessed the frequency of teachers' game-based pedagogy use and were created based on the Nousiainen et al. (2018) classification system. The three items asked how frequently educators used a) educational games, b) entertainment games, and c) designing games as a pedagogical approach in their teaching. A sample item is "*How often do you use educational games for instructional purposes in your classroom?*" These items were evaluated on a 7-point scale from 1 (Never) to 7 (Daily).

Teacher Scaffolding Questionnaire during Game-based Learning (TSQ-GBL)

To measure teachers' scaffolding usage during game-based learning, a new measurement tool was developed, TSQ-GBL, based on previously established theoretical and empirical research (e.g., Kim & Hannafin, 2011; Sharma & Hannafin, 2007; Wood et al., 1976). Initially, a total of 20 items were developed using the standard survey development process, including initial item development, expert consultation, review, and rewriting iteratively (see Fig. 1 for the survey creation & validation process).

Figure 1

The Questionnaire' Creation and Validation Procedure



Creating a TSQ-GBL scale involved rational-theoretical and factor-analytical approaches at every stage of the process (Simms, 2008). Rather than using inductive methods for scale development, this process began with a theory-based substantive validity phase. For content validity, the researcher checked that the items created after reviewing the literature in the questionnaire were relevant and representative of the construct being measured through the team of experts in game-based learning and scaffolding research through several sessions. Then, the face validity was also taken into account by collecting a few teachers' opinions about scaffolding use in game-based learning environments to ensure the items in the scale were clear and easily understood by the intended population. This process finally resulted in six dimensions of teachers' scaffolding being identified (a fundamental study by Wood et al., 1976 was used to identify each scaffold) which were operationalized for game-based learning environments.

Further, each scaffolding dimension was adjusted to the level of complexity of the main construct being measured based on more recent scaffolding literature (Neitzel & Stright, 2003, 2004; Stright et al., 2009). Table 1 in the literature review summarizes and defines the proposed dimensions of teacher scaffolding and provides sample item content for each dimension. As a result, items assessing three groups of main scaffolding types with six sub-dimensions were included. The number of items per subdimension of each main scaffold varied; for cognitive scaffold, reduction (3 items), marking (3 items) and demonstration (4 items) were included; for transfer of responsibility scaffold, recruitment (4 items) and direction (3 items) were included, finally, for emotional scaffold, control (3 items) was included. A sample item is "*I simplify or clarify the gameplay procedure by showing students how to play step-by-step.*" The items were assessed on a scale from 1 (Never)to 7 (Always).

Data Analysis Rationale and Procedure

Before performing primary analysis, assumption checks were done through tests of normality and multicollinearity. Kolmogorov-Smirnov Test and Shapiro-Wilk Test results indicated a violation of normality according to Kline's (2011) criteria. However, this is not an issue as the scale was Likert-type data (Norman, 2010). VIF above ten (VIF>10) is considered a sign of severe multicollinearity to detect whether a potential multicollinearity issue that exists (Naser & Hassan, 2013). The result showed that VIF values were less than 10.

Model Comparison and Validation

The partial least square (PLS) algorithm with SmartPLS version 3.2.1 software (Ringle et al., 2015) was used to validate the questionnaire (*TSQ-GBL*) by comparing different dimension models and establishing the structural path relationship in the proposed model. PLS was chosen over CB-SEM because the data were non-normal; PLS can better handle reflective and formative complex constructs existing in the model (Models 1, 2 and 3 employed first-order, second-order, formative, and reflective constructs (Esposito Vinzi et al., 2010). PLS is also preferred for theory testing in exploratory studies or at an early stage of development, like the model that underlies this research (Chin, 1998; Hooper et al., 2008). As a result, three alternative measurement models were proposed and systematically tested to verify whether a six-dimensional model, three-dimensional model or a single unidimensional model could better describe the data.

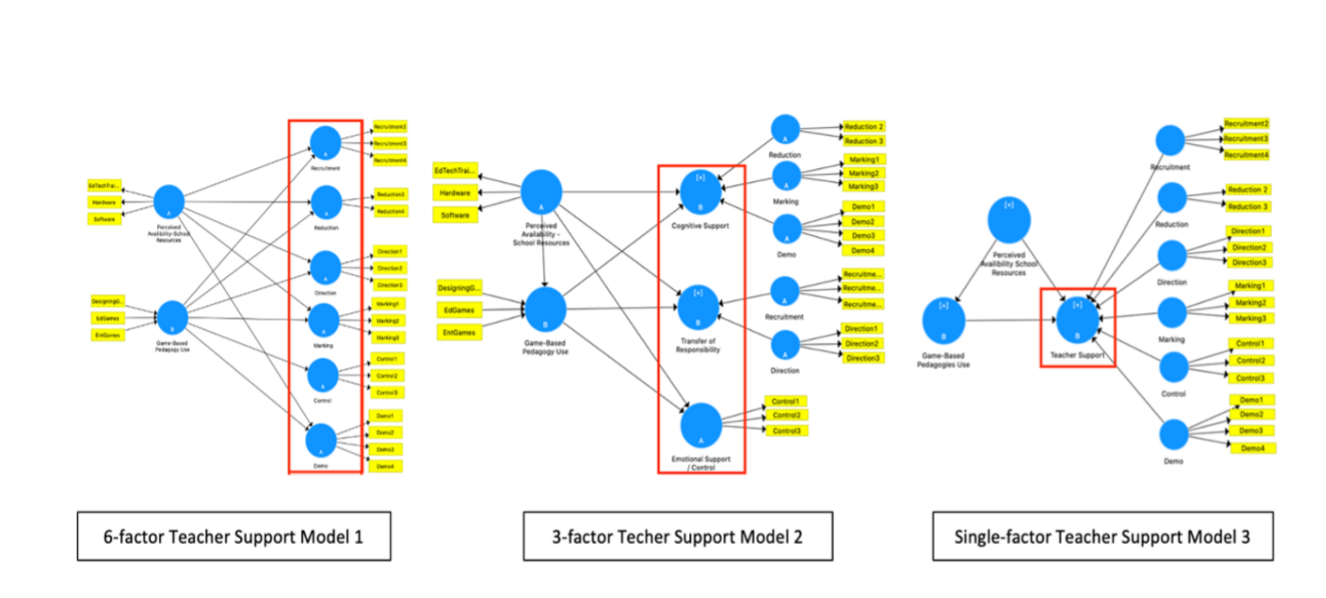
Model 1 consists of a six-dimension TSQ-GBL (Fig. 2), with seven first-order reflective constructs (six distinct scaffolds and PA-SR) and one formative first-order construct (i.e., GBP Use). In *Model 1*, *the* "*Teacher Scaffolding*" concept involves six distinct, reflective first-order scaffolds (i.e., recruitment, reduction, direction, marking, control, and demo). Each item in the six-different scaffolding types is loaded on its own separated latent constructs (i.e., recruitment1, recruitment2, recruitment3 items to the "Recruitment" construct). Due to only having first-order reflective constructs in *Model 1*, a single-stage analysis approach is used.

Model 2 consists of a three-dimension TSQ-GBL (Fig. 2), with five constructs in total, two formative-reflective second-order constructs (Transfer of Responsibility-TOR and Cognitive Scaffolding-CS), two reflective-first orders (i.e., Emotional Scaffolding-ES and PA-SR), and one formative first-order (i.e., GBP-use). The "*Teacher Scaffolding*" concept in *Model 2* includes the 3 dimensions: cognitive scaffolds (reduction, marking, demonstration), transfer of responsibility scaffolds (recruitment, direction), and emotional scaffolds (control). This assumes that first-order scaffolds could form as second-order constructs. A disjoint two-stage approach is used to evaluate *Model 2* (Sarstedt et al., 2019). Other approaches, like repeated indicators, would be easy to apply. However, the disjoint approach has less bias and estimates path coefficients between exogenous and higher-order constructs and between higher-order and endogenous constructs (Becker et al., 2012; Sarstedt et al., 2019).

Model 3 consists of one single/unidimensional TSQ-GBL (Fig 2.) with one second-order reflective construct (i.e., Teacher Scaffolding), which reflects all six distinct scaffolds (i.e., recruitment, reduction, direction, marking, control, and demo) as well as one first-order reflective (i.e., PA-SR) and one formative first order construct (i.e., GBP Use). Similarly**,** the disjoint two-stage approach is applied to establish *Model 3*. Initially, the first-order components of the second-order construct saved the construct scores (i.e., Recruitment, Direction, Control, Demo, Marking and Reduction) in stage one. Then, these scores are used to measure *"Teacher Scaffolding" as a* single dimension.

Figure 2

Six-dimension, Three-dimension, or Single/Unidimensional Factor Structure Potentially Underlying TSQ-GBL Items



Validity and Reliability

Assessing the measurement models of the TSQ-GBL process in the three models mentioned above differs for reflective and formative dimensions when analyzing validity and reliability. Reflective constructs are when indicator items are highly correlated with the measured construct or variable. The reflective constructs of a measurement model were evaluated through the following methods ***individual item reliability, internal consistency, convergent validity, and discriminant validity***. A measurement model may also include formative constructs. Formative constructs are when endogenous variables or indicator items are uncorrelated. However, they can still cause the exogenous variable. For example, the designing games pedagogy construct of GBP is a different instructional act from the using educational games pedagogy, but both can be considered together as they represent teachers' tendency to engage in game-based pedagogies (Nousiainen et al., 2018). Therefore, GBP is defined as forming of three game-based pedagogical approaches (Nousiainen et al., 2018). This is similar to the cognitive and transfer of responsibility scaffolds, considered second-order formative constructs in *Model 2.* For example, demonstration and marking might include different types of scaffolding, but both mainly focus on activating the cognitive process of learners. However, when assessing both first and second-order formative constructs (i.e., CS, ToR, and GBP-use) in the measurement model, there is no need to report reliability, internal consistency, and discriminant validity in the formative model because outer loadings, composite reliability, and AVE are meaningless for a latent variable that is made up of uncorrelated indicators. Instead, the following criteria are used to assess formative constructs in the models: ***indicator collinearity, statistical significance, and relevance of the indicator weights*** (Hair et al., 2017a).

Model Fitness and Quality

In addition to the methods mentioned above for the measurement model assessment, ***the model's data fitness, variance, and prediction capabilities*** are used to assess model quality before assessing the structural path relationship of the proposed model. PLS-SEM provides several model fit indicators (e.g., ***SRMR, NFI, d_ULS, d_G, RMS_theta***); however, RMS theta is applicable only for the reflective models (Lohmöller 1989). Due to having models mixed with formative and reflective constructs, RMS_theta cannot be considered a model fit indicator. Since there have not yet been any internationally acknowledged PLS-SEM model-fit indices to date (Hair et al., 2021; Nikou, 2019), and it needs to be interpreted cautiously, we also consulted some other quality criteria, ***such as the coefficient determination (*** r^2 ***) and predictive validity (*** Q^2 ***),*** for a rigorous assessment of the measurement model and to validate the structural model. After verifying the dimension structure of TSQ-GBL, both GBP-use and PA-SR constructs were used to explore the relationship between whether teachers' GBP-use and PA-SR affect their use of scaffolding in GBL. The results in all three models are shown as path coefficients with their bootstrapped (10,000 replicates) 95% intervals.

Results

Descriptive Statistics

This section provides an overview of the measure outcomes and differences between models using descriptive statistics for the TSQ-GBL scale for primary and secondary school teachers. Table 3 presents the means and standard deviations for standardized items of each model. These data will be analyzed further below to investigate the frequency of game-based pedagogies teachers use and any differences between primary and secondary school teachers. Overall, both primary and secondary school teachers are reported to occasionally (once per month) use different game-based pedagogies for instructional purposes in their classrooms. However, primary school teachers had a relatively higher mean average for GBP use than secondary school teachers. Both primary and secondary school teachers reported that the educational technology resources are adequately available in their schools.

Table 3

Models of TSQ-GBL' Descriptive Statistics among Primary and Secondary School Teachers

	Primary School Teachers		Secondary School Teachers		Total	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Model 1 (1 Never to 7 Always)						
Recruitment	5.39	1.24	5.45	1.21	5.42	1.22
Direction	4.71	1.22	4.86	1.24	4.78	1.23
Reduction	4.27	1.32	4.32	1.43	4.29	1.37
Marking	3.81	1.38	4.12	1.15	3.95	1.29
Control	5.08	1.31	4.83	1.22	4.97	1.27
Demo	4.56	1.26	4.89	1.20	4.71	1.24
Model 2 (1 Never to 7 Always)						
Cognitive Support	4.25	0.98	4.51	0.97	4.36	0.99
Transfer of Responsibility	5.05	1.05	5.16	1.00	5.10	1.03
Emotional Support	5.08	1.31	4.83	1.22	4.97	1.27
Endogenous Variable (1 Never to 7 Daily)						
Game-based Pedagogy Use	3.30	1.13	2.98	1.00	3.15	1.08
Exonogous Variable (1 Very under-resourced to 5 Very highly resourced)						
Perceived Availability of School Resources	3.04	.73	2.88	.84	2.97	.78

R.1. Are the Measures Reliable and Valid?

Reflective Constructs' Validity and Reliability

Individual item reliability through factor loadings testing is used to determine how closely an item or set of items from a TSQ-GBL are related to the variables they are intended to measure (Urbach & Ahlemann, 2010). All first-order reflective constructs' individual factor loadings (FL) in *Models 1, 2* and *3* (i.e., rec_1, rec_2, and rec_3 to recruitment; red_1, red_2 to reduction…etc.) are above the recommended threshold value in the first stage of the assessment (see Table 4). This indicates the confirmation of each item within each construct in all three models. However, recruitment, demo, and marking constructs in the second stage of analyzing and establishing the "*Teacher Scaffolding*" as a single reflective-reflective factor in *Model 3*, the factor loadings become lower (0.52, 0.53, and 0.54, respectively) but still meet the requirements of FL' criteria. ***Internal Consistency.*** To evaluate the correlations of individual item scores, the internal consistency of the measurement constructs is investigated using Cronbach Alpha (CA; Cronbach, 1951) and Composite Reliability (CR; Hair et al., 2019) analysis. CA (α; Cronbach, 1951) is the most frequently used indicator for internal consistency (Cho, 2016; Hogan et al., 2000; Osburn, 2000). However, owing to the underestimation problem with CA, such as it holds the assumption of tau-equivalence (equal factor loading for all items) and it is a less precise measure of reliability, as the items are unweighted, there is a need for a greater estimation of true reliability, e.g., composite reliability (CR) (Garson, 2012; Hair et al., 2019; Peterson & Kim, 2013). CR describes how well-observed variables indicate latent variables (McDonald, 1970). In contrast, with CR, the items are weighted based on the construct indicators' individual loadings; hence, this reliability is higher than Cronbach's alpha (Hair et al., 2017a; 2019). In the present study, when assessing the internal consistencies of reflective constructs through a single stage as well as the first and second stages of the disjoint approach assessment, all the constructs' CA values are >0.7 in all models, except for "*Reduction*" (Cronbach's α 0.66). Further, all the reflective first- and reflective-reflective second-order constructs in the single stage and first/second stages of the disjoint approach meet the threshold of composite reliability, including "*Reduction*" (Table 4) in the three models. ***Convergent Validity*** is the extent to which the latent variable converges to explain the overall variance of its items, and it is assessed through the average variance extracted metrics (AVE; Fornell & Larcker, 1981; Hair et al., 2011). All first-order reflective constructs through the single stage and first stage of the disjoint approach fulfill the minimum requirement of the AVE criteria in *Models 2 and 3* (Table 4). However, "*Teacher*

Scaffolding" as the second-order reflective-reflective construct' in *Model 2,* AVE (0.43) fails to cross this baseline.

Table 4

Assessment of Three Measurement Models through Factor Loadings, Outer Weights, Internal Consistency, Convergent Validity, and Multicollinearity

Model (s)	HOC	LOC	Latent Constructs/ Individual Items	FL	OL	IW or OW	Internal Consistency CA >.70	Internal Consistency CR >.70	Conver. Valid. AVE >.50	Multicollinear. (VIF) Reflect.	Multicollinear. (VIF) Format.
Model 1	n/a	**Recruitment** (Reflective-First Order-Mode A)	**Recruitment**			n/a	0.71	0.83	0.62		
			Rec_2	0.82						1.62	
			Rec_3	0.73						1.62	
			Rec_4	0.81						1.22	
		Direction (Reflective-First Order-Mode A)	**Direction**			n/a	0.74	0.85	0.66		
			Dir_1	0.76						1.35	
			Dir_2	0.87						1.63	
			Dir_3	0.80						1.53	
		Reduction (Reflective-First Order-Mode A)	**Reduction**			n/a	0.66	0.86	0.75		
			Red_2	0.87						1.33	
			Red_3	0.86						1.33	
		Marking (Reflective-First Order-Mode A)	**Marking**			n/a	0.77	0.87	0.68		
			Mark_1	0.84						1.76	
			Mark_2	0.85						1.78	
			Mark_3	0.79						1.37	
		Demo (Reflective-First Order-Mode A)	**Demo**			n/a	0.82	0.87	0.63		
			Demo_1	0.69						1.63	
			Demo_2	0.73						1.90	
			Demo_3	0.92						2.25	
			Demo_4	0.83						1.67	
		Control (Reflective-First Order-Mode A)	**Control**			n/a	0.83	0.90	0.75		
			Cont_1	0.83						2.22	
			Cont_2	0.90						2.55	
			Cont_3	0.87						1.64	
	n/a	**PA-SR** (Reflective-First Order-Mode A)	**PA-SR**			n/a	0.74	0.85	0.66		
			Hardware	0.83						1.45	
			Software	0.86						1.66	
			Ed Tech. Training	0.74						1.41	
	n/a	**GBP-Use** (Formative-First Order-Mode B)	**GBP-use**				n/a	n/a	n/a		
			Ed. Games		0.93 *	0.78 *				1.21	
			Ent. Games		0.45 *	-0.00				1.32	
			Designing Games		0.68 *	0.41 *				1.32	
Model 2	**Cognitive Support** (Formative-Second Order -Mode B)	**Reduction** (Reflective-First Order-Mode A)	**Reduction**		0.95 *	0.81 *	0.66	0.86	0.75		1.19
			Red_2	0.87						1.33	
			Red_3	0.86						1.33	
		Marking (Reflective-First Order- Mode A)	**Marking**		0.56 *	0.19	0.77	0.87	0.68		
			Mark_1	0.84						1.76	1.29
			Mark_2	0.85						1.78	
			Mark_3	0.79						1.37	
		Demo (Reflective-First Order- Mode A)	Demo		0.57 *	0.22	0.82	0.87	0.63		
			Demo_1	0.69						1.63	
			Demo_2	0.73						1.90	1.28
			Demo_3	0.92						2.25	

			Demo_4	0.83						1.67	
	Transfer of Responsibility (Formative-Second Order -Mode B)	**Recruitment** (Reflective-First Order- Mode A)	Recruitment		0.84 *	0.60 *	0.71	0.83	0.62		1.21
			Rec_2	0.82						1.62	
			Rec_3	0.73						1.62	
			Rec_4	0.81						1.22	
		Direction (Reflective-First Order- Mode A)	Direction		0.84 *	0.59 *	0.74	0.85	0.66		1.21
			Dir_1	0.76						1.35	
			Dir_2	0.87						1.63	
			Dir_3	0.80						1.53	
		Emotional Support/Control (Reflective-First Order-Mode A)	Control	n/a			0.83	0.90	0.75		n/a
			Cont_1	0.83						2.217	
			Cont_2	0.90		n/a				2.552	
			Cont_3	0.87						1.638	
		GBP-Use (Formative-First Order-Mode B)	GBP-use								
			Ed Games		0.95 *	0.83 *	n/a	n/a	n/a	1.207	
			Ent Games		0.43 *	-0.01				1.318	
			Design Games		0.63 *	0.34				1.315	
		PA-SR (Reflective-First Order- Mode A)	PA-SR				0.74	0.85	0.66		
			Hardware	0.83						1.207	
			Software	0.86		n/a				1.318	
			Ed Tech. Training	0.74						1.315	
	Teacher Support (Reflective-Second Order -Mode A)		Teacher Support				0.82	0.81	0.43		
		Recruitment (Reflective-First Order-Mode A)	Recruitment	0.52			0.71	0.83	0.62		
			Rec_2	0.82						1.618	
			Rec_3	0.73						1.618	
			Rec_4	0.81						1.216	
		Direction (Reflective-First Order-Mode A)	Direction	0.59		n/a	0.74	0.85	0.66		
			Dir_1	0.76						1.354	
			Dir_2	0.87						1.630	
			Dir_3	0.80						1.528	
		Reduction (Reflective-First Order-Mode A)	Reduction	0.92		n/a	0.66	0.86	0.75		
			Red_2	0.87						1.328	
			Red_3	0.86						1.328	
		Marking (Reflective-First Order-Mode A)	Marking	0.54		n/a	0.77	0.87	0.68		
			Mark_1	0.84						1.761	
			Mark_2	0.85						1.776	
			Mark_3	0.79						1.367	
Model 3		**Demo** (Reflective-First Order-Mode A)	Demo	0.53		n/a	0.82	0.87	0.63		
			Demo_1	0.69						1.634	
			Demo_2	0.73						1.902	
			Demo_3	0.92						2.249	
			Demo_4	0.83						1.672	
		Control (Reflective-First Order-Mode A)	Control	0.72		n/a	0.83	0.90	0.75		
			Cont_1	0.83						2.217	
			Cont_2	0.90						2.552	
			Cont_3	0.87						1.638	
	n/a	**PA-SR** (Reflective-First Order-Mode A)				n/a	0.74	0.85	0.66		
			Hardware	0.83						1.448	
			Software	0.86						1.660	
			Ed Tech. Training	0.74						1.409	
	n/a	**GBP-Use** (Formative-First Order-Mode B)					n/a	n/a	n/a		
			Ed Games		0.93 *	0.78 *				1.207	
			Ent Games		0.45 *	-0.00				1.318	
			Design Games		0.68 *	0.41 *				1.315	

HOC = high order construct, LOC = low order construct, FL = factor loading for reflective constructs, OL= outer loadings for formative constructs, IW/OW = indicator/outer weight, CA = Cronbach alpha, CR = composite reliability, AVE =Average Variance Extracted, VIF = variance inflation factor, GBP-use = Game-based Pedagogy Use, PA-SR = Perceived Availability of School Resources, n/a = not applicable

* $p < .05$ & $t < \pm 1.96$

Note*.

- Item reliability was attained by evaluating the item factor loading exceeding the approved values of 0.5 for newly developed items (Awang, 2014; Chin et al., 2010, Hair et al., 2017a).
- The threshold for the reliability of the measure is > 0.7 scores of Cronbach's α (CA) for each of the measures (Hair et al., 2017a); however, reliability values between 0.60 and 0.70 are also considered "acceptable in exploratory research" for both CA and CR.
- An acceptable AVE is 0.50 or higher, indicating that the construct explains at least 50 percent of the variance of its items for establishing convergent validity.
- VIF values of 5 or above indicate critical collinearity issues among the indicators of measured constructs. However, collinearity issues can also occur at lower VIF values of 3 (Becker et al., 2015). Ideally, the VIF values should be close to 3 and lower.
- According to Hair et al. (2017a), indicators with a nonsignificant weight should be eliminated if the loading is also not significant. A low but significant loading of 0.50 and below suggests that one should consider deleting the indicator unless there is strong support for its inclusion on the grounds of measurement theory.

Formative Constructs' Validity and Reliability

The variance inflation factor (VIF) is commonly used to assess formative ***indicator collinearity.*** The first-order construct (i.e., GBP use) in *Model 1, Model 2*, and *Model 3* and second-order formative constructs (i.e., CS and ToR) in *Model 2* VIF values are all below the cut-off, < 3. There is no collinearity among the formative indicators of a construct (Table 4; Hair et al., 2019). The next step to assess the formative construct is examining the ***indicators' outer weights and its' statistical significance***. If the confidence interval for an indicator weight includes zero, the weight is not statistically significant, and the indicator should be removed from the measurement model. However, the absence of a significant indicator weight should not be interpreted as evidence of poor measurement model quality (Hair et al., 2019). Instead, the indicator's absolute contribution to the construct is defined by its outer loading. (Cenfetelli & Bassellier, 2009). Following Hair et al. (2017a) suggestion, indicators with nonsignificant weights are removed if the outer loading is also nonsignificant (Cenfetelli & Bassellier, 2009; Hair et al., 2019). The "using *entertainment games* for instructional purposes" item in the first-order formative construct' (*GBP-use*) in *Model 1, Model 2*, and *Model 3* is statistically insignificant and is the lowest outer weight. The "*designing games* usage" item also has statistically non-significant outer weights in *Model 2*. The second-order formative constructs (*Demo and Marking*) to the second-order construct of "*Cognitive Scaffolding*" in *Model 2* also results in statistically insignificant and lower outer weights. These items are considered for removal after assessing the ***relevance of their indicators.*** Since we have statistically insignificant outer weights for "*Ent Games*" in *Model 1, 2*, and *3;* then the significance of outer loadings of "*Ent Games*" in *Model 1, Model 2*, and *Model 3 and "Designing Games"* in *Model 2* is evaluated, which are found statistically significant; hence "*Ent Games*" in all models and "*Designing Games*" in *Model 2* are retained in GBP-use ($p > 0.5$). "*Demo*" and "*Marking*" in *Model 2* outer loadings are statistically significant, so all the items in formative constructs are retained. ($p > 0.5$; Table 4).

Discriminant Validity is the degree to which a particular latent construct is empirically dissimilar from other latent variables (Duarte & Raposo, 2010; Hair et al., 2019). One way to confirm adequate discriminant validity is based on the Fornell-Larcker criterion (Garson, 2012). However, recent literature has strongly criticized the Fornell-Larcker criterion because it does not accurately reveal the lack of discriminant validity when the indicator loadings on a construct differ only slightly (e.g., all the indicator loadings are between 0.65 and 0.85; Henseler et al., 2015). So, an alternate technique is used, i.e., the Heterotrait-Monotrait Ratio (HTMT) of correlations. Thus, all HTMT ratios in the three models fall below the < 0.90 thresholds (Henseler et al., 2015; see Tables 5,6 and 7).

Table 5

Model 1' Discriminant Validity Assessment of Reflective Constructs Using HTMT Ratio

Constructs	1	2	3	4	5	6	7
1. Control							
2. Demo	0.441						
3. Direction	0.604	0.494					
4. Marking	0.390	0.419	0.492				
5. PA-SR	0.159	0.103	0.132	0.066			
6. Recruitment	0.423	0.379	0.416	0.476	0.062		
7. Reduction	0.449	0.339	0.448	0.349	0.225	0.378	

Note. PA-SR = Perceived Availability of School Resources

Table 6

Model 2' Discriminant Validity Assessment of First Order Constructs Using HTMT Ratio

	Constructs	1	2	3	4	5	6	7	8	9
LOC	1.Demo									
	2.Direction	0.628								
	3.Control/ Emotional Support	0.538	0.764							
	4.Marking	0.518	0.651	0.490						
	5.PA-SR	0.148	0.187	0.187	0.090					
	6.Recruitment	0.534	0.569	0.552	0.612	0.081				
	7.Reduction	0.411	0.630	0.600	0.486	0.326	0.524			
HOC	8-Cognitive Scaffolding	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
	9-Transfer of Responsibility Scaffolding	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	

Note. PA-SR = Perceived Availability of School Resources

Table 7

Model 3' Discriminant Validity Assessment of First Order Constructs Using HTMT Ratio

		1	2	3	4	5	6	7	8
LOC	1.Control								
	2. Demo	0.538							
	3. Direction	0.764	0.628						
	4. Marking	0.490	0.518	0.651					
	5. PA-SR	0.187	0.148	0.187	0.090				
	6. Recruitment	0.552	0.534	0.569	0.612	0.081			
	7. Reduction	0.600	0.411	0.630	0.486	0.326	0.524		
HOR	8. Teacher Support	n/a	n/a	n/a	n/a	0.215	n/a	n/a	

HOC = high order construct, LOC = low order construct, PA-SR = Perceived Availability of School Resources, n/a = not applicable

To ensure discriminant validity, the threshold value should be < 0.90 (Henseler et al., 2015).

Overall, all the reflective (first order and reflective-reflective second order) and formative (first order and second order) factor/outer loadings are above the recommended threshold value (Fornell & Larcker, 1981). All constructs across the three models are above the threshold value, suggesting that internal consistency reliability and discriminant validity are established. The formative constructs in this study are also validated across all three models. Critically, the results support the convergent validity of only the six and three dimensions of *Models 1* and *2* but not the single dimension of the *"Teacher Scaffolding"* construct in *Model 3.*

Comparing the Model Fit Indices and Quality of Three Measurement Models

Among the model fit indices, SRMR, as introduced by Henseler et al. (2014), is the most extensively used model fit measure in PLS-SEM (Buabeng-Andoh, 2021; Mohan et al., 2020; Şahin et al., 2021). The SRMR indicates the difference between observed correlations and model implied correlation matrix. The SRMR value for *Models 1* and *2* is 0.074, and *Model 3* is 0.078. Although all three models indicate acceptable goodness of model fit, *Model 1* and *2* shows better/lesser than the standard value (< .08) compared to *Model 3* (Table 8). The NFI is a ratio of the proposed model's Chi-square value to the null or benchmark model. A major drawback to this index is that it is sensitive to sample size, underestimating fit for samples less than 200 (Bentler, 1990; Mulaik et al., 1989), and is thus not recommended to be solely relied on (Kline, 2011). However, the NFI value for *Model 1* is 0.62, *Model 2* is 0.76, and *Model 3* is 0.64. Although NFI criteria across the three models do not meet the criteria, *Model 2* has the highest value compared to *Models 1* and *3,* which is closer to the standard value (above >.90; see Table 8). The other two metrics, d_ULS and the geodesic distance d_G provide a discrepancy between the empirical covariance matrix and covariance matrix as inferred from the composite factor model (Dijkstra & Henseler 2015; Hair et al., 2017a). Both d_ULS and d_G values are statistically non-significant in *Models 2* and *3* but statistically significant in *Model 1*, which shows that both *Models 2* and *3* fit this model fit criteria well (see Table 8).

Given these mixed results, one thing to note is that model fit in PLS-SEM should be interpreted cautiously (Hair et al., 2017a). Therefore, the validity of the measurement model is further tested by other quality measures: the coefficient of determination (r^2 value) measure and its predictive validity (Q^2). R^2 explains the variance in the endogenous variable explained by the exogenous variable(s). R^2 values of the scaffolding dimensions are weak to moderate in *Models 1 and 2*. However, *Model 3* is the weakest but still > 0.1 (Table 8). Finally, predictive validity is calculated by utilizing the values of communality; all those values have to be positive for all blocks to ensure the measurement model's predictive validity (Dhir & Shukla, 2018). All Q^2 values are positive and exhibit small to medium predictive relevance in all *Models*, but *Model 2* shows the highest predictive validity (i.e., Q^2 emotional scaffolding = 0.47 / %47).

Table 8

Comparison of Three Measurement Models through Model Quality Criteria

Measurement Models	Model Fitness and Quality Indices					
	R^2	Q^2	SRMR	d_ULS	d_G	NFI
Model 1: 6-Dimension Teacher Support Measure			0.074	1.63 (p<0.05)	0.68 (p<0.05)	0.62
Recruitment	0.05	0.25				
Direction	0.06	0.32				
Marking	0.05	0.35				
Reduction	0.12	0.25				
Demo	0.04	0.40				
Control	0.08	0.46				
GBP-Use	0.11	0.16				
PA-SR	-	0.32				
Model 2: 3-Dimension Teacher Support Measure			0.074	0.597 (p>0.05)	0.212 p>0.05)	0.76
Cognitive Support	0.13	0.16				
Transfer of Responsibility	0.08	0.16				
Emotional Support/Control	0.09	0.47				
GBP-Use	0.11	0.16				
PA-SR	-	0.32				
Model 3: Single Dimension Teacher Support Measure			0.078	0.469 (p>0.05)	0.191 (p>0.05)	0.64
Teacher Support	0.15	0.26				
GBP-Use	0.11	0.17				
PA-SR		0.26				

- For SRMR, values less than 0.08 are considered good fit model fit measures (Hu & Bentler, 1998).
- The NFI values above 0.90 indicate strong model fit measures (Bentler & Bonett 1980).
- D_ULS and D_G are required to be non-significant for the model fit (p > 0.05).
- All endogenous latent variables with r^2 >0.1 are acceptable for the model (Falk & Miller, 1992). As per Cohen (1988), r^2 can be classified as 0.26 (substantial), 0.13 (moderate), and 0.02 (weak).
- Predictive accuracy values higher than 0.00, 0.25 and 0.50 depict small, medium, and large predictive accuracy of the PLS model (Hair et al., 2019)
- PA-SR = Perceived Availability of School Resources, GBP-use: Game-based Pedagogy Use

Model Validity and Comparison

Three models are assessed, and the comparisons favour *Model 2* as the best suited for measuring the construct of "*Teachers Scaffolding"* usage during gameplay. Model 2 has fewer violations (n =2) and showed better-fit values compared to *Models 1* and *3* (see Table 9 for the summary of comparisons). We can conclude that *Model 2* is superior to *Models 1* and *3* from Table 9. Thus, *Model 2* (3-dimension TSQ-GBL) is adopted in subsequent analysis to explore whether teachers' game-based pedagogies usage and perceived availability of school resources affect or not their scaffolding use during gameplay.

Table 9

Summary of Three Measurement Models' Comparison Results

Parameter / Criteria	Model-1	Model-2	Model-3	Remarks
	Reflective Part – LOC and HOC			
Factor Loading	0.69	0.62	0.52	All models validated, but *Model 3* has the lowest factor loading value.
Cronbach Alpha	0.66	0.66	0.66	All models validated.
Composite Reliability	0.83	0.83	0.81	All models validated.
AVE	0.62	0.62	**0.43**	*Model 3* have failed values.
HTMT	0.87	0.76	0.76	All models validated.
	Formative Part – LOC and HOC			
VIF	1.32	1.32	1.32	All models validated.
Outer Weight	**-.003**	**-.013**	**-.003**	All models have failed values.
Factor Loading	0.45	0.43	0.45	All models validated.
	Model Quality			
SRMR	0.074	0.074	0.078	All models validated.
d_ULS	$\boldsymbol{p < 0.05}$	$p > 0.05$	$p > 0.05$	*Model 1* was violated.
d_G	$\boldsymbol{p < 0.05}$	$p > 0.05$	$p > 0.05$	*Model 1* was violated.
NFI	**0.62**	**0.76**	**0.64**	All models were violated, but *Model 2* had the closest value to the threshold and was superior to *Models 1* and *3*.
$\boldsymbol{R^2}$	0.12	0.13	0.15*	* *Model 3* has the highest value/highest variance.
$\boldsymbol{Q^2}$	0.46	0.47*	0.26	* *Model 2* has the highest predictive accuracy value.
Number of violations	4	2	3	

LOC = low order construct, HOC = high order construct

Bold = poorest across models, violated.

R.2. The Most Common Types of Scaffolding Supports K-12 Teachers Use during GBL.

After validating and confirming the best TSQ-GBL dimension model (*Model 2*), a within-subjects repeated measures ANOVA was used to compare which of the three scaffolding types are more frequently used by teachers. The results of Mauchly's test indicate that the sphericity assumption is met, X^2 (2) = 23.89, $p < .001$. The mean average and standard deviations of scaffolding support types are presented in Table 3 in the descriptive statistics section. A main effect of scaffolding type, F (2, 358) = 57.48, MSE = 27.77, $p < .001$, $\eta p^2 = 0.24$, indicates that there are statistically significant differences between the usage of the three scaffolds with a large effect. Pairwise comparisons with Bonferroni correction are used to identify statistically significant differences among the three-scaffolding types. Statistically significant differences are found between cognitive scaffolding, transfer of responsibility scaffolding, and emotional scaffolding use. Cognitive scaffolding usage is reported significantly less than the transfer of responsibility (t (179) = -10.05, p <.001) and less than emotional scaffolding (t (179) = -8.26, p <.001) by teachers. No statistically significant differences are found between emotional scaffolding and transfer of responsibility. In summary, these results provide an overall picture that teachers frequently use the transfer of responsibility and emotional scaffolding, while cognitive scaffolding is used less often.

To get a more granular picture of differences in teacher scaffolding use, a 6-level repeated measures within-subjects ANOVA is conducted using the 6-dimension model *(Model 1)*. Mauchly's test indicates that the sphericity assumption is violated, X^2 (14) = 29.41, p = .009. Therefore, Greenhouse-Geisser correction is used. The mean average and standard deviations of each specific scaffolding type are presented in Table 3 above. Results show that the main effect was statistically significant, F (4.71, 842.64) = 51.28, MSE = 50.72, p < .001, $\eta p^2 = 0.22$, indicating that there are statistically significant differences between the usage of the six scaffolds with a large effect.

Pairwise comparisons with Bonferroni correction are used to identify significant differences among the six scaffolds. Teacher' recruitment usage is more common than marking (t (179) = 14.46, p <.001), reduction (t (179) = 11.11, p <.001), demo (t (179) = 6.98, p <.001), direction (t (179) = 6.30, p <.001), and control use (t (179) = 4.44, p <.001). Direction and reduction usage are significantly greater than marking (direction vs marking t (179) = 8.16, p <.001; reduction vs marking t (179) = 3.35 p = 0.01), but no other statistically significant differences are found between direction vs demo usage as well as direction vs control usage. Interestingly, the reduction is used significantly less than control (t (179) = -6.66 p = 0.001), direction (t (179) = -4.81 p = 0.001), and demo (reduction vs demo t (179) = -4.12 p = 0.001). Similarly, marking is used significantly less than control (t (179) = -10.01 p < 0.001) and demo (t

(179) = -7.47 $p < 0.001$). No other statistically significant differences are found between control and demo use. In summary, these results provide an overall picture that teachers frequently use recruitment, direction and reduction scaffold(s) more often than other specific scaffold types, while marking is used less often.

R. 3. The Unique Effects of GBP-use and PA-SR on the Usage of Each Scaffolding Type

The Quality of Three Dimension Teacher Scaffolding Structural Path Model

The structural model's predictive quality is measured using Q^2, r^2 and goodness of fit (GOF). The positive value of Q^2 (>0) indicates the structural path model's acceptable/good quality or predictive relevance. R^2 is the measure of overall effect size, as indicated in Table 11; 13% of PA-SR, 19.9% of GBPU, 54.9% CS, 42.9% ES and 56.8% of TOR are explained by the overall model. GOF is measured by combining effect size and convergent validity (Tenenhaus et al., 2005) with an acceptable limit of 0 to 1. Our GOF values are well-acceptable, confirming our structural path model's overall fitness. Moreover, multicollinearity for the structural model is also assessed. VIF values beyond 3.3 are indications of collinearity (Kock, 2015), and VIF values show that our structural path model is well-fitted (Garson, 2012).

Table 10

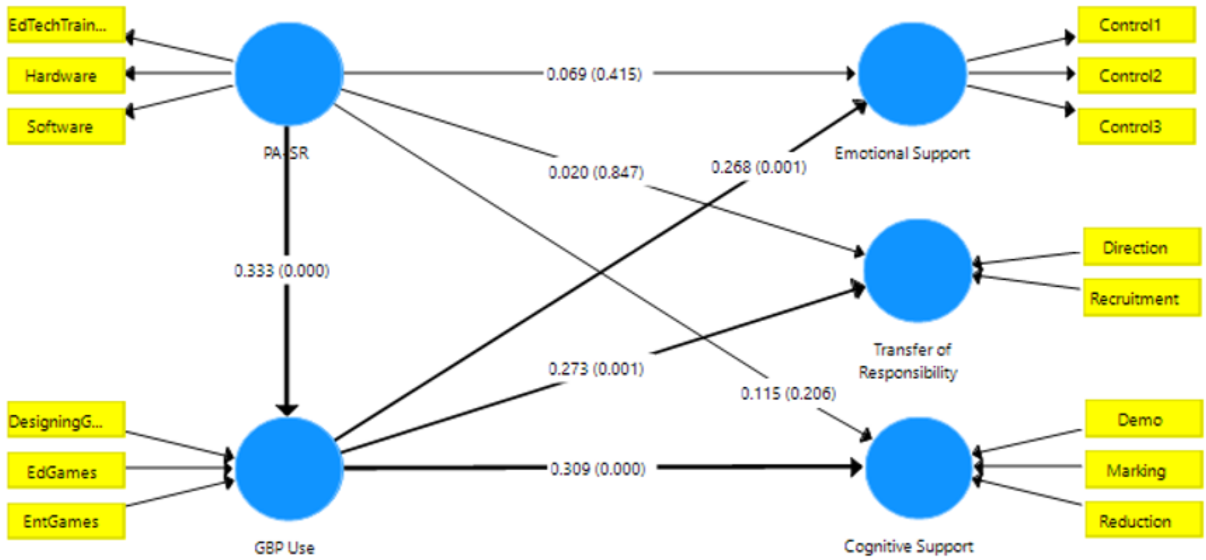
The Quality of the Model

	Q^2	R^2	AVE	GOF	VIF
PA-SR	0.053	0.130	0.739	0.310	1.706
GBP-Use	0.088	0.199	0.575	0.338	2.075
CS	0.294	0.549	0.577	0.563	1.620
ES	0.306	0.429	0.751	0.568	2.006
TOR	0.372	0.568	0.707	0.634	1.490

Note. PA-SR = Perceived Availability of School Resources, GBP-use: Game-based Pedagogy Use, CS = Cognitive Scaffolding, ES = Emotional Scaffolding, TOR= Transfer of Responsibility Scaffolding

Figure 3

Three-Dimension Teacher Scaffolding SEM Path Model



Note. PA-SR = Perceived Availability of School Resources, GBP-use: Game-based Pedagogy Use

Direct Effects.

Bias-corrected 95% confidence intervals are used to explore the extent to which GBP-use and PA-SR directly influence the three types of teacher scaffolds (Fig 4). Findings reveal that GBP-use has statistically significant positive relationships on CS (B = 0.309, t = 3.948, p < .001) with a small effect (f^2 = 0.098), ES (B = 0.268, t = 3.135, p = .002) with a small effect (f^2 = 0.070), and ToR (B = 0.273, t = 3.065, p = .002) with a small effect (f^2 = 0.072). However, PA-SR did not directly influence CS, ES, or ToR scaffolding use (Table 10).

Indirect Effects.

PA-SR has a positive and statistically significant indirect influence on CS (B = 0.103, t = 2.833, p = .005), ES (B = 0.089, t = 2.450, p = .014), and ToR usage via GBPU (B = 0.091, t = 2.311, p = 0.021). Given the direct relationship of PA-SR on CS, ES and TOR was not statistically significant, we conclude that the statistically significant indirect relationship of the

PA-SR on CS, ES and TOR is likely due to better effects of GBP-use on CS, ES and TOR (Table 10).

The relationships between GBP use, PA-SR, and Teacher Scaffolding use are represented in Figure 4 and investigated by evaluating both direct and indirect effects.

Table 11

Direct and Indirect Relationships between GBP-U, PA-SR and Use of Scaffolding Types

Path	Beta (*b*)	SE	T value	P value	f^2	Results
GBPU → CS	0.309	0.078	3.948	< .001	0.098	Supported
GBPU → ES	0.268	0.085	3.135	0.002	0.070	Supported
GBPU → TOR	0.273	0.089	3.065	0.002	0.072	Supported
PA-SR → CS	0.115	0.093	1.227	0.206	0.013	Not Supported
PA-SR → ES	0.069	0.089	0.781	0.415	0.005	Not Supported
PA-SR → TOR	0.020	0.100	0.204	0.847	0.000	Not Supported
PA-SR → GBPU → CS	0.103	0.036	2.833	0.005	n/a	Supported
PA-SR → GBPU → ES	0.089	0.036	2.450	0.014	n/a	Supported
PA-SR → GBPU → TOR	0.091	0.039	2.311	0.021	n/a	Supported
PA-SR → GBPU	0.333	0.072	4.639	< .001	0.125	Supported

Note. PA-SR = Perceived Availability of School Resources, GBP-use: Game-based Pedagogy Use, CS = Cognitive Scaffolding, ES = Emotional Scaffolding, TOR= Transfer of Responsibility Scaffolding

Discussion

The current study provides strong evidence for the reliability and validity of a newly developed self-report questionnaire assessing three distinct external scaffolds provided by teachers in the context of GBL environments: cognitive, transfer of responsibility, and emotional scaffolds. This instrument has strong psychometric properties in terms of reliability and internal validity and is externally validated. Previously, instruments for the quantitative assessment of discrete external scaffoldings provided by teachers in GBL environments needed to be more robust. This work addresses this gap by establishing the reliability and validity of the TSQ-GBL, exploring which scaffolding supports teachers provide in GBL environments, and detailing the relationships among teacher support usage, their use of game-based pedagogies, and the level of ICT resources available to them in their school.

Validating the TSQ-GBL Measure

Comparing the three measurement models for the TSQ-GBL shows the construct validity of each version. The results indicate acceptable to good reliability in terms of Cronbach's alphas (values ranging from .66 to .83), composite reliabilities (values from .81 to .90), and convergent validity (values from .62 to .75). However, the single-second-order construct *"Teacher Scaffolding"* in Model 3 displays low convergent validity (.43), indicating that the first-order constructs do not adequately explain the single second-order construct. This could be due to the complexity of the construct and the overlap between indicators (Segars & Grover, 1998), leading to unreliable assessment of *"Teacher Scaffolding."*

Examination of three models and the creation of a parametric/criterion matrix reveals that Model 3 has the most standardized model fitness requirements violations (Hair et al., 2021; Nikou, 2019). In contrast, Model 2 has fewer violations and supports grouping teacher scaffolds into three main dimensions: cognitive, transfer of responsibility, and emotional scaffolding. This three-dimension model was found to be superior to either a single-dimension model or a six-dimension model (see Fig. 1 for the three models) and best suited for capturing teachers' cognitive, transfer of responsibility, and emotional scaffolding as distinct constructs in GBL environments.

Findings revealed that the multidimensional approach of assessing the TSQ-GBL explain scaffolding practices greater than the Wood et al. (1976) approach. The Wood et al., (1976) approach lists six features of a well-designed scaffolded lesson but does not distinguish between the three main components of scaffolding, instead of six discrete features. This finding can be explained that multidimensional approach may allow for a more simplified, streamlined, and systematic analysis of scaffolding practices in GBL environments.

The multidimensional approach validated in this study may also captures the complex and interconnected nature of scaffolding in GBL by identifying three distinct dimensions of support as cognitive, emotional, and transfer of responsibility (Hughes, 2015, Mermelshtine, 2017; Neitzel & Stright, 2004; Stright et al., 2009). For example, cognitive scaffolding focuses on providing scaffolds to learners to help them understand and process information (Mermelshtine, 2017), whereas emotional scaffolds aim to help learners regulate their emotions and manage the affective aspects of learning (Mermelshtine, 2017). Transfer of responsibility scaffolding involves gradually transferring responsibility for learning from the teacher to the student, allowing them to develop independence and self-regulated learning skills (Neitzel & Stright, 2004). By distinguishing these three dimensions of scaffolding, the multidimensional approach recognizes that scaffolding is a complex and interconnected process that involves multiple types of support identified by Wood et al. (1976)' fundamental work. For example, emotional scaffolding can impact cognitive scaffolding, as regulating emotions can help students stay engaged in the learning process and better process information. Similarly, transfer of responsibility scaffolding can impact emotional scaffolding, as students may experience anxiety or frustration when faced with increased responsibility for their learning. Although the current study presents a new multidimensional approach to assess scaffolding types provided by teachers during GBL, there is still a need for more research to validate and refine this measure, especially in real classroom settings. To achieve this goal, future research could implement our approach in GBL contexts and collect data to examine whether the measure accurately captures the different dimensions of scaffolding (cognitive, emotional, and transfer of responsibility) and their effects on learning outcomes in actual classrooms.

How Teachers Scaffold Game-Based Learning

The study results provide insight into the scaffolding strategies teachers tend to use when supporting GBL. Teachers use transfer of responsibility the most frequently, of the three scaffolds, suggesting they prioritize creating opportunities for students to take ownership of their learning and foster emotional engagement in learning (Van de Pol J. et al., 2010). This aligns with the fading concept of scaffolding theory, which emphasizes the importance of student autonomy and self-directed learning (Belland, 2011, Collins et al., 1989, Puntambekar & Hubscher, 2005; Wood et al., 1976). On the other hand, teachers use the recruitment, direction, and reduction scaffolds more often than other specific scaffolds, which are focused on providing guidance and support to help students navigate the game (Van de Pol J. et al., 2010). In contrast, cognitive scaffolding is less frequently used. Various studies have supported the use of different types of scaffolding during game-based learning, with evidence indicating that games should be facilitated by competent educators who are proficient in scaffolding learning, engaging students in reflection, and drawing connections between gameplay and other curricular materials (Chen & Law, 2016; Kangas et al., 2017; Muhonen et al., 2016; Nousiainen et al., 2018; Sun et al., 2021; Van de Pol et al., 2010).

The findings of this study hold significant implications for the field of game-based learning (GBL), particularly in relation to pedagogy, teacher training, and education. These implications underscore the importance of equipping teachers with a diverse set of scaffolding strategies when designing GBL experiences. Effective teacher training should encompass a range of scaffolding practices, with an emphasis on cognitive support to facilitate student navigation of games and active engagement in the learning process. Additionally, educators should deliberate on the selection of scaffolding techniques that best facilitate student learning in GBL environments. However, it is important to note that further research is needed to comprehensively evaluate the effectiveness of various scaffolding strategies in fostering student learning outcomes within GBL contexts.

Relationships Among Game-Based Pedagogy, Resources, and Teacher Supports

Furthermore, the three scaffolding types in GBL environments show differential relationships with other constructs. The current research provided evidence that TSQ-GBL shows acceptable external validity in correlations with related constructs: GBP use and PA-SR. As expected, the general tendency to use game-based pedagogies also relates to implementing different types of scaffolding into teaching. Teachers must understand the characteristics and affordances of different game-based approaches or game types to correctly support and facilitate GBL via scaffolding. Access to adequate school resources, such as technological infrastructure, is undoubtedly a prerequisite for effective game-based learning. However, it's important to note that the availability of hardware, software, and educational technology training did not directly correlate with the usage of various types of teacher scaffolding in GBL environments. Instead, the relationship between resource availability and scaffolding usage is more indirect (Aoki et al., 2013; Bingimlas, 2009; De Witte & Rogge, 2014; Gil-Flores et al., 2017; Lee, 2002). This implies that while such resources may be necessary, they are not sufficient on their own to enhance teacher scaffolding during GBL.

Interestingly, the presence of greater or lesser amounts of ICT infrastructure in schools did not consistently impact the frequency of classroom ICT use. Notably, different types of infrastructure have varying effects on ICT use. While the availability of computers and internet access didn't show a statistically significant relationship with ICT use frequency, the presence of suitable educational software did have a significant impact. Schools equipped with such software demonstrated a higher likelihood of frequent ICT use. These findings underscore the importance of educational software availability over hardware, a perspective supported by previous research (Bingimlas, 2009; Lee, 2002).

Limitations

Our study has limitations related to the nature of the data and study design. First, we are not claiming causal inferences using our measurement and structural path models. The data are cross-sectional, and the design is correlational. As such, the terms "effect" and "influence" we use always signifies a statistical parameter representing a linear relationship between an independent and a dependent variable, considering other exogenous variables. Second, since the data comes from a self-report questionnaire, data may not represent the actual level of scaffolding usage during gameplay. Future research needs to employ additional measures, such as identifying and reporting the frequency of scaffolding use through observations. Third, the direct effect of game-based pedagogy usage and the indirect effect of available school resources on teacher' scaffolding use was relatively weak and sometimes statistically non-significant. The different game-based pedagogies, such as using educational games vs designing games, might require different types of scaffolds and grouping them into a single construct may weaken the observed relationship. Similarly, receiving sufficient technology training might play a more important role than other school resources (e.g., hardware) in terms of familiarity with scaffolding types. Thus, future research may differentiate between each game-based pedagogies and the availability of school resources to explore the association with each scaffolding type.

Conclusion

The current study aimed to evaluate the reliability and validity of the TSQ-GBL questionnaire, a measure designed to assess the external scaffolds provided by teachers in GBL environments. The study found that the questionnaire had strong psychometric properties, including reliability and internal validity, and was externally validated based on theoretical foundations. The best fit was a three-dimension model, which separates the scaffolds into the cognitive, transfer of responsibility, and emotional types. The results showed that teachers use the transfer of responsibility scaffold most frequently in general, followed by recruitment, direction, and reduction scaffolds specifically. The study also found that the availability of school resources indirectly affects scaffold usage, emphasizing the importance of providing adequate resources for effective implementation.

The practical implications of the study are significant. The TSQ-GBL can serve as a valuable tool for teachers and instructional designers to observe and assess their scaffolding practices in real-world settings, providing a practical and straightforward way to evaluate the use of cognitive, transfer of responsibility, and emotional scaffolds in GBL environments and identify areas for improvement. The study also sheds light on the relationship between game-based pedagogies use and the use of scaffolding in GBL environments, which can help instructional designers and teachers to design games that provide the appropriate scaffolds to support student learning depending on game pedagogies, even different types of games. The findings can inform future research on the effects of different scaffold types on student learning outcomes and the relationship between scaffold types and student learning, engagement, and gameplay experiences. Finally, the study’s findings could be incorporated into teacher training programs, workshops, and online resources like YouTube videos to increase awareness and understanding of the different scaffold types and how they can be effectively implemented in GBL environments. Overall, the study offers a foundation for understanding the role of scaffolding in game-based learning and provides a first shot at teachers' practices in GBL environments.

References

Abdul Jabbar, A. I., & Felicia, P. (2015). Gameplay engagement and learning in game-based learning: A systematic review. *Review of Educational Research*, *85*(4), 740-779. https://doi.org/10.3102/0034654315577210

Anghileri, J. (2006). Scaffolding practices that enhance mathematics learning. *Journal of Mathematics Teacher Education*, *9*, 33-52. https://doi.org/10.1007/s10857-006-9005-9

Aoki, H., Kim, J., & Lee, W. (2013). Propagation & level: Factors influencing in the ICT composite index at the school level. *Computers & Education*, *60*(1), 310-324. https://doi.org/10.1016/j.compedu.2012.07.013

Awang, Z. (2014). *A handbook on SME: For Academicians and practitioners*. MPWS Rich Resources.

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70*, 65-79. https://doi.org/10.1016/j.compedu.2013.08.003

Becker, H. J. (1994). How exemplary computer-using teachers differ from other teachers: Implications for realizing the potential of computers in schools. *Journal of Research on Computing in Education*, *26*(3), 291-321. https://doi.org/10.1080/08886504.1994.10782093

Becker, J. M., Klein, K., & Wetzels, M. (2012). Hierarchical latent variable models in PLS-SEM: guidelines for using reflective-formative type models. *Long Range Planning*, *45*(5-6), 359-394. https://doi.org/10.1016/j.lrp.2012.10.001

Becker, J. M., Ringle, C. M., Sarstedt, M., & Völckner, F. (2015). How collinearity affects mixture regression results. *Marketing Letters*, *26*, 643-659. https://doi.org/10.1007/s11002-014-9299-9

Becker, K. (2007). Digital game-based learning once removed: Teaching teachers. *British Journal of Educational Technology*, *38*(3), 478-488. https://doi.org/10.1111/j.1467-8535.2007.00711.x

Bell, A., & Gresalfi, M. (2017). The role of digital games in a classroom ecology: Exploring instruction with video games. In M.F. Young, & S.T. Slota (Eds.). *Exploding the castle: Rethinking how video games and game mechanics can shape the future of education*, (pp. 67-92). Charlotte, NC: Information Age, Inc.

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2011). Problem-based learning and argumentation: Testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instructional Science, 39*, 667–694. https://doi.org/10.1007/s11251-010-9148-z

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin*, *107*(2), 238 –246. https://doi.org/10.1037/0033-2909.107.2.238

Bentler, P. M., & Bonett, D. G. (1980). Significance tests and goodness of fit in the analysis of covariance structures. *Psychological Bulletin, 88*(3), 588 606. https://doi.org/10.1037/0033-2909.88.3.588.

Bingimlas, K. A. (2009). Barriers to the successful integration of ICT in teaching and learning environments: A review of the literature. *Eurasia Journal of Mathematics, Science and Technology Education*, *5*(3), 235-245. https://doi.org/10.12973/ejmste/75275

Bruner, J. (1985). *Vygotsky: A historical and conceptual perspective. Culture, communication, and cognition: Vygotskian perspectives*. London, UK: Cambridge University Press.

Buabeng-Andoh, C. (2021). Exploring university students' intention to use mobile learning: A research model approach. *Education and Information Technologies, 26*(1), 241 256. https://doi.org/10.1007/s10639-020-10267-4

Calantone, R. J. (2014). Common beliefs and reality about PLS: Comments on Rönkkö and Evermann (2013). *Organizational Research Methods, 17*(2), 182-209. https://doi.org/10.1177/10944281145269

Cenfetelli, R. T., & Bassellier, G. (2009). Interpretation of formative measurement in information systems research. *MIS quarterly*, 689-707. https://doi.org/10.2307/20650323

Charsky, D., & Ressler, W. (2011). "Games are made for fun": Lessons on the effects of concept maps in the classroom use of computer games. *Computers & Education, 56*(3), 604-615. https://doi.org/10.1016/j.compedu.2010.10.001

Chen, C. H., & Law, V. (2016). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. *Computers in Human Behavior, 55*, 1201-1212. https://doi.org/10.1016/j.chb.2015.03.010

Chin, W. W. (1998). The partial least squares approach to structural equation modelling. *Modern Methods for Business Research, 295*(2), 295-336.

Cho, E. (2016). Making reliability reliable: A systematic approach to reliability coefficients. *Organizational Research Methods*, *19*(4), 651-682. https://doi.org/10.1177/1094428116656239

Clark, D. B., Nelson, B. C., Chang, H. Y., Martinez-Garza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring Newtonian mechanics in a conceptually integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States. *Computers & Education, 57*(3), 2178-2195. https://doi.org/10.1016/j.compedu.2011.05.007

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics. In L. B. Resnick (Ed.), *Knowing, learning and instruction: Essays in honor of Robert Glaser* (pp. 453–494). Hillsdale, NJ: Lawrence Erlbaum.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297-334. https://doi.org/10.1007/BF02310555

Dawson, C., & Rakes, G. C. (2003). The influence of principals' technology training on the integration of technology into schools. *Journal of Research on Technology in Education*, *36*(1), 29-49. https://doi.org/10.1080/15391523.2003.10782401

De Witte, K., & Rogge, N. (2014). Does ICT matter for effectiveness and efficiency in mathematics education? *Computers & Education*, *75*, 173-184. https://doi.org/10.1016/j.compedu.2014.02.012

Dhir, S., & Shukla, A. (2018). The influence of personal and organisational characteristics on employee engagement and performance. *International Journal of Management Concepts and Philosophy*, *11*(2), 117-131. https://doi.org/10.1504/IJMCP.2018.092321

Dijkstra, T. K., & Henseler, J. (2015). Consistent and asymptotically normal PLS estimators for linear structural equations. *Computational Statistics & Data Analysis, 81*, 10-23. https://doi.org/10.1016/j.csda.2014.07.008

Duarte, P. A. O., & Raposo, M. L. B. (2010). A PLS model to study brand preference: An application to the mobile phone market. In *Handbook of partial least squares methods* (pp. 449-485). Berlin Heidelberg: Springer.

Dubé, A. K., Kacmaz, G., Wen, R., Alam, S. S., & Xu, C. (2020). Identifying quality educational apps: Lessons from 'top' mathematics apps in the Apple App store. *Education and Information Technologies*, *25*, 5389-5404. https://doi.org/10.1007/s10639-020-10234-z

Eastwood, J. L., & Sadler, T. D. (2013). Teacher' implementation of a game-based biotechnology curriculum. *Computers & Education, 66*, 11-24. https://doi.org/10.1016/j.compedu.2013.02.003

Esposito Vinzi, V., Chin, W. W., Henseler, J., & Wang, H. (2010). *Handbook of partial least squares*. Springer Handbooks of Computational Statistics Series. Vol. II. Heidelberg: Springer.

Fleer, M. (1992). Identifying teacher–child interaction which scaffolds scientific thinking in young children. *Science & Education, 76*, 373–397.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*(1), 39-50. https://doi.org/10.1177/002224378101800104

Foster, A., & Shah, M. (2015). The play curricular activity reflection discussion model for game-based learning. *Journal of Research on Technology in Education, 47*(2), 71-88. https://doi.org/10.1080/15391523.2015.967551

Garson, G. D. (2012). Structural equation modeling. Asheboro, NC.

Gil-Flores, J., Rodríguez-Santero, J., & Torres-Gordillo, J. J. (2017). Factors that explain the use of ICT in secondary-education classrooms: The role of teacher characteristics and school infrastructure. *Computers in Human Behavior*, *68*, 441-449. https://doi.org/10.1016/j.chb.2016.11.057

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer-Assisted Learning, 29*(3), 207-219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Haataja, E., Moreno-Esteva, E. G., Salonen, V., Laine, A., Toivanen, M., & Hannula, M. S. (2019). Teacher's visual attention when scaffolding collaborative mathematical problem-solving. *Teaching and Teacher Education, 86*, 102877. https://doi.org/10.1016/j.tate.2019.102877

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. https://doi.org/10.1080/10508406.2010.508029

Hair, J. F., Hult, G.T.M., Ringle, C.M. and Sarstedt, M. (2017a), *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, Sage Publications, Thousand Oaks, CA.

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2021). *A primer on partial least squares structural equation modeling (PLS-SEM)*. Sage Publications. Thousand Oaks, CA.

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. *Journal of Marketing Theory and Practice*, *19*(2), 139-152. https://doi.org/10.2753/MTP1069-6679190202

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, *31*(1), 2-24. https://doi.org/10.1108/EBR-11-2018-0203

Hanghøj, T., & Brund, C. E. (2011). Teachers and serious games: Teacher's roles and positionings in relation to educational games. In S. Egenfeldt-Nielsen, B. Meyer, & B. H. Sørensen (Eds.), *Serious games in education: A global perspective* (pp. 125–136). Aarhus: Aarhus Universitetsforlag.

Haruehansawasin, S., & Kiattikomol, P. (2018). Scaffolding in problem-based learning for low-achieving learners. *The Journal of Educational Research, 111*(3), 363–370. https://doi.org/10.1080/00220671.2017.1287045

Henseler, J., Dijkstra, T. K., Sarstedt, M., Ringle, C. M., Diamantopoulos, A., Straub, D. W., Ketchen Jr., D.J., Hair, J, F., Hult M., Tomas G., & Calantone, R. J. (2014). Common beliefs and reality about PLS: Comments on Rönkkö and Evermann (2013). *Organizational Research Methods, 17*(2), 182-209. https://doi.org/10.1177/1094428114526928

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science, 43*(1), 115–135 https://doi.org/10.1007/s11747-014-0403-8

Hogan, T. P., Benjamin, A., & Brezinski, K. L. (2000). Reliability methods: A note on the frequency of use of various types. *Educational and Psychological Measurement*, *60*(4), 523-531. https://doi.org/10.1177/0013164002197069

Hooper, D., Coughlan, J., & Mullen, M. (2008, June). Evaluating model fit: A synthesis of the structural equation modelling literature. In A. Brown (Ed.), *Proceedings of the 7th*

European Conference on Research Methodology for Business and Management Studies (pp. 195–200). Regent's College, London, United Kingdom.

Hsu, C. Y., Liang, J. C., Chai, C. S., & Tsai, C. C. (2013). Exploring preschool teachers' technological pedagogical content knowledge of educational games. *Journal of Educational Computing Research*, *49*(4), 461-479. https://doi.org/10.2190/EC.49.4.c

Hughes, C. (2015). The transition to school. *Psychologist*, *28*(9), 714-717.

Inan, F. A., & Lowther, D. L. (2010). Factors affecting technology integration in K-12 classrooms: A path model. *Educational Technology Research and Development*, *58*, 137-154. https://doi.org/10.1007/s11423-009-9132-y

Kangas, M., Koskinen, A., & Krokfors, L. (2017). A qualitative literature review of educational games in the classroom: the teacher's pedagogical activities. *Teachers and Teaching, 23*(4), 451-470. http://dx.doi.org/10.1080/13540602.2016.1206523

Kao, G. Y. M., Chiang, C. H., & Sun, C. T. (2017). Customizing scaffolds for game-based learning in physics: Impacts on knowledge acquisition and game design creativity. *Computers & Education*, *113*, 294-312. https://doi.org/10.1016/j.compedu.2017.05.022

Ke, F. (2009). A Qualitative meta-analysis of computer games as learning tools. In R. F. Ferdif (Ed.), *Handbook of research on effective electronic gaming in education* (pp. 1–32). New York, NY: Hershey.

Kiili, K., Ketamo, H., Koivisto, A., & Finn, E. (2014). Studying the user experience of a tablet-based math game. *International Journal of Game-Based Learning (IJGBL), 4*(1), 60-77. http://doi.org/10.4018/IJGBL.2014010104

Kim, M. C., & Hannafin, M. J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers & Education*, *56*(2), 403-417. https://doi.org/10.1016/j.compedu.2010.08.024

Kirriemuir, J., & McFarlane, A. (2004). Literature review in games and learning.

Kline, R. B. (2011). *Principles and practice of structural equation modeling,* (3rd ed.). New York: Guilford Press

Kock, N. (2015). Common method bias in PLS-SEM: A full collinearity assessment approach. *International Journal of e-Collaboration, 11*(4), 1–10. http://doi.org/10.4018/ijec.2015100101

Lee, K. T. (2002). Effective teaching in the information era: Fostering an ICT-based integrated learning environment in schools. *Asia-Pacific Journal of Teacher Education & Development*, *5*(1), 21-45.

Leerkes, E. M., Blankson, A. N., O'Brien, M., Calkins, S. D., & Marcovitch, S. (2011). The relation of maternal emotional and cognitive support during problem-solving to pre-academic skills in preschoolers. *Infant and Child Development,20*, 353–370. doi:10.1002/icd.728

Lohmöller, JB. (1989). Predictive vs. Structural Modeling: PLS vs. ML. In *Latent variable path modeling with partial least squares* (pp. 199-226). New York: Springer.

McDonald, R. P. (1970). The theoretical foundations of principal factor analysis, canonical factor analysis, and alpha factor analysis. *British Journal of Mathematical and Statistical Psychology*, *23*(1), 1-21. https://doi.org/10.1111/j.2044-8317.1970.tb00432.x

Meade, A. W. & Craig, S. B. (2012). Identifying careless responses in survey data. *Psychological Methods, 17(*3), 437–455. DOI: 10.1037/a0028085

Mermelshtine, R. (2017). Parent–child learning interactions: A review of the literature on scaffolding. *British Journal of Educational Psychology*, *87*(2), 241-254. https://doi.org/10.1111/bjep.12147

Mermelshtine, R., & Barnes, J. (2016). Maternal responsive–didactic caregiving in play interactions with 10-month-olds and cognitive development at 18 months. *Infant and Child Development,25*(3), 296–316. doi: 10.1002/icd.1961

Mohan, M. M., Upadhyaya, P., & Pillai, K. R. (2020). Intention and barriers to use MOOCs: An investigation among the post graduate students in India. *Education and Information Technologies, 25*(6), 5017–5031. https://doi.org/10.1007/s10639-020-10215-2

Muhonen, H., Rasku-Puttonen, H., Pakarinen, E., Poikkeus, A. M., & Lerkkanen, M. K. (2016). Scaffolding through dialogic teaching in early school classrooms. *Teaching and Teacher Education, 55,* 143-154. https://doi.org/10.1016/j.tate.2016.01.007

Mulaik, S. A., James, L. R., Van Alstine, J., Bennett, N., Lind, S., & Stilwell, C. D. (1989). Evaluation of goodness-of-fit indices for structural equation models. *Psychological Bulletin*, *105*(3), 430 – 445. https://doi.org/10.1037/0033-2909.105.3.430

Naser, K., & Hassan, Y. (2013). Determinants of corporate social responsibility reporting: Evidence from an emerging economy. *Journal of Contemporary Issues in Business Research, 2*(3), 56–74.

Neitzel, C., & Stright, A. D. (2003). Mothers' scaffolding of children's problem solving: Establishing a foundation of academic self-regulatory competence. *Journal of Family Psychology,17*(1), 147–159. doi:10.1037/0893-3200.17.1.147

Neitzel, C., & Stright, A. D. (2004). Parenting behaviours during child problem solving: The roles of child temperament, mother education and personality, and the problem-solving context. *International Journal of Behavioral Development,28*(2), 166–179. doi:10.1080/01650250344000370

Nikou, S. (2019). Factors driving the adoption of smart home technology: An empirical assessment. *Telematics and Informatics, 45*(101283), 1–12. https://doi.org/10.1016/j.tele.2019.101283

Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in Health Sciences Education*, *15*, 625-632. https://doi.org/10.1007/s10459-010-9222-y

Nousiainen, T., Kangas, M., Rikala, J., & Vesisenaho, M. (2018). Teacher competencies in game-based pedagogy. *Teaching and Teacher Education*, *74*, 85-97. https://doi.org/10.1016/j.tate.2018.04.012

Osburn, H. G. (2000). Coefficient alpha and related internal consistency reliability coefficients. *Psychological Methods, 5*(3), 343–355. https://doi.org/10.1037/1082-989X.5.3.343

Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2017). Closing the gap: Efficacy of a tablet intervention to support the development of early mathematical skills in UK primary school children. *Computers & Education, 108*, 43-58. https://doi.org/10.1016/j.compedu.2017.01.011

Ozgur, H. (2020). Relationships between teachers' technostress, technological pedagogical content knowledge (TPACK), school support and demographic variables: A structural equation modeling. *Computers in Human Behavior*, *112*, 106468. https://doi.org/10.1016/j.chb.2020.106468

Pata, K., Sarapuu, T., & Lehtinen, E. (2005). Tutor scaffolding styles of dilemma solving in network-based role-play. *Learning and Instruction, 15*(6), 571-587. https://doi.org/10.1016/j.learninstruc.2005.08.002

Pei-Wen, T., Jennifer, I. O. P. L., Chien-Hui, Y., & Vivian, H. H. C. (2012). Reconceptualizing pedagogical usability of and teachers' roles in computer game-based learning in school. *Educational Research and Reviews, 7(*20), 419-429. https://doi.org/10.5897/ERR11.072

Peterson, R. A., & Kim, Y. (2013). On the relationship between coefficient alpha and composite reliability. *Journal of Applied Psychology, 98*, 194 –198. http://dx.doi.org/10.1037/a0030767

Puntambekar, S., & Hübscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist, 40*(1), 1–12. https://doi.org/10.1207/s15326985ep4001_1

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences*, *13*(3), 337-386. https://doi.org/10.1207/s15327809jls1303_4

Rienties, B., Giesbers, B., Tempelaar, D., Lygo-Baker, S., Segers, M., & Gijselaers, W. (2012). The role of scaffolding and motivation in CSCL. *Computers & Education, 59*(3), 893-906. https://doi.org/10.1016/j.compedu.2012.04.010

Ringle, C. M., Wende, S., & Becker, J. M. (2015). SmartPLS 3. Bonningstedt: SmartPLS. Retrieved from https://www.smartpls.com/

Sahin, F., Doğan, E., İlic, U., & Şahin, Y. L. (2021). Factors influencing instructors' intentions to use information technologies in higher education amid the pandemic. *Education and Information Technologies, 26*(4), 4795–4820. https://doi.org/10.1007/s10639-021-10497-0

Sarstedt, M., Hair Jr, J. F., Cheah, J. H., Becker, J. M., & Ringle, C. M. (2019). How to specify, estimate, and validate higher-order constructs in PLS-SEM. *Australasian Marketing Journal*, *27*(3), 197-211. https://doi.org/10.1016/j.ausmj.2019.05.003

Segars, A. H., & Grover, V. (1998). Strategic information systems planning success: an investigation of the construct and its measurement. *MIS quarterly*, 139-163. https://doi.org/10.2307/249393

Shah, M. & Foster, A. (2015). Developing and assessing teachers' knowledge of game-based learning. *Journal of Technology and Teacher Education, 23*(2), 241-267. https://www.learntechlib.org/primary/p/147391/.

Shamon, H., & Berning, C. C. (2020). Attention Check Items and Instructions in Online Surveys with Incentivized and Non-Incentivized Samples: Boon or Bane for Data Quality? *Survey Research Methods, 14*(1), 55-77. DOI/10.18148/srm/2020.v14i1.7374

Sharma, P., & Hannafin, M. J. (2007). Scaffolding in technology-enhanced learning environments. *Interactive Learning Environments*, *15*(1), 27-46. https://doi.org/10.1080/10494820600996972

Silseth, K. (2012). The multivoicedness of game play: Exploring the unfolding of a student's learning trajectory in a gaming context at school. *International Journal of Computer-Supported Collaborative Learning*, *7*, 63-84. https://doi.org/10.1007/s11412-011-9132-x

Simms, L. J. (2008). Classical and modern methods of psychological scale construction. *Social and Personality Psychology Compass*, *2*(1), 414-433. https://doi.org/10.1111/j.1751-9004.2007.00044.x

Soper, D. (2018) A-Priori sample size calculator for structural equation models [Software].

Soper, D. S. (2021). A-priori sample size calculator for structural equation models [Software]. Retrieved from https://www. danielsoper.com/statcalc

Stright, A. D., Herr, M. Y., & Neitzel, C. (2009). Maternal scaffolding of children's problem solving and children's adjustment in kindergarten: Hmong families in the United States. *Journal of Educational Psychology,101*(1), 207–218. doi: 10.1037/a0013154

Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction, 28*, 100457. https://doi.org/10.1016/j.lcsi.2020.100457

Tabak, I., & Kyza, E. A. (2018). Research on scaffolding in the learning sciences: A methodological perspective. In *International Handbook of the Learning Sciences* (pp. 191-200). Routledge.

Takeuchi, L. M., & Vaala, S. (2014). Level up Learning: A National Survey on Teaching with Digital Games. In *Joan Ganz Cooney Center at Sesame Workshop.*

Tenenhaus, M., Vinzi, V. E., Chatelin, Y. M., & Lauro, C. (2005). PLS path modeling. *Computational Statistics & Data analysis*, *48*(1), 159-205. https://doi.org/10.1016/j.csda.2004.03.005

Tourangeau, R., Rips, L. J., & Rasinski, K. (2000). *The psychology of survey response.* Cambridge: Cambridge University Press

Tzuo, P.-W., Ling, J. I. O. P., Yang, C.-H., & Chen, V. H.-H. (2012). Reconceptualizing pedagogical usability of and teachers' roles in computer game-based learning in school. *Educational Research and Reviews,7*, 419–429. DOI: 10.5897/ERR11.072

Urbach, N., & Ahlemann, F. (2010). Structural equation modeling in information systems research using partial least squares. *Journal of Information Technology Theory and Application (JITTA)*, *11*(2), 2.

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *EDUCAUSE review, 41*(2), 16.

Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review*, *22*, 271-296. https://doi.org/10.1007/s10648-010-9127-6

Vandercruysse, S., Vandewaetere, M., Cornillie, F., & Clarebout, G. (2013). Competition and students' perceptions in a game-based language learning environment. *Educational Technology Research and Development, 61*(6), 927-950. https://doi.org/10.1007/s11423-013-9314-5

Vygotsky, L. S., & Cole, M. (1978). *Mind in society: Development of higher psychological processes*. Harvard University Press.

Waiyakoon, S., Khlaisang, J., & Koraneekij, P. (2015). Development of an instructional learning object design model for tablets using game-based learning with scaffolding to enhance mathematical concepts for mathematic learning disability students. *Procedia-Social and Behavioral Sciences, 174*, 1489-1496. https://doi.org/10.1016/j.sbspro.2015.01.779

Watson, W. R., Mong, C. J., & Harris, C. A. (2011). A case study of the in-class use of a video game for teaching high school history. *Computers & Education, 56*(2), 466-474. https://doi.org/10.1016/j.compedu.2010.09.007

Westland, J. C. (2010). Lower bounds on sample size in structural equation modeling. *Electronic Commerce Research and Applications, 9(*6), 476–487. https://doi.org/10.1016/j.elerap.2010.07.003

Wood, D., & Middleton, D. (1975). A study of assisted problem-solving. *British Journal of Psychology*, *66*(2), 181-191. https://doi.org/10.1111/j.2044-8295.1975.tb01454.x

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Child Psychology & Psychiatry & Allied Disciplines, 17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wood, D., Wood, H., & Middleton, D. (1978). An experimental evaluation of four face-to-face teaching strategies. *International Journal of Behavioral Development*, *1*(2), 131-147. https://doi.org/10.1177/016502547800100203

Young, M. F., Slota, S., Cutter, A. B., et al. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research*, *82*(1), 61–89. https://doi.org/10.3102/0034654312436980

Bridging Text

Chapter 4 discusses the construction and validation of the Teacher Scaffolding Use Questionnaire during Game-Based Learning (TSQ-GBL). An online pilot survey was conducted to collect data from 180 K-12 teachers to validate this newly developed scale. Several psychometric measures were used to test the reliability, such as internal item consistency, and validity, such as content, convergent and discriminant validity, of the TSQ-GBL. The measurement model displayed adequate results. Following that, the study aimed to understand whether the general use of game pedagogies by teachers and perceived availability of school resources impacted the use of scaffolding strategies in GBL environments by investigating the following question: what the unique effects of teachers' game-based pedagogy usage and perceived availability of school resources on the usage of each scaffolding type of the TSQ-GBL are. Overall, the findings showed that the TSQ-GBL is a validated tool to assess and identify teachers' scaffolding use during GBL. Teachers use the transfer of responsibility most frequently of the three scaffolds, and they use the recruitment, direction, and reduction scaffolds more often than other specific scaffolds. Additionally, game-based pedagogy use was directly related, whereas the availability of school resources was indirectly related to the teachers' scaffolding use. Thus, this study contributes to the literature by enabling a tool/scale for researchers to assess and identify teachers' scaffolding practices during GBL, as well as demonstrating the impact of other factors, namely game pedagogy uses and available school resources, on the use of teachers' scaffold during GBL, which can be other potential factors that ultimately influence the effectiveness of GBL.

In Chapter 5, the focus shifts to exploring whether teachers' knowledge of games also affects their scaffolding practices in GBL. Hence, a cross-sectional correlational design study was designed with 330 K-12 teachers to first confirm the model by integrating TPACK-G framework with scaffolding theory. Additionally, differences were examined between teachers who have less teaching experience and those with more teaching experience to investigate if this is another factor that differs in terms of their scaffolding usage in GBL. This chapter concludes by highlighting the importance of considering these additional factors when designing teacher training programs to improve the effectiveness of GBL.

Overall, these chapters emphasize the importance of recognizing that game-based learning is not solely dependent on the game itself, but on the teacher's role in facilitating and scaffolding student learning during gameplay. The chapters highlight not only the importance of understanding the factors that influence teachers' scaffolding practices in GBL, but also the need for systematic and differentiated professional development and training programs to support teachers in integrating GBL into their instruction.

Chapter 5. Manuscript 3

Does Teachers' Knowledge of Games Matter in Facilitating Game-based Learning? Investigating the Relationship Between Teachers' Technological, Content, and Pedagogical Knowledge of Games and Teachers' Use of Scaffolding during Gameplay

Kacmaz, G., & Dubé, A. K. (In preparation). Does Teachers' Knowledge of Games Matter in Facilitating Game-based Learning? Investigating the Relationship Between Teachers' TPACK-G and TSQ-GBL. *Computers and Education*.

Abstract

Games are effective pedagogical tools for engaging and motivating students. However, teachers' knowledge of games (TPACK-G) and their teaching experience are crucial factors in facilitating successful game-based learning (GBL). TPACK-G influences the way teachers leverage their game, content, and pedagogical knowledge, whereas teaching experience shapes their attitudes towards adopting games in the classroom. However, it is unknown whether teachers' TPACK-G influences the usage of scaffolding in GBL and whether differences exist between junior and senior teachers. A total of 327 junior and senior K-12 teachers participated in this study. Using a clustering approach, it was found that junior teachers had higher scores in game knowledge than game content knowledge, game pedagogical knowledge, and game pedagogical content knowledge. Further, junior teachers' TPACK-G had a more significant impact on their use of different types of scaffolding during GBL compared to senior teachers. Finally, transfer of responsibility and emotional scaffolding were more frequently used than cognitive scaffolding by both junior and senior teachers. Future studies could further examine the effectiveness of professional training programs aimed at improving teachers' use of different types of scaffolding and their game, content, game pedagogical and game pedagogical knowledge based on their TPACK-G levels.

Keywords: Game-based learning, TPACK-G, Scaffolding, Teachers, Teaching experience

Digital games are among the most popular instructional technologies in today's educational settings (Mayer, 2014b; Tobias & Fletcher, 2011). According to a national survey on teaching with digital games conducted in 2014, 55% of the 694 K–8 teachers in the United States who participated had integrated games into their lessons weekly (Takeuchi & Vaala, 2014). The use of games as a pedagogical tool by teachers has become increasingly prevalent. However, the effectiveness of this approach may depend on teachers' level of familiarity with games and their ability to facilitate game-based learning (GBL). Undoubtedly, teachers play an essential role in facilitating GBL for students by providing scaffolds such as offering support, controlling the learning process, encouraging participation, and providing additional resources and immediate feedback (Haruehansawasin & Kiattikomol, 2018). However, teachers' ability to effectively leverage their game, content, and pedagogical knowledge, known as TPACK-G, is a critical factor in the success of facilitating GBL (Koehler & Mishra, 2009; Hsu et al., 2017; 2021). Additionally, teaching experience is a differentiating variable in shaping teachers' attitudes and beliefs about adopting games in the classroom, with more experienced teachers having different perceptions than less experienced teachers (Baek, 2008; Hsu et al., 2021), which could potentially influence the way they facilitate GBL. Thus, this paper aims to explore the relationship between teachers' TPACK-G and their use of scaffolding during GBL and examine whether or not any differences exist between junior and senior teachers.

Theoretical Background

Scaffolding During Game-based Learning

One of the main challenges in integrating Game-Based Learning (GBL) into formal educational settings is the limited understanding of effective scaffolding strategies. Such strategies are essential for introducing new games or concepts to learners, as well as for connecting the knowledge acquired through gameplay with the knowledge taught in the classroom which has been highlighted in various studies (Clark et al., 2011; Habgood & Ainsworth 2011; & Quintana et al., 2004).To address this challenge, researchers have examined the utility of types of scaffolding to guide students to bridge the gap between game structures and content learning (Barzilai & Blau, 2014). However, the impact of scaffolding on GBL outcomes has been inconsistent and sometimes negative depending on how it is used (Barzilai & Blau, 2014; Chen & Law, 2016; Huizenga et al., 2009; Wouters & van Oostendorp, 2013). For example, Barzilai and Blau (2014) found that scaffolds improved the perceived ease of learning but had a negative impact on learners' enjoyment and perceptions of the game's contribution to their learning, whereas Charsky and Ressler (2011) also found that adding concept maps as a scaffold decreased student motivation to learn through gameplay. Conversely, recent studies have also emphasized the important role that teachers' scaffolds can provide to enhance GBL outcomes (Barzilai & Blau, 2014; Chen & Law, 2016; Honey & Hilton, 2011). The impact of scaffolding on GBL environment is mixed and may depend on various factors such as the type of game being used, the students' level of understanding and comprehension of the task, as well as the type of scaffold used, how it is implemented or the knowledge that teachers need to possess. These factors require more careful consideration.

To have a solid understanding of the theoretical foundations of scaffolding, it is important to note that in 1976, Wood, Bruner, and Ross popularized the term "scaffolding" to describe the support or guidance provided by an expert to a beginner to help them achieve a task or goal that would otherwise be challenging to accomplish on their own. Although, the concept of scaffolding has been discussed in educational contexts, it received renewed attention due to Wood, Bruner, and Ross' (1976) work. Scaffolding is a complex and multifaceted process, leading to discrepancies in its definition and measurement approaches (Pea, 2004), making the diverse forms of scaffolding used in the literature challenging to understand (Granott, 2005). To tackle this issue, a recent scaffolding approach has employed a multidimensional framework that groups scaffolding behaviors into three major components: cognitive, emotional, and responsibility facets (Hughes, 2015; Leerkes et al., 2011; Mermelshtine & Barnes, 2016; Neitzel & Stright, 2003, 2004; Stright et al., 2009). These three major groups of scaffolds encompass the six scaffolding features (recruitment, reduction, direction, marking, control, and demo) identified by Wood et al. (1976). Implementing these scaffolds to improve learning can be cost-effective, as they are easily created and used by many teachers (Barzilai & Blau, 2014; Chen & Law, 2016); however, evidence is needed to identify the extent to which teachers employ these different types of scaffolding strategies during GBL. This gap is partially due to the inadequacy of measuring the scaffolds provided by teachers in GBL environments (Shah, 2019). Therefore, it is imperative to assess the scaffolding strategies used by educators, including the types of scaffolds used, to gain a better understanding of the role of scaffolding in GBL.

To address this gap Kacmaz and Dubé (in preparation) have provided strong evidence for the reliability and validity of a newly developed theory-driven self-report measure called the "*Teacher Scaffolding Questionnaire in Game-Based Learning* (TSQ-GBL; see Table 1)" to determine the frequency of teachers' scaffolding usage (Neitzel & Stright, 2004; Mermelshtine, 2017). Findings revealed that teachers tend to use transfer of responsibility and emotional scaffolding more frequently than cognitive scaffolding through the validated best-fit 3-dimensional model. Furthermore, a more granular analysis exploring six individual scaffolds reveals that recruitment, direction, and reduction scaffolds are used more often than other specific scaffold types, whereas marking is used less often (Kacmaz & Dubé, in preparation).

One possible reason why certain scaffolds, such as cognitive supports, are used less frequently by teachers could be a lack of the teacher's knowledge about the games, which may hinder their ability to use such scaffolds effectively. Bourgonjon and Hanghøj (2011) support this notion that teachers do not necessarily need to be experts in every new medium, but they should have a basic understanding of what is happening within the medium to integrate their instructions effectively. Teachers who have a good understanding of how games work or have experience using games in their instruction or curriculum, are more likely to have well-developed repertoire of strategies to provide relevant and meaningful guidance (Hsu et al., 2021; Nousiainen et al., 2018; Shah & Foster, 2015). Therefore, further investigation is needed to determine whether teachers' understanding or familiarity with games impact their scaffold use in GBL environments.

Table 1

Dimensions of TSQ-GBL' Definition, Operationalization, and Sample Items

Dimensions of Scaffolding	Subdimensions	Definition (Based on Wood et al., (1976)' scaffolding theory)	Operationalization	Examples	Sample items
Cognitive Scaffold(s)	Reduction	To simplify the task and reduce the cognitive load required to complete the task, making it more manageable and achievable for the learner.	Simplifying the gameplay by showing or prompting each component step-by-step: This could involve providing in-game tutorials or instructions that break down the gameplay into smaller, more manageable steps, and guide the player through each step. **OR,** breaking down complex concepts into simpler, more manageable parts: This could involve breaking down complex concepts or tasks into smaller, more manageable parts.	For example, a game that teaches math skills might prompt the player to solve a simple addition problem before moving on to more complex problems. **OR** a game that teaches coding might break down a complex coding task into smaller steps to help the player understand the coding process.	I simplify the gameplay by showing students how to play step-by-step. **OR** I make the gameplay easier by explaining the difficulty levels clearly.
	Marking	To draw learners' attention to important features or concepts of the task or point out important events in the task helping them understand and remember the information more effectively.	Highlighting/marking important game design/features relevant to gameplay: This could involve highlighting or marking important game design elements, such as key objects or areas, to draw the player's attention to them. **OR**, highlighting/marking the key learning concepts or tasks: This could involve highlighting or marking key learning concepts or tasks, such as important vocabulary or math formulas, to help the player remember them.	For example, in a game that teaches geography, important landmarks or regions could be highlighted to help the player learn their names and locations. **OR**, in a game that teaches language skills, important words or phrases could be highlighted to help the player learn and remember them.	I highlight key game design features, game rules or elements in the game. **OR** I underline key learning content or concepts in the game.
	Demonstration	To provide learners clear examples or	Demonstrating how to play the game: This could involve showing	For example, in a game that teaches programming, a	I explicitly demonstrate how to play the game

		explanations of how to complete tasks and understand the concepts they are learning by modelling or demonstrating.	the player how to complete certain tasks or challenges in the game. **OR,** explaining explicitly the learning concepts in the game: This could involve providing clear explanations of the learning concepts or objectives in the game, helping the player understand the purpose of the game and what they should be learning.	demonstration could be provided to show the player how to write a particular piece of code. **OR,** for example, in a game that teaches history, an explanation could be provided to help the player understand the context and significance of the events they are experiencing in the game.	step-by-step. **OR** I explicitly explain the key learning concepts/tasks involved in the game.
Transfer of Responsibility Scaffold(s)	Recruitment	To engage the learner's interest and motivation, and to help them understand the importance of the learning objectives to initiate the task.	Focusing on students' attention on the game's learning goals: This could involve highlighting the specific learning goals or objectives of the game, and why they are important**. OR,** focusing students' attention on the game itself: This could involve explaining the rules or mechanics of the game, and how they relate to the learning objectives.	For example, in a game that teaches math skills, the learning goals could be explained to the player, such as to learn how to solve equations or understand fractions. **OR,** in a game that teaches geography, the rules could be explained to the player, such as how to navigate a map or identify different countries.	Before students start playing the game in class, I explain the game's learning goals to get them ready and interested to learn. **OR,** before students start playing the game in class, I explain the game rules to get them ready and interested to learn.
	Direction	To keep the learner engaged and motivated, and to guide them towards achieving the learning objectives of the game.	Providing confirmation prompts: This could involve providing feedback to the player on their progress and performance and guiding them towards the next steps or actions to take in the game. **OR** providing reminder prompts. This could involve adjusting the prompts or reminder based on the needs of learners as the task progresses.	For example, in a game that teaches science concepts, the player could receive feedback on their understanding of a concept and be guided towards related topics. **OR,** using a game to teach math skill by providing frequent reminders and prompts for them to use a multiplication table or calculator to help them solve problems.	I provide confirmation prompts that students are heading in the right direction during gameplay to sustain their attention. **OR** I provide reminder prompts to students to keep them on task.

Emotional Scaffold(s)	Control	To help familiarize them with the task/activity and reduce students' frustration while taking control of their learning without creating too much dependency on the instructor.	Providing alternative gameplay suggestions or strategies: When students encounter a challenging section of the game that may lead to frustration, the instructor can provide alternative gameplay suggestions or strategies to help them overcome the challenge. **OR** providing emotional support or strategies: The instructor should provide feedback and support to students throughout the game-based learning activity. This can help reduce frustration by letting students know that they are making progress and by providing them with guidance when they are struggling.	For instance, in a language learning game, a student may struggle with understanding and using a particular grammar rule. The instructor can provide an alternative strategy by suggesting that the student focus on practicing that particular grammar rule in a separate mini-game or activity within the game, or by providing additional examples and explanations of the rule. **OR** offering encouraging feedback to students when they are struggling with a difficult level or concept and guiding them towards the next steps or actions to take in the game.	When students get frustrated with the game, I help by providing alternative gameplay suggestions or strategies. **OR,** when students get frustrated with the game, I help by providing emotional support or strategies.

Teachers' Game, Content and Pedagogical Knowledge of Games

One important factor that affects the teachers' facilitation strategies in practice is the teachers' knowledge of games as well as their experiences. To address this, researchers have proposed the Technological, Pedagogical, Content Knowledge for games (TPACK-G) framework as a valuable tool (Hsu et al., 2013). This framework serves to outline the knowledge that teachers need to successfully integrate games into their instruction and support learning (Hsu et al., 2017). Essential components of this framework include understanding the principles and concepts behind the games and connecting them with their facilitation strategies. These components have been highlighted as pre-conditions for effective implementation of GBL in the classroom (Hsu et al., 2017; 2020). By understanding the underlying concepts and principles of the TPACK-G framework, researchers and educators can better utilize the games to develop targeted training programs for teachers, ultimately leading to improved scaffolding strategies integration of games into instruction (Bourgonjon & Hanghøj, 2011).

Theoretically, the TPACK-G framework, which stands for Technological Pedagogical Content Knowledge-Games, is a theoretical framework that helps to guide the integration of technology, specifically digital games, in education (Hsu et al., 2013). This framework, developed from TPACK (Chai et al., 2013; Mishra & Koehler, 2006; Voogt et al., 2013), is comprised of four components: game knowledge (GK), game pedagogical knowledge (GPK), game content knowledge (GCK), and game pedagogical content knowledge (GPCK). GK refers to the knowledge of using games, GPK refers to understanding how games can be effectively implemented pedagogically soundly, and GCK refers to using games to represent subject matter. GPCK refers to integrating games, pedagogy, and content to create or teach the designated subject content (Hsu et al., 2013). Thus, to ensure the success of GBL activities, educators should possess sufficient knowledge of games, pedagogy, and content (Nousiainen et al., 2018).

Previous research has utilized TPACK-G to examine the relationship between different types of TPACK-G knowledge among preschool teachers and their attitudes towards games (Hsu et al., 2013). The findings showed positive correlation between preschool teachers' GK, GPK, and GPCK and their attitudes towards using games in teaching. Similarly, another study by Hsu et al., (2017) revealed that elementary and middle school teachers' GPCK was significantly predicted by their motivation, confidence, GK, and GPK, which also highlights the importance of teachers' professional knowledge in leveraging game-based learning environments in their teaching and provides insights into the factors that contribute to effective GPCK. Moreover, Hsu et al. (2021)' results indicated that junior teachers had higher scores in GK, GCK, and GPCK than senior teachers. The study also found that GK alone may not be sufficient to predict teachers' actual teaching usage. Junior teachers were more likely to rely on their GPCK to predict their actual teaching usage, whereas senior teachers relied more on their GPK. These consistent findings of Hsu et al. (2013, 2017, 2021) demonstrate that teachers' TPACK-G is essential in predicting their positive attitudes toward and use of games in teaching. Further, these studies highlight the relationship between TPACK-G components and the usage of games in teaching varies between teachers based on their teaching level or experience. This differentiation highlights the importance of TPACK-G for junior teachers who may have less teaching experience and are more focused on game-based learning, whereas senior teachers who have more experience may prioritize their general pedagogical knowledge. Therefore, understanding these differences among TPACK-G components is essential for effective integration of games in teaching across different teacher groups. Moreover, the findings suggest that the need for further research on how teachers' TPACK-G affects specifically their scaffolding usage during GBL and whether this difference exists between junior and senior teachers in their in-class practices.

The Current Investigation

Game-based learning is becoming an increasingly popular approach for educators to engage and motivate students in the classroom. However, for this practice to be successful, it is important for teachers to not only have a familiarity with games, but also to understand how to effectively facilitate game-based learning. One theoretical framework that can guide the facilitation of game-based learning is scaffolding theory, which suggests that the level and types of support provided by a teacher can significantly impact a student's understanding and comprehension of a subject or task (Belland., 2013; Van de Pol, J et al., 2010). The TPACK-G framework also highlights the knowledge, skills, and beliefs teachers need to have to integrate games effectively into their instruction (Hsu et al., 2013). A teacher's TPACK-G may influence their use of different scaffolding strategies to facilitate student learning, reflecting their knowledge and confidence in using games in classroom settings. For example, teachers with a strong or weak TPACK-G may be more likely to use certain scaffolding practices to facilitate student learning. Hence, further research is needed to understand the relationship between TPACK-G and teachers' scaffolding usage in game-based learning environments.

Additionally, previous research (Hsu et al., 2021) has shown that teachers' teaching experience may influence their perceptions and confidence in using games. For example, Li and Huang (2016) found that more experienced teachers were less likely to adopt game-based learning. Also, Hsu et al. (2021) discovered that teachers with less than ten years of experience had more self-confidence in their knowledge and ability to use games effectively in teaching than more experienced teachers. These studies suggest that there may be differences in game, content, and pedagogical knowledge between junior and senior teachers. However, it is unknown whether these different groups of teachers' TPACK-G influence the usage of different types of scaffolding in game-based learning environments. Thus, the present study aims to examine the following three research questions:

1. Can TPACK-G and TSQ-GBL instruments used in this study accurately assess both teachers' TPACK-G and TSQ-GBL?
2. Do junior and senior teachers differ in their TPACK-G and TSQ-GBL?
3. What is the relationship between junior and senior teachers' TPACK-G perceptions and their use of TSQ-GBL(s)?

Method

Participants

K-12 teachers were recruited to participate using the online recruitment tool Prolific. A power analysis was conducted using an a priori sample size online calculator (Soper, 2023). Based on assumptions (given the models' 35 observed items and 12 latent variables and to achieve the anticipated effect size (0.3), the desired probability (0.05), and statistical power levels (0.08)), the required minimum sample size was 244 (Cohens, 1988, Westland, 2010). 797 teachers were eligible using the pre-screening criteria in Prolific, such as being K-12 teachers who primarily work in the primary/secondary (K-12) education sector. Only 341 teachers completed the study, and fourteen were excluded due to missing attention checks. Attention checks were included to identify participants who needed to read the instructions or questions properly (Tourangeau et al., 2000), also known as careless respondents (Meade & Craig, 2012) or insufficient effort respondents (Shamon & Berning, 2019).

A total of 327 K-12 teachers (141-man, 183 woman, and 3 nonbinary/third gender) residing in a North American or majority native English-speaking European country are included in this study, which fits the literature recommendations (Soper, 2021; Westland, 2010). The median time for study completion was 10.36 min. Descriptive statistics, such as gender, age, teaching years, employment status, level of education, and teaching country, were obtained to characterize the sample (See Table 2 for details). The process for labelling teachers as junior vs senior is explained in the results section.

Table 2

Demographics of K-12 Teachers

	Junior Teachers (N =216)				Senior Teachers (N =111)				Total (N= 327)			
	N	%	*M*	*SD*	N	%	*M*	*SD*	N	%	*M*	*SD*
Age			33.74	6.79			46.09	7.47			37.93	9.14
Teaching Years			6.90	2.96			19.12	6.22			11.05	7.24
Gender												
Man	104	48.1 %			37	33.3 %			141	43.1 %		
Woman	109	1.4 %			74	66.7 %			183	56.0 %		
Third Gender/Binary	3	1.4 %			n/a	n/a			3	0.9 %		
Level of Education												
≤ Bachelor's Degree	127	58..8 %			64	57.7 %			191	58.4 %		
≥ Master's Degree	89	41..2 %			47	42..3 %			136	41.6 %		
Employment Status												
Full-time teacher	170	78.7 %			84	75.7 %			254	77.7 %		
Part-time teacher	30	13.9 %			22	19.8 %			52	15.9 %		
Others	16	7.4 %			5	4.5 %			21	6.4 %		
Teaching Country												
Canada	14	6.5 %			7	6.3 %			21	6.4 %		
United States	114	52.8 %			66	59.5 %			180	55.0 %		
United Kingdom	81	37.5 %			30	27.0 %			111	33.9 %		
Others	7	3.2 %			8	7.2 %			15	4.6 %		

Procedure

The Research Ethics Committee approved the research study at a Canadian university. Before obtaining demographic information, the participants were presented with a consent form and responded to questions about their demographic details. After consent was obtained, the participants simultaneously responded to two questionnaires: the TPACK-G and the TSQ-GBL. The order of items in each construct, each construct within each questionnaire, and the order of the two questionnaires were randomized to account for order effects.

Measures

Demographics

Participants were asked to provide basic information, including age, gender, educational background, current employment status, teaching experience, and the country where they teach.

Teachers' Technological, Pedagogical, and Content Knowledge of Games (TPACK-G)

This study employed the TPACK-G questionnaire to investigate teachers' game pedagogical content knowledge. The internal reliability was high in the earlier studies, such as the overall

Cronbach's alpha coefficients of .97, .94 and .96, respectively (Hsu et al., 2013; Hsu et al., 2015, Hsu et al., 2021). The TPACK-G questionnaire consists of four factors: 'Game Knowledge, GK,' 'Game Content Knowledge, GCK,' 'Game Pedagogical Knowledge, GPK,' and 'Game Pedagogical Content Knowledge, GPCK.' The measure included 16 items and was measured with a 7-point Likert scale ranging from strongly agree (7 points) to strongly disagree (1 point).

Game Knowledge (GK). This factor assesses teachers' confidence in digital games, including four items. The coefficient was .95 (Hsu et al., 2021). A sample item is, '*I can quickly understand the rules while playing digital learning games.*'

Game Content Knowledge (GCK). Teachers' confidence in using digital games to represent specific content is measured with this factor, including three items. The coefficient was .96 (Hsu et al., 2021). A sample item is, '*I can identify whether the subject knowledge is applied in digital games*.'

Game Pedagogical Knowledge (GPK). This factor measures teachers' confidence in using digital games to help their teaching in the classroom and includes four items. The coefficient was .96 (Hsu et al., 2021). A sample item is, '*I know how to integrate digital games into teaching.*'

Game Pedagogical Content Knowledge (GPCK). This factor evaluates teachers' confidence in using digital games and appropriate instructional skills to teach the designated subject content and includes five items. The coefficient was .97 (Hsu et al., 2021). A sample item is, '*I can select digital games to use in my classroom that enhances what I teach, how I teach, and what students learn*.'

Teacher Scaffolding Questionnaire in Game-based Learning Environments (TSQ-GBL)

Teachers' scaffolding usage during gameplay was assessed using a recently developed measurement tool, the TSQ-GBL (Kacmaz & Dubé, in preparation) based on previously established theoretical and empirical research (e.g., Mermelshtine, 2017; Neitzel & Stright, 2004; Wood et al., 1976). Based on the results of the previous study, the TSQ-GBL includes three distinct scaffolding types "*Cognitive Scaffolding-CS*," "*Transfer of Responsibility-ToR*," and "*Emotional Scaffolding-ES.*" A total of 20 items are included and assessed on a scale from 1 (Never) to 7 (Always). Description of three scaffolding types and examples are presented below.

Cognitive Scaffolding (CS). CS include 11 items and assesses how teachers provide students with different learning strategies and is linked with task simplification (Reduction-four items), demonstration (Demo-four items), and marking critical features (Marking-three items) sub scaffolds. In an earlier pilot study, the coefficient was 0.66, 0.82, and 0.77, respectively (Kacmaz & Dubé, in preparation). Sample items are *"I clarify complex game rules/concepts by breaking or dividing them into small pieces (Reduction), I explicitly explain the key learning concepts/tasks involved in the game (Demo), I underline key learning content or concepts in the game (Marking)."*

Transfer of Responsibility (ToR). ToR includes six items, which is associated with recruitment (Recruitment-three items) and attention maintenance (Direction-three items) sub scaffolds and may help to foster students' agency and autonomy. The coefficient was 0.71 and 0.74, respectively (Kacmaz & Dubé, in preparation). Sample items are "*Before students start playing the game in class, I explain the game's learning goals to get them ready and interested to learn (Recruitment), I ask questions to my students to focus on their learning process (Direction).*"

Emotional Scaffolding (ES). The ES component of TSQ-GBL includes three items and assess how teachers manage and control students' frustration through a warm and sensitive manner of instruction. The coefficient in the pilot study was 0.83 (Kacmaz & Dubé, in preparation). A sample item is "*When students get frustrated with the game, I help by providing emotional support or strategies.*"

Data Analysis Rationale and Procedure

First, teachers were grouped into junior and senior categories based on their teaching experiences to address the research questions. Before performing primary analysis, assumption checks were done through tests of normality and multicollinearity. Second, the partial least square (PLS) approach was used to test and verify the measurement model and explore the structural relationships of grouped teachers through the measurement and structural models. PLS is a well-established technique for estimating path coefficients in structural models. It has become increasingly popular in educational research in the past decade because of its ability to model latent constructs under conditions of non-normality and small-to-medium sample sizes (Hair et al., 2013). In addition, PLS analysis was performed and found to be suitable for this study, as there were both formative and reflective first and second-order constructs (Hair et al., 2013). Thus, the PLS algorithm procedure was performed to determine the significance levels of the loadings, weights, and path coefficients, followed by the bootstrapping technique (5000 resample), which was applied to determine the significance levels of the proposed relationships. Following the procedure suggested by Anderson and Gerbing (1988), the measurement model's validity and goodness of fit were estimated before testing the structural relationships outlined in the structural model. Third, independent t-tests were also applied to examine the differences between the grouped K-12 teachers' perceptions of TPACK-G and TSQ-GBL. Fourth, Pearson's correlation was also conducted to explore the relationships between teachers' TPACK-G and their TSQ-GBL. Lastly, based on the measurement model results, the goodness of fitness indices, and correlation results, the structural relationships among the latent variables of the two questionnaires were evaluated via structural equation modelling (SEM) analysis for both groups of teachers to find the differences between the two groups of teachers in how the teachers' TPACK-G relates to their TSQ-GBL.

Results

Grouping Teachers

First, a hierarchical cluster analysis with the ward linkage method was performed using teaching experience as the splitting criteria, which was of central interest to this study. Previous researchers used simple mean splits to group teachers according to experience, which creates more equally sized groups. In contrast, the aim of the cluster analysis approach was to generate two groups of experienced teachers (junior vs senior) with greater homogeneity and more distinctiveness from each other but also more meaningful groups within themselves (Hair et al., 1998). Ward's method was chosen as the linkage method because it combines clusters by minimizing the sum of squared deviations within a group; therefore, the clusters produced by this method should have greater similarities within clusters and greater differences between clusters based on the clustering variables (Ward, 1963). Results revealed two groups: junior and senior teachers. There are 216 in the junior group (104-man, 109 woman, and three non-binary/third gender) and 111 (37 man and 74 woman) in the senior group. There was a statistically significant difference between the junior and senior teacher groups in both average years of teaching experience ($t_{teaching\ experience} = -24.08$, $p = .00$) and average age ($t_{age} = -15.04$, $p = 0.00$). The junior and senior teachers were found to differ in both age and teaching experience (see Table 2 for demographics for both groups).

Verification of the Validity and Structure of the Two Questionnaires (TPACK-G and TSQ-GBL)

The measurement model was assessed to verify the construct validity of both the TPACK-G (Technological, Pedagogical, Content Knowledge of Games) and TSQ-GBL (Teacher Scaffolding in Game Based Learning) questionnaires in one model for K-12 teachers and both groups of teachers. Revalidating the measurement model is necessary to ensure the quality and robustness of the data and results in the current study due to the use of different sample groups and the goal of addressing specific research goals. The measurement model consists of two second-order formative constructs (*CS*: Cognitive Scaffolding and *ToR:* Transfer of Responsibility in TSQ-GBL) and five first-order reflective constructs (*GK:* Game Knowledge, *GCK*: Game Content Knowledge, *GPK:* Game Pedagogical Knowledge, *GPCK:* Game Pedagogical and Content Knowledge in TPACK-G, *ES:* Emotional Scaffolding in TSQ-GBL). Assessing the measurement model process is different for reflective and formative constructs. The validity and reliability of the second order were established using a disjoint two-stage approach. Tables 1, 2 and 3 show the evidence related to factor/outer loadings (OL), the relevance of the indicator's outer weights (OW) and their statistical significances, Internal consistency reliabilities e.g., Cronbach alpha-CA, composite reliability-CR), convergent validities (i.e., average variance extracted-AVE) and indicators' variance inflation factors (VIFs) of all first-order reflective and second-order formative constructs in both measures for K-12 overall as well as junior and senior teachers separately (Hair et al., 2017a).

Table 3

Verification of the Validity and Structure of the TPACK-G and TSQ-GBL for Both Samples

HO Factors	LO Factors	Item	FL	OL (*p*)	OW	Internal Consistency		Convergent Validity	Multicollinearity	
						CA	CR	AVE	VIF for Reflective	VIF for Formative
n/a	**GK**	GK1	0.91			0.90	0.93	0.78	3.35	
		GK2	0.88						2.63	
		GK3	0.88						2.78	
		GK4	0.85						2.19	
n/a	**GCK**	GCK1	0.91			0.88	0.92	0.80	2.60	
		GCK2	0.89						2.26	
		GCK3	0.89						2.32	
n/a	**GPK**	GPK1	0.86			0.89	0.92	0.75	2.28	
		GPK2	0.88						2.63	
		GPK3	0.87						2.45	
		GPK4	0.86						2.24	
n/a	**TPACK**	TPACK1	0.84			0.90	0.93	0.72	2.27	
		TPACK2	0.82						2.06	
		TPACK3	0.88						2.91	
		TPACK4	0.88						2.90	
		TPACK5	0.84						2.25	
CS	REDUCTION	Red_1	0.54	0.75*	**0.37**	0.70	0.80	0.51	1.36	1.39
		Red_2	0.65						1.41	
		Red_3	0.87						1.54	
		Red_4	0.76						1.38	
	MARKING	Mark_1	0.75	0.87*	0.60*	0.70	0.83	0.61	1.46	1.32
		Mark_2	0.77						1.61	
		Mark_3	0.83						1.25	
	DEMO	Demo_1	0.60	0.73*	**0.28**	0.82	0.86	0.61	1.72	1.46
		Demo_2	0.73						2.00	
		Demo_3	0.92						2.08	
		Demo_4	0.84						1.62	
ToR	RECRUITMENT	Rec_1	----	0.64*	0.36*	0.73	0.88	0.79		1.13
		Rec_2	0.92						1.50	
		Rec_3	0.85						1.50	
	DIRECTION	Dir_1	0.64	0.94*	0.82*	0.67	0.81	0.58	1.26	1.13
		Dir_2	0.75						1.37	
		Dir_3	0.88						1.28	
n/a	ES/ CONTROL	Cont_1	0.85			0.82	0.89	0.74	2.13	
		Cont_2	0.87						2.24	
		Cont_3	0.85						1.59	

Note. HOC = high order construct, LOC = low order construct, FL = factor loading for reflective constructs, OL = outer loading for formative constructs, OW = outer weight for formative constructs, CA = Cronbach alpha, CR = composite reliability, AVE =Average Variance Extracted, n/a = not applicable GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control * $p < .05$ & $t < \underline{+}1.96$

According to Awang (2014), the recommended value for factor loadings of items should be at least .60 for established items and .50 for newly developed items. The factor loadings of the measured items in the current study ranged from 0.54 to 0.92 in the overall sample, from 0.60 to 0.93 in the group of junior teachers, and from 0.58 to 0.95 in the group of senior teachers. However, the items "*recruitment_1"* had weak factor loadings in all groups, and the item "*reduction"* had a weak factor loading only in the senior teacher group. For reduction_2 in the senior teacher group, the small sample size of senior teachers (*N*=111) may have contributed to the weak factor loadings. Whereas it also would be ideal to use the same questionnaire for both groups to facilitate comparison, deleting reduction_2 did not improve the models fit. Therefore, "recruitment_1" was removed from the TSQ-GBL scale, but "reduction" was retained. The measurement model results presented in Tables 3, 4, and 5 show that 16 items in the TPACK-G scale and 19 in the TSQ-GBL scale were retained (see Appendix for both measures).

Table 4

Verification of the Validity and Structure of the TPACK-G and TSQ-GBL for Junior Teachers

HO Factors	LO Factors	Item	FL	OL (p)	OW	Internal Consistency		Convergent Validity	Multicollinearity	
						CA	CR	AVE	VIF for Reflective	VIF for Formative
n/a	GK	GK1	0.90			0.90	0.93	0.77	2.94	
		GK2	0.88						2.59	
		GK3	0.88						2.63	
		GK4	0.86						2.29	
n/a	GCK	GCK1	0.91			0.88	0.92	0.80	2.60	
		GCK2	0.89						2.31	
		GCK3	0.89						2.28	
n/a	GPK	GPK1	0.86			0.89	0.92	0.75	2.28	
		GPK2	0.89						2.88	
		GPK3	0.87						2.66	
		GPK4	0.84						2.08	
n/a	TPACK	TPACK1	0.79			0.88	0.92	0.68	1.88	
		TPACK2	0.80						1.91	
		TPACK3	0.86						2.71	
		TPACK4	0.88						2.87	
		TPACK5	0.81						2.00	
CS	REDUCTION	Red_1	0.60	0.73*	0.46*	0.73	0.82	0.54	1.36	1.42
		Red_2	0.64						1.39	
		Red_3	0.86						1.61	
		Red_4	0.81						1.46	
	MARKING	Mark_1	0.80	0.90*	0.73*	0.72	0.84	0.64	1.48	1.29
		Mark_2	0.78						1.54	
		Mark_3	0.81						1.29	
	DEMO	Demo_1	0.61	0.56*	**-0.00**	0.81	0.85	0.60	1.67	1.53
		Demo_2	0.72						1.83	
		Demo_3	0.88						1.99	
		Demo_4	0.85						1.56	
ToR	RECRUITMENT	Rec_1	---	0.65*	**0.32**	0.72	0.87	0.77		1.19
		Rec_2	0.93						1.46	
		Rec_3	0.83						1.46	
	DIRECTION	Dir_1	0.62	0.96*	0.83*	0.67	0.80	0.57	1.28	1.19
		Dir_2	0.70						1.35	
		Dir_3	0.92						1.30	
n/a	ES/ CONTROL	Cont_1	0.86			0.81	0.89	0.72	1.95	
		Cont_2	0.87						2.04	
		Cont_3	0.82						1.53	

Note. HOC = high order construct, LOC = low order construct, FL = factor loading for reflective constructs, OL = outer loading for formative constructs, OW = outer weight for formative constructs, CA = Cronbach alpha, CR = composite reliability, AVE =Average Variance Extracted, n/a = not applicable ,GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control * $p < .05$ & $t < +1.96$

The reliability (Cronbach's alpha) coefficients for the constructs of TPACK-G and TSQ-GBL ranged from 0.67 to 0.90 in the complete sample and the junior teachers' group and from 0.64 to 0.94 in the senior teachers' group. For composite reliability, coefficients ranged from 0.81 to 0.93 in the complete sample, from 0.80 to 0.93 in the junior teachers, and from 0.73 to 0.95. The AVE (s) ranged from 0.51 to 0.80 in the complete sample, from 0.54 to 0.80 in the juniors' teachers' group and from 0.43 to 0.80 in the senior teachers group.

Table 5

Verification of the Validity and Structure of the TPACK-G and TSQ-GBL for Senior Teachers

						Internal Consistency		Convergent Validity	Multicollinearity	
HO Factors	LO Factors	Item	FL	OL (p)	OW	CA	CR	AVE	VIF for Reflective	VIF for Formative
n/a	GK	GK1	0.92			0.90	0.93	0.78	3.87	
		GK2	0.87						2.50	
		GK3	0.88						2.84	
		GK4	0.85						2.16	
n/a	GCK	GCK1	0.91			0.88	0.93	0.80	2.69	
		GCK2	0.89						2.20	
		GCK3	0.89						2.46	
n/a	GPK	GPK1	0.86			0.89	0.93	0.76	2.35	
		GPK2	0.87						2.42	
		GPK3	0.85						2.21	
		GPK4	0.89						2.79	
n/a	TPACK	TPACK1	0.92			0.94	0.95	0.79	4.16	
		TPACK2	0.85						2.43	
		TPACK3	0.91						3.85	
		TPACK4	0.90						3.28	
		TPACK5	0.89						3.19	
CS	REDUCTION	Red_1	**0.34**	0.68*	**0.29**	0.64	0.73	**0.43**	1.41	1.32
		Red_2	0.65						1.50	
		Red_3	0.90						1.40	
		Red_4	0.61						1.26	
	MARKING	Mark_1	0.62	0.71*	**0.30**	0.67	0.78	0.55	1.50	1.37
		Mark_2	0.69						1.76	
		Mark_3	0.90						1.24	
	DEMO	Demo_1	0.58	0.90*	0.66*	0.84	0.87	0.63	1.88	1.29
		Demo_2	0.77						2.56	
		Demo_3	0.95						2.30	
		Demo_4	0.84						1.80	
ToR	RECRUITMENT	Rec_1	---	0.60*	0.43*	0.76	0.89	0.81		1.05
		Rec_2	0.91						1.62	
		Rec_3	0.89						1.62	
	DIRECTION	Dir_1	0.66	0.91*	0.82*	0.66	0.81	0.59	1.25	1.05
		Dir_2	0.83						1.41	
		Dir_3	0.81						1.27	
n/a	ES/ CONTROL	Cont_1	0.85			0.85	0.91	0.76	2.63	
		Cont_2	0.88						2.83	
		Cont_3	0.89						1.70	

Note. HOC = high order construct, LOC = low order construct, FL = factor loading for reflective constructs, OL = outer loading for formative constructs, OW = outer weight for formative constructs, CA = Cronbach alpha, CR = composite reliability, AVE =Average Variance Extracted, n/a = not applicable, GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control * $p < .05$ & $t < +1.96$

The relevance of the indicator's outer weights (OW) of the second-order formative constructs is evaluated when assessing formative constructs. *"Reduction*" and *"Demo"* to form CS in the complete model, *"Demo"* to form CS and *"Recruitment"* to form ToR in the juniors' teachers, and *"Reduction"* and *"Marking"* to form CS in the seniors' group have statistically insignificant and lower outer weights. However, the outer loadings of all these constructs were found to be statistically significant. Lastly, all the VIF values for reflective, formative, first, and second-order constructs were below the recommended threshold value (less than 5). Thus, the measurement models of the complete samples, junior and senior teachers' samples, were found to have sufficient reliability and validity values.

The Goodness of Fit (Model's predictive capabilities)

As PLS does not generate overall goodness of fit indices, R^2 is the primary way to evaluate the model's explanatory power (Wasko &Faraj, 2005). However, another diagnostic tool is presented by Tenenhaus et al. (2005) to assess model fit, known as the goodness of fit (GoF) index. The GoF measure uses the geometric mean of the average communality and the average R^2 (for endogenous constructs). Hoffmann and Birnbrich (2012) report the following cut-off values for assessing the results of the GoF analysis: GoF_{small} 0.1; GoF_{medium} 0.25; GoF_{large} 0.36. For the model used in this study, a GoF value of 0.45 for the complete sample, 0.45 for junior teachers, and 0.48 for senior teachers are calculated, which indicates a very good model fit.

Although caution is advised when reporting and using model fit in PLS-SEM modelling (Hair et al. 2017), we checked the most common goodness of fit indices. The Structural Equation Modelling Root Mean Square Residual (SRMR) measure, introduced by Henseler et al. (2014), is widely used in PLS-SEM literature (Buabeng-Andoh, 2021; Mohan et al., 2020; Şahin et al., 2021) and provides information on the difference between observed correlations and the model-implied correlation matrix. A value less than 0.10 or 0.08 (Hu & Bentler, 1999) indicates a good fit. For the model used in this study, a SRMR value of 0.05 for the complete sample, 0.05 for junior teachers, and 0.06 for senior teachers are calculated. The findings from our analysis indicate that the measurement models have an acceptable fit, as evidenced by the SRMR values being less than 0.08 for all models. These models will be used in the subsequent analyses.

Table 6

The Descriptive(s) for TPACK-G and TSQ-GBL between Junior and Senior Teachers

	GK Mean (SD)	GPK Mean (SD)	GCK Mean (SD)	GPCK Mean (SD)	CS Mean (SD)	ToR Mean (SD)	ES Mean (SD)
Junior Teachers (*n* =216)	6.00 (.82)	5.57 (.93)	5.81 (.83)	5.60 (.86)	4.31 (.97)	5.13 (0.98)	5.03 (1.18)
Senior Teachers (*n*=111)	5.64 (.91)	5.57 (.88)	5.82 (.68)	5.54 (.94)	4.32 (.98)	5.18 (.91)	5.12 (1.27)

Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

Comparison of Junior and Senior K-12 Teachers' TPACK-G and TSQ-GBL

A mixed-model ANOVA with a 4 (TPACK-G: game knowledge, game content knowledge, game pedagogical knowledge, game pedagogical content knowledge) x 2 (Teaching Experience: junior vs senior) design was conducted to examine potential differences in TPACK-G constructs between junior and senior teachers. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, x2(5) = 100.56, p < .001. Using the Greenhouse-Geisser correction, the results revealed no main effect of teaching experience, indicating no statistically significant differences in overall TPACK-G constructs between junior and senior teachers. However, the main effect for TPACK-G constructs was statistically significant, indicating that the mean scores for game knowledge (GK), game content knowledge (GCK), game pedagogical knowledge (GPK), and game pedagogical content knowledge (GPCK) differed significantly. GK was significantly greater than GPK and GPCK, GCK was significantly greater than GPK and GPCK. No other statistically significant differences were found between GK, GCK, GPK, and GPCK. However, a statistically significant interaction was observed, suggesting that the differences among the TPACK-G constructs differed significantly between junior and senior teachers (see Table 7). Follow-up post hoc Holm tests were conducted to further explore the interaction effect. For junior teachers, GK was significantly higher than GCK, GPK, and GPCK, whereas GCK was significantly higher than GPK and GPCK (see Table 8). For senior teachers, GCK was significantly higher than GPK and GPCK, but no other statistically significant differences were found (see Table 8).

Table 7

Mixed Model ANOVA Results among TPACK-G between Junior vs Senior Teachers

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	ω^2
Between Subjects Effects						
Teaching Levels	2.990	1	2.990	1.391	.239	5.997
Residuals	698.524	325	2.149			
Within Subjects Effects						
TPACK-G	18.224	3	6.075	22.558	< .001	0.018
TPACK-G ✻ Teaching Levels	6.343	3	2.114	7.851	< .001	0.006
Residuals	262.561	975	0.269			

Note. Type III Sum of Squares
[a] Mauchly's test of sphericity indicates that the assumption of sphericity is violated (p < .05).
TPACK-G: Technological, Pedagogical, Content Knowledge of Games

Table 8

*Post Hoc Comparisons – Teaching Levels * TPACK-G*

	Mean Difference	SE	*df*	*t*	*p*
Junior Teachers					
GK-GCK	0.185	0.050	325	3.701	0.005**
GK-GPK	0.428	0.050	325	8.570	<.001***
GK-GPCK	0.401	0.050	325	8.024	<.001***
GCK-GPK	0.243	0.050	325	4.869	<.001***
GCK-GPCK	0.216	0.050	325	4.323	<.001***
GPK-GPCK	-0.027	0.050	325	-0.546	1.000
Senior Teachers			325		
GK-GCK	-0.168	0.100	325	-1.669	1.000
GK-GPK	0.077	0.070	325	1.099	1.000
GK-GPCK	0.104	0.070	325	1.491	1.000
GCK-GPK	0.249	0.070	325	3.578	0.007**
GCK-GPCK	0.277	0.070	325	3.970	0.002**
GPK-GPCK	0.027	0.070	325	0.392	1.000

Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge

A 3 (Scaffolding Types: cognitive, transfer of responsibility and emotional scaffold) x 2 (Teaching Experiences: Junior vs Senior) mixed-model ANOVA was conducted to investigate whether there were statistically significant differences in scaffolding use between junior and senior teachers (see Table 9). The assumption of sphericity was violated, $x^2(2) = 53.455$, $p <$ .001). Using the Greenhouse-Geisser correction, the main effect of scaffolding type was statistically significant, indicating that ToR and ES was significantly greater than CS and there are no statistically significant differences between ToR and ES (see Table 10). However, the main effect of teacher groups was not statistically significant, suggesting that there were no statistically significant differences between junior and senior teachers in their use of CS, ToR, and ES (Table 9). Further, the interaction between the scaffolding types and teacher groups was also not statistically significant, indicating that the relationships between scaffolding types and teacher groups were similar.

Table 9

Mixed Model ANOVA Results among Three-dimension TSQ-GBL Constructs between Junior and Senior Teachers

Cases	Sum of Squares	*df*	Mean Square	*F*	*p*	*ω²*
Between Subjects Effects						
Teaching Levels	0.460	1	0.460	0.197	.657	0.000
Residuals	758.606	325	2.334			
Within Subjects Effects						
TSQ-GBL	126.247	1.736	72.724	127.116	< .001	0.104
TSQ-GBL ✻ Teaching Levels	0.247	1.736	0.142	0.248	0.749	0.000
Residuals	322.778	564.190	0.269			

Note. Type III Sum of Squares
[a] Mauchly's test of sphericity indicates that the assumption of sphericity is violated (p < .05).
TPACK-G = Technological, Pedagogical, and Content Knowledge of Games

Table 10

Post Hoc Comparisons of Three-Scaffolding Types in TSQ-GBL

	Mean Difference	SE	*df*	*t*	*p*
CS-ToR	-0.841	0.058	325	-14.454	<.001***
CS-ES	-0.760	0.058	325	-13.057	<.001***
ToR-ES	0.081	0.058	325	1.397	0.163

Note. CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

Relationship among Junior and Senior K 12 Teachers' TPACK-G and TSQ-GBL

To explore the relationships between teachers' TPACK-G and their TSQ-GBL use, Pearson's correlation coefficients were calculated between the teachers' responses for each TPACK-G construct and those of the TSQ-GBL constructs. The correlations among the constructs of these two questionnaires are presented in Table 11. For junior teachers, positive and statistically significant correlations were found among all constructs, with correlation coefficients ranging from 0.185 to 0.350. In the case of senior teachers, positive correlations were found between TPACK-G and both ToR and ES usage, with coefficients ranging from

0.202 to 0.367. However, CS usage was only positively correlated with GPCK but not with the other components of TPACK-G, including GK, GCK, and GPK.

Table 11

Correlations K-12 Teachers' TPACK-G and TSQ-GBL

Teaching Experiences	TPACK-G Constructs	TSQ-GBL Constructs		
		CS	ToR	ES
Complete sample (*n* = 327)	GK	.190**	.230**	.341**
	GCK	.219**	.281**	.270**
	GPK	.209**	.205**	.261**
	GPCK	.230**	.282**	.307**
Junior Teachers (*n*= 216)	GK	.246**	.252**	.350**
	GCK	.273**	.312**	.276**
	GPK	.261**	.185**	.231**
	GPCK	.251**	.254**	.273**
Senior Teachers (*n*= 111)	GK	**.097**	.202*	.361**
	GCK	**.090**	.202*	.266**
	GPK	**.100**	.248**	.322**
	GPCK	.192*	.339**	.367**

** p <.01 (2-tailed); *p <.05 (2-tailed)

Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge

Following the measurement model, the goodness of fit, and correlation results, the structural relationships between the latent constructs of the two questionnaires were tested. The final structural models for both junior and senior teachers and complete samples are shown separately in Figures 1, 2, and 3.

Table 12

Direct and Indirect Relationships for Complete Sample

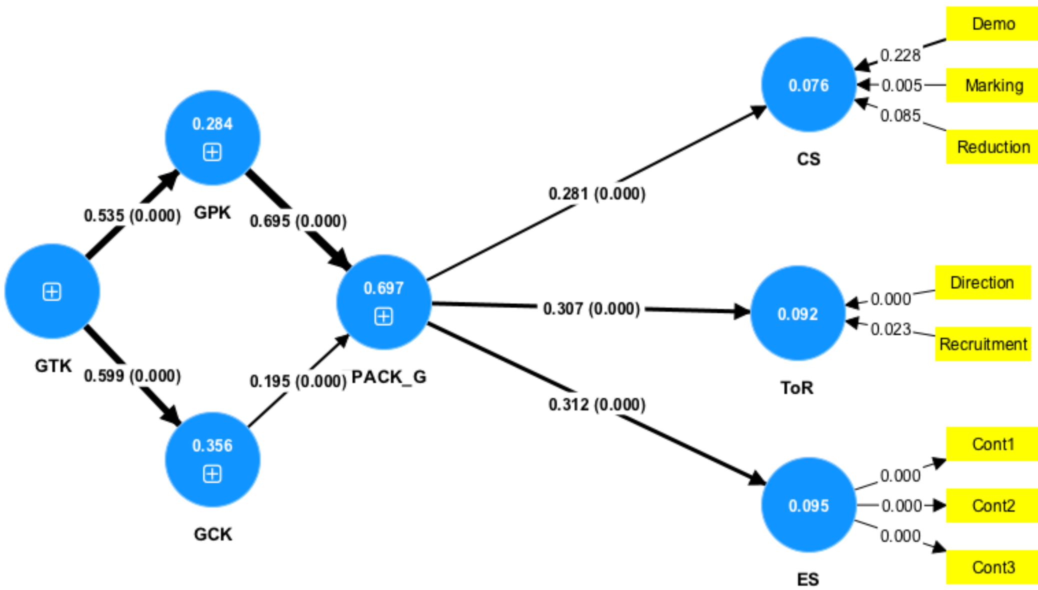
Path	Beta (*b*)	SD	T value	P value	f^2	Status
TPACK-G → CS	0.281	0.053	5.283	< .001	0.014	Direct effect
TPACK-G → ToR	0.307	0.052	5.947	< .001	0.005	Direct effect
TPACK-G → ES	0.312	0.054	5.743	< .001	0.007	Direct effect
~~**GTK → TPACK-G → CS**~~	~~0.017~~	~~0.016~~	~~1.055~~	~~**0.146**~~	~~n/a~~	No relationship found
~~**GTK → TPACK-G → ToR**~~	~~0.018~~	~~0.017~~	~~1.099~~	~~**0.136**~~	~~n/a~~	No relationship found
~~**GTK → TPACK-G → ES**~~	~~0.019~~	~~0.018~~	~~1.060~~	~~**0.145**~~	~~n/a~~	No relationship found
GCK → TPACK-G → CS	0.055	0.017	3.317	< .001	n/a	Indirect effect
GCK → TPACK-G → ToR	0.060	0.018	3.281	< .001	n/a	Indirect effect
GCK → TPACK-G → ES	0.061	0.019	3.232	< .001	n/a	Indirect effect
GPK → TPACK-G → CS	0.195	0.042	4.662	< .001	n/a	Indirect effect
GPK → TPACK-G → ToR	0.214	0.040	5.363	< .001	n/a	Indirect effect
GPK → TPACK-G → ES	0.217	0.041	5.240	< .001	n/a	Indirect effect

Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; TPACK-G = Technological, Pedagogical, and Content Knowledge of Games, CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

The PLS-SEM analysis revealed in the complete sample that teachers' TPACK-G is significantly related to teachers' CS usage in GBL environments. GPK and GCK significantly and indirectly affect the usage of CS, ToR, and ES through TPACK-G but not GTK (Table 12). The r^2 values for CS, ToR and ES were .08, .10, and .10, respectively (see Fig. 1).

Figure 1

Structural Path Model of TPACK-G and TSQ-GBL with Complete Sample



Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; TPACK-G = Technological, Pedagogical, and Content Knowledge of Games, CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

For junior teachers, TPACK-G is significantly related to teachers' CS, To, and ES usage in GBL environments. GPK and GCK significantly and indirectly affect the usage of CS, ToR, and ES through TPACK-G not GTK (Table 13). The r^2 values for CS, ToR and ES were .10, .09, and .06, respectively (see Fig. 2).

Table 13

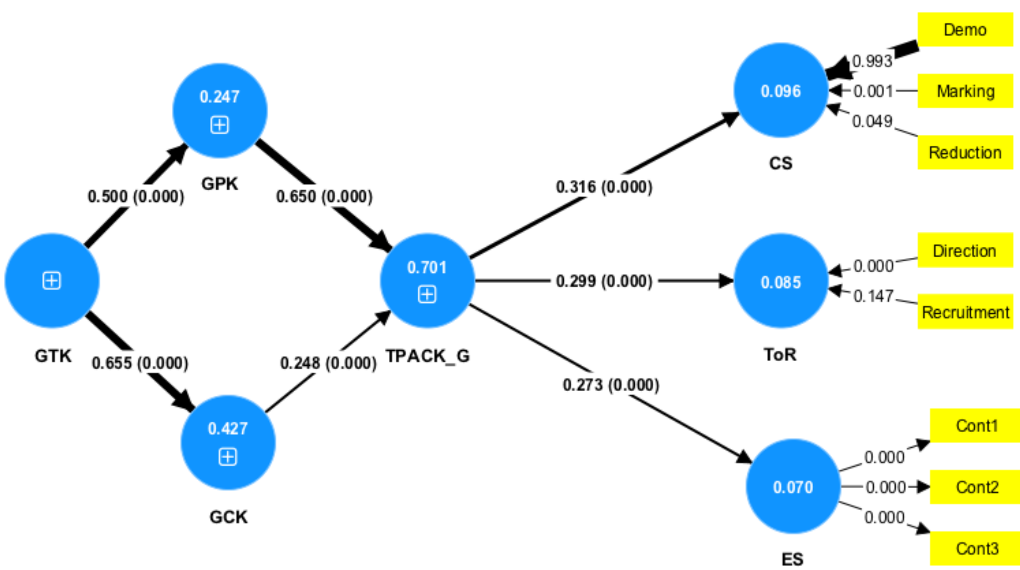
Direct and Indirect Relationships for Junior Teachers

Path	Beta (*b*)	SD	T value	P value	f^2	Status
TPACK-G → CS	0.316	0.060	5.280	< .001	0.034	Direct effect
TPACK-G → ToR	0.299	0.061	4.924	< .001	0.035	Direct effect
TPACK-G → ES	0.273	0.070	3.904	< .001	0.109	Direct effect
~~**GTK → TPACK-G → CS**~~	~~0.019~~	~~0.025~~	~~0.767~~	~~**0.443**~~	~~n/a~~	No relationship found
~~**GTK → TPACK-G → ToR**~~	~~0.018~~	~~0.022~~	~~0.813~~	~~**0.416**~~	~~n/a~~	No relationship found
~~**GTK → TPACK-G → ES**~~	~~0.016~~	~~0.022~~	~~0.751~~	~~**0.453**~~	~~n/a~~	No relationship found
GCK → TPACK-G → CS	0.078	0.024	3.317	< .001	n/a	Indirect effect
GCK → TPACK-G → ToR	0.074	0.025	2.906	0.004	n/a	Indirect effect
GCK → TPACK-G → ES	0.068	0.026	2.594	0.010	n/a	Indirect effect
GPK → TPACK-G → CS	0.206	0.045	4.562	< .001	n/a	Indirect effect
GPK → TPACK-G → ToR	0.194	0.041	4.726	< .001	n/a	Indirect effect

Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; TPACK-G = Technological, Pedagogical, and Content Knowledge of Games, CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

Figure 2

Structural Path Model of TPACK-G and TSQ-GBL with Junior Teachers



Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; TPACK-G = Technological, Pedagogical, and Content Knowledge of Games, CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

For senior teachers, TPACK-G is significantly related to teachers' CS, ToR, and ES usage in GBL environments. Only GPK significantly and indirectly affects the usage of CS, ToR, and ES through TPACK-G but not GTK and GCK (Table 14). The r^2 values for CS, ToR and ES were .09, .12, and .15, respectively (see Fig. 3).

Table 14

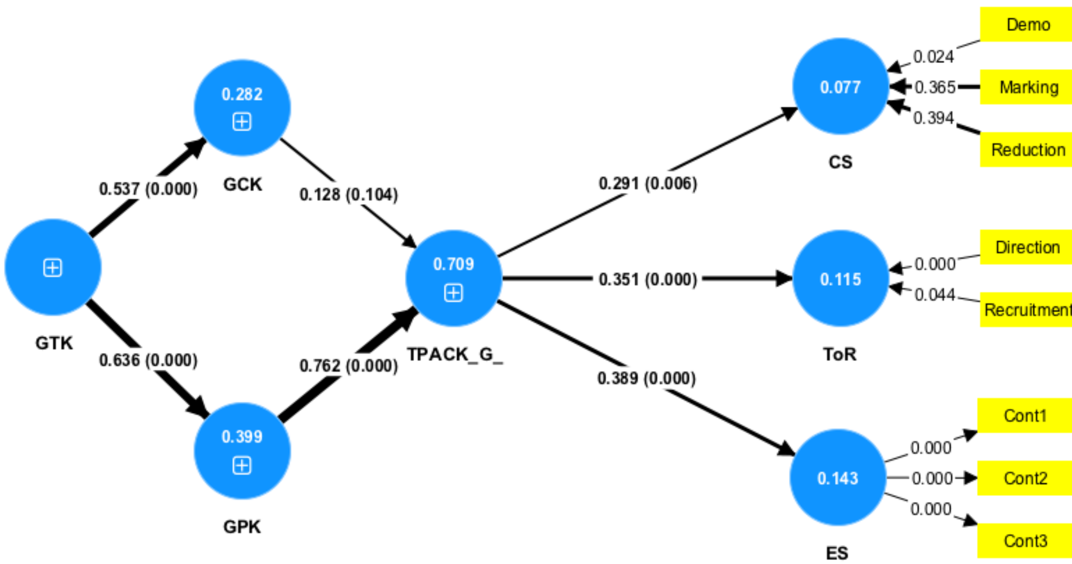
Direct and Indirect Relationships for Senior Teachers

Path	Beta (*b*)	SD	T value	P value	f^2	Status
TPACK-G → CS	0.291	0.106	2.761	0.006	0.287	Direct effect
TPACK-G → ToR	0.350	0.085	4.129	< .001	0.109	Direct effect
TPACK-G → ES	0.389	0.081	4.782	< .001	0.054	Direct effect
~~**GTK → TPACK-G → CS**~~	~~-0.005~~	~~0.026~~	~~0.197~~	~~**0.844**~~	~~n/a~~	No relationship found
~~**GTK → TPACK-G → ToR**~~	~~-0.006~~	~~0.030~~	~~0.211~~	~~**0.833**~~	~~n/a~~	No relationship found
~~**GTK → TPACK-G → ES**~~	~~-0.007~~	~~0.032~~	~~0.218~~	~~**0.828**~~	~~n/a~~	No relationship found
~~**GCK → TPACK-G → CS**~~	~~0.039~~	~~0.026~~	~~1.511~~	~~**0.131**~~	~~n/a~~	No relationship found
~~**GCK → TPACK-G → ToR**~~	~~0.047~~	~~0.026~~	~~1.778~~	~~**0.076**~~	~~n/a~~	No relationship found
~~**GCK → TPACK-G → ES**~~	~~0.052~~	~~0.028~~	~~1.836~~	~~**0.066**~~	~~n/a~~	No relationship found
GPK → TPACK-G → CS	0.244	0.090	2.714	0.007	n/a	Indirect effect
GPK → TPACK-G → ToR	0.294	0.073	4.020	< .001	n/a	Indirect effect
GPK → TPACK-G → ES	0.326	0.073	4.455	< .001	n/a	Indirect effect

Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; TPACK-G = Technological, Pedagogical, and Content Knowledge of Games, CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

Figure 3

Structural Path Model of TPACK-G and TSQ-GBL with Senior Teachers



Note. GK = Game knowledge; GCK = Game content knowledge; GPK = Game pedagogical knowledge; GPCK = Game pedagogical content knowledge; TPACK-G = Technological, Pedagogical, and Content Knowledge of Games, CS = Cognitive Support; ToR = Transfer of Responsibility Support; ES/CONT = Emotional Support/Control

Discussion

The goal of this research was to investigate whether there is a relationship between teachers' TPACK-G and their use of scaffolding strategies in GBL environments or not, while also considering differences in knowledge and use of different scaffolds between junior and senior teachers with varying levels of experience in GBL. Specifically, the study aims to explore whether teachers' TPACK-G influences their use of scaffolding practices in GBL and whether there are differences in the practices of junior and senior teachers regarding game, content, and pedagogical knowledge.

We decided to use a cluster approach to create meaningful groups and provide a more accurate picture of the distribution of teachers, in comparison to previous studies (Garcia et al., 2015). Our goal is to understand and confirm whether the differences between junior and senior teachers in terms of their knowledge of games and their use of scaffolding during game-based learning are significant, compared to the findings of previous studies (Hsu et al., 2020; 2021). We believe that using cluster analysis would be a more appropriate method for grouping teachers than simply relying on the mean average of their teaching experience. This is because a simple mean average can create an artificial dichotomy between two groups that may not be truly different in terms of their teaching experience. By using cluster analysis, teachers can be grouped accurately based on their actual experience and identify any significant differences between junior and senior teachers.

The results indicate that the TPACK-G and TSQ-GBL questionnaires used in the research continue to be valid and reliable measures for evaluating K-12 teachers' technological pedagogical content knowledge and game-based learning scaffolding use (Hsu et al., 2020; 2021; Kacmaz & Dubé, in preparation). Previous studies on TPACK-Games only validated the questionnaires with preschool teachers as a sample or a sample consisting of both junior and senior elementary school teachers (Hsu et al., 2020; 2021). This study's extension to K-12 teachers, presents a more comprehensive sample, and a more representative picture. The current measurement model's results confirmed that the TPACK-G questionnaire is suitable for assessing K-12 teachers' knowledge of games and the TSQ-GBL is suitable for assessing teachers' scaffolding use.

In a previous study, junior elementary school teachers were found to be more positive about their TPACK-G than senior teachers, showing higher confidence in all components of TPACK-G (Hsu et al., 2017, 2021). However, in the current study, junior teachers had higher scores in GK than GCK, GPK, and GPCK, and had significant differences between GCK and GPK/GPCK, which suggests they have a stronger overall understanding of games but may not be sufficiently knowledgeable about how to incorporate games into pedagogy (Hsu et al., 2017). On the other hand, senior teachers only showed significant differences between GCK and GPK/GPCK (Cheng, 2017). The difference in teaching experience of around 12.5 years may have contributed to these outcomes, with junior teachers being more exposed to games due to games growing prevalence and proliferation occurring during these teachers' formative years (Hsu et al., 2021; Lee & Tsai, 2010; Koh et al., 2014). This difference may also undermine senior teachers' knowledge in GK, GPK, and GPCK. This means that senior teachers may have a better understanding of the content of games (GCK) than GPK or GPCK, such as they have more expertise in selecting appropriate games to represent specific content, but they may not have as much experience using games as a pedagogical tool in the classroom. This could also be explained by senior teachers having more extensive experience with traditional pedagogical methods, and therefore, may not report having as much experience or training in game-based pedagogy, relatively speaking.

Importantly, both junior and senior teachers use all three types of scaffolds (e.g., transfer of responsibility, emotional, and cognitive) in GBL regardless of their varying levels of teaching experience. Specifically, the transfer of responsibility and emotional scaffold is used more frequently than the cognitive scaffold, which is consistent with previous research findings (Kacmaz & Dubé, in preparation). The transfer of responsibility scaffold involves gradually shifting control from the teacher to the student, allowing them to take ownership of their own learning (Mermelshtine, 2017). This scaffold could be crucial in GBL, where students need to actively explore and discover game mechanics and content. The emotional scaffold, on the other hand, involves teachers providing emotional support to their students to keep them motivated and engaged in the learning process, which can be perceived as a natural and integral aspect of effective teaching (Mermelshtine, 2017). Teachers naturally provide emotional support to their students in various ways without even realizing it, such as by showing empathy and encouragement, creating a safe and supportive learning environment, and being responsive to their students' needs and concerns. There are several possible explanations for why transfer of responsibility and emotional scaffolding are more commonly used in GBL compared to cognitive scaffolding. Firstly, these scaffolds may be more intuitive and easier for teachers to implement. Secondly, cognitive scaffolding may require a higher level of expertise and specialized knowledge that not all teachers possess, particularly when it comes to using games as a pedagogical tool (Takeuchi & Vaala 2014 & Williamson, 2009). Furthermore, providing cognitive scaffolding in game-based learning requires teachers to have a deep understanding of both the game mechanics and the subject matter being taught, as well as the ability to make connections between the two (Hsu et al., 2015). However, this can be a challenge for teachers who lack experience with games or who struggle to integrate cognitive scaffolding into their game-based instruction. Without a strong understanding of the game mechanics and subject matter, teachers may find it difficult to identify key concepts and knowledge that the game is designed to teach, or to create effective instructional strategies that connect the game to the subject matter.

Findings from both correlation and structural path analyses in this current study suggest that there are positive relationships between teachers' knowledge of games and their usage of certain types of scaffolding in GBL environments. Junior teachers' TPACK-G has a more significant impact on the different types of scaffolding use compared to senior teachers. This could be because junior teachers are still in the early stages of their teaching career and are therefore more likely to have had recent exposure to integrating technology, including game-based technologies, into their teaching practices (Bourgonjon et al., 2013; Sánchez-Mena et al., 2017; Stieler-Hunt & Jones 2015). This may make them more proficient in using scaffolding strategies in their teaching during GBL. One possible reason why senior teachers may not show as strong a relationship between their TPACK-G and scaffolding use is that they have developed more established teaching practices over the course of their careers, which may be more resistant to change. As a result, they may be less likely to vary their scaffolding supports or adopt new teaching strategies, even if they have knowledge of game-based technologies (Hayak &Avidov-Ungar, 2020). Another possibility is that senior teachers may provide less overall scaffolding than junior teachers, regardless of their TPACK-G knowledge. This could be due to several factors, such as reduced motivation to innovate, or a belief that their current instructional practices are effective (Konstantinidou & Scherer, 2022)

Moreover, the indirect effect of GPK and GCK on CS, ToR, and ES usage through TPACK-G indicates that these two components of TPACK-G are essential in influencing the use of scaffolding strategies in GBL by junior teachers. The finding highlights the importance of junior teachers having a strong understanding of the content they teach and the pedagogical approaches they use in combination with their technology integration skills to maximize the potential of GBL in their classrooms (Baek 2008; Chung-Yuan et al., 2017).

The findings for senior teachers suggest that their TPACK-G is positively correlated with ToR and ES usage in GBL environments. However, unlike junior teachers, CS usage was only positively correlated with GPCK but not with the other components of TPACK-G, including GK, GCK, and GPK. Further, PLS-SEM analysis showed that only GPK significantly and indirectly affects the usage of CS, ToR, and ES through TPACK-G but not GK and GCK. These findings suggest that for senior teachers, their TPACK-G, particularly their GPK knowledge, is more closely related to the use of different types of scaffolding strategies in their teaching practices, especially for ToR and ES usage (Chung-Yuan et al., 2017).This can be explained that senior teachers may have more experience in teaching, have a more developed pedagogical knowledge base, or feeling more confident and comfortable with using pedagogical strategies. This confidence and comfort level may come from years of teaching experience (Hayak &Avidov-Ungar, 2020, Hsu et al., 2021). It is also worth noting that for senior teachers, CS usage seems to be more closely related to their GPCK knowledge, which suggests that their focus may be more on using scaffolding strategies to support their content knowledge rather than using technology as a primary mode of instruction (Chung-Yuan et al., 2017). This could be because senior teachers have been teaching for a longer period of time and have accumulated a considerable amount of knowledge and experience in their subject area and are more likely to view game-based learning as a tool to enhance their instruction rather than a replacement for it. Moreover, senior teachers may be more likely to use cognitive scaffolding to help students understand the key concepts and knowledge that the game is designed to teach, rather than relying solely on the game to convey this information.

Limitations

The present study has some limitations that need to be addressed. First, we did not observe the actual scaffolding behaviors of teachers during GBL contexts, which hinders our understanding of whether K-12 teachers will use scaffolding strategies during GBL environments. This limitation is consistent with previous studies that have questioned the causal relationship between intention and the use of technology (Montano & Kasprzyk, 2015; Scherer et al., 2020), and highlights the need for further research to examine the actual usage of scaffolding during GBL environments. Further, participants may not answer honestly or may not answer accurately in the Likert type of self-report scale that helps mitigate the effects of social desirability bias (Garland, 1991). Collaborations between researchers and teachers can facilitate this assessment by observing or conducting interviews with teachers (All et al., 2016). Secondly, the current study has a correlational design using a quantitative approach. Although these methods are useful in identifying relationships between variables, they do not provide a deep understanding of how teachers' knowledge may or may not impact scaffolding use. Therefore, future research should adopt both qualitative and quantitative design approaches and measure multiple types of data to gain a more comprehensive understanding of teachers' scaffolding use during GBL. Finally, future studies can also consider other factors that may influence teachers' scaffolding of learning in GBL, such as their prior experience with games, beliefs, or attitudes. By considering these factors, researchers can obtain a more complete understanding of the challenges and opportunities associated with scaffolding in GBL environments, which can ultimately lead to better learning outcomes for students.

Conclusion

Game-based learning (GBL) is a popular instructional tool in modern classrooms. However, teachers may lack the necessary knowledge and training to effectively incorporate games into their instruction. Our research validated the TPACK-Games and TSQ-GBL scales, providing reliable measures of teachers' game-enhanced teaching practices and knowledge of games. We also found that junior teachers outperformed senior teachers in their game-related knowledge and scaffolding usages, emphasizing the importance of early and more exposure to game-based instruction in teacher preparation programs. Our findings underscore the need for professional development opportunities to increase teachers' GPK, including relevant instructional strategies and successful cases of game-based learning.

References

All, A., Castellar, E. P. N., & Van Looy, J. (2016). Assessing the effectiveness of digital game-based learning: best practices. *Computers & Education*, *92*, 90-103. https://doi.org/10.1016/j.compedu.2015.10.007

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin*, *103*(3), 411. DOI:10.1037/0033-2909.103.3.411

Awang, Z. (2014). *A handbook on SME: For Academicians and practitioners*. MPWS Rich Resources.

Baek, Y. K. (2008). What hinders teachers in using computer and video games in the classroom? Exploring factors inhibiting the uptake of computer and video games. *CyberPsychology & Behavior*, *11*(6), 665-671. https://doi.org/10.1089/cpb.2008.0127

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70*, 65-79. https://doi.org/10.1016/j.compedu.2013.08.003

Belland, B. R. (2013). Scaffolding: Definition, current debates, and Future Directions. *Handbook of Research on Educational Communications and Technology*, 505–518. https://doi.org/10.1007/978-1-4614-3185-5_39

Bourgonjon, J., & Hanghøj, T. (2011, October). What does it mean to be a game literate teacher? Interviews with teachers who translate games into educational practice. In *Proceedings of the 5th European Conference on Games Based Learning* (pp. 67-73). Reading: Academic.

Bourgonjon, J., De Grove, F., De Smet, C., Van Looy, J., Soetaert, R., & Valcke, M. (2013). Acceptance of game-based learning by secondary school teachers. *Computers & Education*, *67*, 21-35. https://doi.org/10.1016/j.compedu.2013.02.010

Buabeng-Andoh, C. (2021). Exploring University students' intention to use mobile learning: A research model approach. *Education and Information Technologies*, *26*(1), 241-256. https://doi.org/10.1007/s10639-020-10267-4

Chai, C. S., Ng, E. M., Li, W., Hong, H. Y., & Koh, J. H. (2013). Validating and modelling technological pedagogical content knowledge framework among Asian preservice teachers. *Australasian Journal of Educational Technology*, *29*(1). https://doi.org/10.14742/ajet.174

Charsky, D., & Ressler, W. (2011). "Games are made for fun": Lessons on the effects of concept maps in the classroom use of computer games. *Computers & Education, 56*(3), 604-615. https://doi.org/10.1016/j.compedu.2010.10.001

Chen, C. H., & Law, V. (2016). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. *Computers in Human Behavior, 55*, 1201-1212. https://doi.org/10.1016/j.chb.2015.03.010

Chung-Yuan, H., Meng-Jung, T., Yu-Hsuan, C., & Liang, J. C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Journal of Educational Technology & Society, 20*(1), 134.

Clark, D. B., Nelson, B. C., Chang, H. Y., Martinez-Garza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring Newtonian mechanics in a conceptually integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United

States. *Computers & Education*, *57*(3), 2178-2195. https://doi.org/10.1016/j.compedu.2011.05.007

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd Edition). Hillsdale, NJ: Lawrence Earlbaum Associates.

Garcia, D., MacDonald, S., & Archer, T. (2015). Two different approaches to the affective profiles model: median splits (variable-oriented) and cluster analysis (person-oriented). *PeerJ*, *3*, e1380. 10.7717/peerj.1380

Garland, R. (1991). The mid-point on a rating scale: Is it desirable. *Marketing bulletin*, *2*(1), 66-70.

Granott, N. (2005). Scaffolding dynamically toward change: Previous and new perspectives. *New Ideas in Psychology*, *23*(3), 140-151. https://doi.org/10.1016/j.newideapsych.2006.07.002

Habgood, M. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *Journal of the Learning Sciences*, *20*(2), 169-206. https://doi.org/10.1080/10508406.2010.508029

Hair J.F., Anderson R.E., Tatham R.L., & Black W.C., (1998). *Multivariate Data Analysis.* Prentice-Hall: New Jersey.

Hair Jr, J. F., Matthews, L. M., Matthews, R. L., & Sarstedt, M. (2017). PLS-SEM or CB-SEM: updated guidelines on which method to use. *International Journal of Multivariate Data Analysis*, *1*(2), 107-123. https://doi.org/10.1504/IJMDA.2017.087624

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2013). Partial least squares structural equation modeling: Rigorous applications, better results and higher acceptance. *Long Range Planning*, *46*(1-2), 1-12. https://doi.org/10.1016/j.lrp.2013.01.001

Hair, J.F., Hult, G.T.M., Ringle, C.M. and Sarstedt, M. (2017a), *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, Sage, Thousand Oaks, CA.

Haruehansawasin, S., & Kiattikomol, P. (2018). Scaffolding in problem-based learning for low-achieving learners. *The Journal of Educational Research*, *111*(3), 363-370. https://doi.org/10.1080/00220671.2017.1287045

Hayak, M., & Avidov-Ungar, O. (2020). The integration of digital game-based learning into the instruction: Teachers' perceptions at different career stages. *TechTrends*, *64*, 887-898. https://doi.org/10.1007/s11528-020-00503-6

Henseler, J. (2014, May). Assessing and testing the goodness-of-fit of PLS path models. In *The 3rd Annual Conference of the Dutch/Flemish Classification Society (Vereniging voor Ordinatie en Classificatie-VOC)*.

Hoffmann, A. O., & Birnbrich, C. (2012). The impact of fraud prevention on bank-customer relationships: An empirical investigation in retail banking. *International Journal of Bank Marketing*, *30*(5), 390-407. https://doi.org/10.1108/02652321211247435

Honey, M. A., & Hilton, M. L. (2011). *Learning science through computer games.* National Academies Press, Washington, DC.

Hsu, C. Y., Liang, J. C., & Su, Y. C. (2015). The role of the TPACK in game-based teaching: Does instructional sequence matter? *The Asia-Pacific Education Researcher*, *24*, 463-470. https://doi.org/10.1007/s40299-014-0221-2

Hsu, C. Y., Liang, J. C., & Tsai, M. J. (2020). Probing the structural relationships between teachers' beliefs about game-based teaching and their perceptions of technological pedagogical and content knowledge of games. *Technology, Pedagogy and Education*, *29*(3), 297-309. https://doi.org/10.1080/1475939X.2020.1752296

Hsu, C. Y., Liang, J. C., Chai, C. S., & Tsai, C. C. (2013). Exploring preschool teacher'' technological pedagogical content knowledge of educational games. *Journal of Educational Computing Research*, *49*(4), 461-479. https://doi.org/10.2190/EC.49.4.c

Hsu, C. Y., Liang, J. C., Chuang, T. Y., Chai, C. S., & Tsai, C. C. (2021). Probing in-service elementary school teachers' perceptions of TPACK for games, attitudes towards games, and actual teaching usage: a study of their structural models and teaching experiences. *Educational Studies*, *47*(6), 734-750. https://doi.org/10.1080/03055698.2020.1729099

Hsu, C. Y., Tsai, M. J., Chang, Y. H., & Liang, J. C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Journal of Educational Technology & Society*, *20*(1), 134-143. https://www.jstor.org/stable/jeductechsoci.20.1.134

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1-55.

Hughes, C. H. (2015). The transition to school. *The Psychologist, 28,* 714–717.

Huizenga, J., Admiraal, W., Akkerman, S., & ten Dam, G. (2009). Learning History by playing a mobile city game. *Journal of Computer Assisted Learning, 25*, 332–344.

Kacmaz, G., & Dubé, A. K. (In preparation). Comparing and Validating the Three-Measurement Models of Teacher Scaffolding Questionnaire during Game-based Learning and Relationship with its Antecedents. *Learning Environments Research.*

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60-70. https://www.learntechlib.org/primary/p/29544/.

Koh, J. H. L., Chai, C. S., & Tsai, C. C. (2014). Demographic factors, TPACK constructs, and teachers' perceptions of constructivist oriented TPACK. *Journal of Educational Technology & Society*, *17*(1), 185-196.

Konstantinidou, E., & Scherer, R. (2022). Teaching with technology: A large-scale, international, and multilevel study of the roles of teacher and school characteristics. *Computers & Education*, *179*, 104424. https://doi.org/10.1016/j.compedu.2021.104424

Lee, M. H., & Tsai, C. C. (2010). Exploring teachers' perceived self-efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web. *Instructional Science*, *38*, 1-21. doi:10.1007/s11251-008-9075-4.

Leerkes, E. M., Blankson, A. N., O'Brien, M., Calkins, S. D., & Marcovitch, S. (2011). The relation of maternal emotional and cognitive support during problem solving to pre-academic skills in preschoolers. *Infant and Child Development, 20,* 353–370. doi:10.1002/icd.728

Li, S. C. S., & Huang, W. C. (2016). Lifestyles, innovation attributes, and teachers' adoption of game-based learning: Comparing non-adopters with early adopters, adopters and likely adopters in Taiwan. *Computers & Education*, *96*, 29-41. https://doi.org/10.1016/j.compedu.2016.02.009

Mayer, R. E. (2014b). *Computer games for learning: An evidence-based approach.* Cambridge, MA: MIT Press

Meade, A. W. & Craig, S. B. (2012). Identifying careless responses in survey data. *Psychological Methods, 17(*3), 437–455. DOI: 10.1037/a0028085

Mermelshtine, R. (2017). Parent–child learning interactions: A review of the literature on scaffolding. *British Journal of Educational Psychology*, *87*(2), 241-254. https://doi.org/10.1111/bjep.12147

Mermelshtine, R., & Barnes, J. (2016). Maternal responsive–didactic caregiving in play interactions with 10-month-olds and cognitive development at 18 months. *Infant and Child Development, 25*(3), 296–316. doi:10.1002/icd.1961

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mohan, M. M., Upadhyaya, P., & Pillai, K. R. (2020). Intention and barriers to use MOOCs: An investigation among the post graduate students in India. *Education and Information Technologies*, *25*, 5017-5031. https://doi.org/10.1007/s10639-020-10215-2

Montano, D. E., & Kasprzyk, D. (2015). Theory of reasoned action, theory of planned behavior, and the integrated behavioral model. *Health Behavior: Theory, Research and Practice*, *70*(4), 231.

Neitzel, C., & Stright, A. D. (2003). Mothers' scaffolding of children's problem solving: Establishing a foundation of academic self-regulatory competence. *Journal of Family Psychology, 17*(1), 147– 159. doi:10.1037/0893-3200.17.1.147

Neitzel, C., & Stright, A. D. (2004). Parenting behaviours during child problem solving: The roles of child temperament, mother education and personality, and the problem-solving context. *International Journal of Behavioral Development, 28*(2), 166–179. doi:10.1080/01650250344000370

Nousiainen, T., Kangas, M., Rikala, J., & Vesisenaho, M. (2018). Teacher competencies in game-based pedagogy. *Teaching and Teacher Education*, *74*, 85-97. https://doi.org/10.1016/j.tate.2018.04.012

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences*, *13*(3), 423–451. https://doi.org/10.1207/s15327809jls1303_6

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences*, *13*(3), 337-386. https://doi.org/10.1207/s15327809jls1303_4

Şahin, F., Doğan, E., İlic, U., & Şahin, Y. L. (2021). Factors influencing instructors' intentions to use information technologies in higher education amid the pandemic. *Education and Information Technologies*, *26*, 4795-4820. https://doi.org/10.1007/s10639-021-10497-0

Sánchez-Mena, A., Martí-Parreño, J., & Aldás-Manzano, J. (2017). The Effect of Age on Teachers' Intention to Use Educational Video Games: A TAM Approach. *Electronic Journal of E-Learning*, *15*(4), 355-366.

Scherer, R., Siddiq, F., & Tondeur, J. (2020). All the same or different? Revisiting measures of teachers' technology acceptance. *Computers & Education*, *143*, 103656. https://doi.org/10.1016/j.compedu.2019.103656

Shah, M. (2019). Scaffolding and Assessing Teachers' Examination of Games for Teaching and Learning. *Game-based Assessment Revisited*, 185-210.

Shah, M., & Foster, A. (2015). Developing and assessing teachers' knowledge of game-based learning. *Journal of Technology and Teacher Education*, *23*(2), 241-267. https://www.learntechlib.org/primary/p/147391/.

Shamon, H., & Berning, C. C. (2020). Attention Check Items and Instructions in Online Surveys with Incentivized and Non-Incentivized Samples: Boon or Bane for Data Quality? *Survey Research Methods, 14*(1), 55-77. DOI/10.18148/srm/2020.v14i1.7374

Soper, D.S. (2021). A-priori Sample Size Calculator for Structural Equation Models [Software]. Available from https://www.danielsoper.com/statcalc

Stieler-Hunt, C., & Jones, C. M. (2015). Educators who believe: understanding the enthusiasm of teachers who use digital games in the classroom. *Research in Learning Technology*, *23*. https://doi.org/10.3402/rlt.v23.26155

Stright, A. D., Herr, M. Y., & Neitzel, C. (2009). Maternal scaffolding of children's problem solving and children's adjustment in kindergarten: Hmong families in the United States. *Journal of Educational Psychology, 101*(1), 207–218. doi:10.1037/a0013154

Takeuchi, L. M., & Vaala, S. (2014). Level up Learning: A National Survey on Teaching with Digital Games. In *Joan Ganz Cooney Center at Sesame Workshop*.

Tenenhaus, M., Vinzi, V. E., Chatelin, Y. M., & Lauro, C. (2005). PLS path modeling. *Computational Statistics & Data Analysis*, *48*(1), 159-205. https://doi.org/10.1016/j.csda.2004.03.005

Tobias, S. E., & Fletcher, J. D. (2011). *Computer games and instruction*. IAP Information Age Publishing.

Tourangeau, R., Rips, L. J., & Rasinski, K. (2000). *The psychology of survey response*. Cambridge: Cambridge University Press

Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review*, *22*, 271-296. https://doi.org/10.1007/s10648-010-9127-6

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge–a review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109-121. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Ward Jr, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association*, *58*(301), 236-244.

Wasko, M. M., & Faraj, S. (2005). Why should I share? Examining social capital and knowledge contribution in electronic networks of practice. *MIS quarterly*, 35-57. https://doi.org/10.2307/25148667

Westland, J.C. (2010). Lower bounds on sample size in structural equation modeling. *Electronic Commerce Research and Applications, 9*(6), 476-487. https://doi.org/10.1016/j.elerap.2010.07.003

Williamson, B. (2009). *Computer games, schools, and young people: A report for educators on using games for learning*. Bristol: Futurelab.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60,* 412–425. https://doi.org/10.1016/j.compedu.2012.07.018

Chapter 6: A Comprehensive Discussion of all Findings and Conclusion

This dissertation investigates the potential of GBL to improve teaching and learning. Games are popular among young learners due to their high rates of technology access and use (Felt & Robb, 2016; Rikkers et al., 2016). Over the past decade, games have been rapidly developed and adopted in classrooms with the aim to improve learning and instruction (Clark et al., 2016; Wouters & van Oostendorp, 2013). However, inconsistent findings across studies challenge the effectiveness of GBL (Clark et al., 2016; Connolly et al., 2012; Girard et al., 2013; Wouters et al., 2013; Young et al., 2012), which can be attributed to several factors related to the games themselves and teacher related.

To fully realize the potential of GBL as an effective instructional approach, this dissertation highlighted that there is a crucial need for rigorous research that investigates the factors which influence the implementation of game technologies and their efficacy in promoting learning. Such research should examine the extent to which various types of games facilitate learning and identify the specific factors through which they do so. Additionally, teachers play a critical role in creating and managing learning environments that foster GBL. Effective GBL requires teachers to possess a range of knowledge and skills, including expertise in GBL, knowledge of games, and scaffolding practices that support student learning. Teachers must be intentional in designing and managing learning environments that prioritize GBL and utilize games as effective learning tools. To maximize the impact of GBL activities on various learning outcomes, teachers must also prioritize their pedagogical knowledge over solely focusing on games, game systems, and game content (Mishra & Koehler, 2006). A holistic approach to GBL that prioritizes both the technical aspects of game design and the pedagogical knowledge necessary for effective implementation is crucial. By shedding light on these factors, we can develop more effective interventions that support student learning through GBL.

Thus, the aim of this dissertation was to advance our understanding the underlying factors of the effectiveness of GBL. The three studies included in this dissertation address a pressing need to explore the in-game and teacher-related factors that influence the quality of GBL. Chapter 3 reviewed various game-related factors, such as the pedagogical foundations of games, the types of knowledge they seek to impart, and their impact on learning outcomes in math games. In addition, two empirical studies in Chapter 4 and 5 focused on teacher- and pedagogy-related factors that may influence the successful implementation of GBL. First, Chapter 4 validated a new scale for assessing teachers' scaffolding use in GBL environments and identifies the most commonly reported types of scaffolding supports. Second, Chapter 5 examined how the technological pedagogical content knowledge for games (TPACK-G) of junior and senior teachers relates to their scaffolding usage during game-based learning (TSQ-GBL). Specifically, the purpose of this study was to explore how teachers' knowledge and their teaching experiences in using games may influence their instructional practices by employing the TPACK-G framework and scaffolding theory. Overall, the findings of this dissertation provide valuable insights for advancing GBL research and identifying future research directions.

Games have the potential to address several issues in education, specifically in math, such as low student engagement, lack of motivation and understanding of complex mathematical concepts (Bray & Tangney, 2017; Clark et al., 2016; Outhwaite et al., 2019). Therefore, Chapter 3 aimed to evaluate the effectiveness of different pedagogical approaches and types of mathematical knowledge used in educational math games to enhance students' mathematical learning. One of the key findings of Chapter 3 was that learner-centered approaches, such as experiential, discovery, and constructivist approaches, were effective for promoting procedural and conceptual knowledge in math games. These approaches resulted in small or mixed effects, but they were found to be more effective for promoting conceptual knowledge compared to direct instructional approaches. Recent research investigating the effectiveness of two different types of games revealed that both games were effective in improving and sustaining students' gains in conceptual knowledge (Chan et al., 2023). Further, comparison of two games provided directions for future research by focusing on shared game related features or differences in game design that may support the development of conceptual knowledge. These included reward systems, dynamic platforms (e.g., interactive digital environments that provides students with the opportunity to actively engage with math concepts and objects through interactive and manipulative actions), goals of included tasks, and uses of mathematical symbols in the tasks included (Chan et al., 2023). All these can be also considered as part of the underlying pedagogical foundations of math games design. Practically, this is crucial information for educators and game designers when selecting and implementing educational games into instruction (Dubé et al., 2020). By identifying which pedagogical approaches and types of mathematical knowledge are more effective for learners or specific mathematical concepts, educators and games designers can make informed decisions about when using and making educational games.

Chapter 3's findings are important indicators for educators seeking to design and create effective game-based learning activities by considering the different pedagogical approaches and types of knowledge present in games. This information can help teachers make informed decisions about which scaffolding practices to use for a particular game. Teachers' scaffolding in using a game can affect how well students learn from it. Therefore, different types of scaffolding may be necessary to facilitate or improve the quality of learning experiences or learning outcomes in different games based on their pedagogical approaches or knowledge type. For example, if games use a learner centered approach to promote conceptual understanding, educators may want to provide scaffolding that encourages exploration, discovery, or self-directed learning, by asking students to focus on their learning processes, or providing prompts to encourage students. In contrast, if a game relies on direct instruction, educators may need to provide explicit guidance or instruction.

Moreover, as there is currently a lack of established and validated scales for assessing or capturing teacher scaffolding practices in GBL environments, Chapter 4 aims to address this gap by proposing a newly developed scale, called TSQ-GBL, derived from scaffolding theory to support educators' pedagogical practices. The TSQ-GBL was validated by comparing different models to establish the best dimension teacher scaffolding scale. The newly developed TSQ GBL scale, which takes a multidimensional approach to assessing scaffolding practices, was found to be superior to single- or six-dimension models in terms of its strong psychometric properties. This study (Chapter 4) further concluded that the use of scaffolding practices is related to teachers' game-based pedagogies usage for their instructional purposes and the perceived availability of school resources. Importantly, one of the main findings of this chapter is that teachers tend to use transfer of responsibility scaffolding most frequently in GBL environments, followed by recruitment, direction, and reduction scaffolds. Cognitive scaffolding, specifically marking scaffolds, was less frequently used. Chapter 4's findings on the validation and use of the TSQ-GBL scale are significant contributions to the field of game-based learning. Furthermore, the study's conclusion that scaffolding practices are related to teachers' game-based pedagogies usage and perceived availability of school resources emphasizes the importance of considering contextual factors when designing GBL activities. Teachers' ability to provide effective scaffolding practices may be influenced by the resources and support available to them in their specific school environment, such as availability of hardware or software materials, even quality of them.

The findings presented in Chapter 4 have practical implications, especially for teachers. The TSQ-GBL can be a valuable tool for assessing their own scaffolding practices in game-based learning environments. Since the scale takes a multidimensional approach, examining various aspects of scaffolding, teachers can identify areas where they need to provide more scaffolding or adjust their approach to better support their students' learning. By using the TSQ-GBL, teachers may gain a better understanding of their scaffolding practices and improve the effectiveness of their instruction in game-based learning environments.

The development of this new scale has also prompted further questions regarding the factors that influence usage of teachers' scaffolding. Effective scaffolding may require teachers to possess sufficient knowledge about games as well as knowledge of game mechanics and how they can support learning (Hsu et al., 2013; 2017; 2021). Game mechanics are the fundamental rules and systems that govern how a game operates and how players interact with it, which includes feedback systems, adaptive difficulty, and quest structures (Arnab et al., 2015). Pedagogical knowledge is also essential for structuring learning activities and providing effective scaffolding. Teachers need to understand how students learn, as well as the different instructional strategies and techniques that can be used to facilitate learning. Furthermore, teachers require content knowledge about the specific learning concepts or skills taught in the game to provide proper scaffolding that aligns with the game's learning objectives. For example, to provide proper scaffolding, a teacher needs to have a solid understanding of the underlying math concepts in a math game, such as how to find common denominators, how to simplify fractions, and how to add and subtract fractions. Without this knowledge, the teacher may not be able to provide the appropriate guidance and support that students need to succeed in the game. By possessing knowledge of game mechanics, pedagogical practices, and content knowledge, teachers might be able to use various scaffoldings to improve the effectiveness of GBL.

Therefore, the main goal of Chapter 5 was to investigate how teachers' knowledge of games as well as their teaching experiences influence the use of different types of scaffolding provide an overall picture of the effectiveness of GBL. The findings in Chapter 5 demonstrate a positive relationship between teachers' TPACK-G and TSQ-GBL. Findings suggests that teachers who have a better understanding of how technology can be integrated into teaching and learning, and how it relates to their subject matter knowledge and pedagogical practices, are more likely to use different types of scaffolding practices in GBL. Additionally, there were differences in specific components of TPACK-G and scaffolding usage between junior and senior teachers, there were no significant differences in overall TPACK-G or scaffold usage between the two groups. Overall, there is a positive relationship between teachers' technological pedagogical content knowledge (TPACK-G) and their use of scaffolding practices during game-based learning (TSQ-GBL). This suggests that teachers who have a better understanding of how technology can be integrated into teaching and learning, and how it relates to their subject matter knowledge and pedagogical practices, are more likely to support GBL via scaffolding.

In summary, Chapter 3 makes important contributions to the field of educational games by providing insights into the effectiveness of different pedagogical approaches and types of knowledge used in educational math games. The use of a rigorous methodology and comprehensive analysis enhances the credibility and usefulness of its findings, making them valuable for both researchers and practitioners in the field. Chapter 4 makes important contributions to the field of educational games by proposing a new theoretically driven scale for measuring teacher scaffolding practices in GBL, advancing the understanding of scaffolding practices in GBL, and providing evidence-based recommendations for using the new scale. Chapter 5 makes important contributions to the field of educational games by adopting a theoretical framework that integrates the TPACK framework to provide a more comprehensive understanding of how teachers' knowledge and skills influence the use of scaffolding practices in GBL environments.

Limitations and Future Directions

Despite these contributions, the dissertation is not without limitations. Although the limitations and future directions for Chapters 3-5 are discussed within each respective chapter, there are still some overall limitations that need to be addressed in future studies.

The limited number of articles included in Chapter 3 presents a challenge in estimating the average effect of each pedagogical approach on individual knowledge types and exploring the impact of research design, grade levels, or other possible moderators such as game duration (Clark et al., 2016). As such, future studies in the field of math and other fields should focus on conducting more game-based studies to investigate the influence of different pedagogical approaches on learning outcomes (Kebritchi & Hirumi, 2008). Furthermore, providing a larger pool of articles in different subjects (e.g., reading) might yield interesting findings in terms of pedagogical approaches and types of knowledge across various learning domains.

One of the most significant limitations highlighted in Chapter 3 is also the lack of clear and specific information regarding the definition of the game's pedagogical approach and intended learning outcomes. Future studies could implement more standardized reporting practices for game-based studies, including the use of clear and specific definitions for pedagogical approaches. Also, this lack of clarity regarding knowledge targets can make it challenging to ensure that the game is accurately measuring the types of knowledge it claims to measure (Crooks & Alibali, 2014). Additionally, when outcome measures used across different studies are inconsistent or poorly defined, it can be difficult to compare the effectiveness of different games or interventions and draw meaningful conclusions about which interventions are most effective. Moreover, unclear, or overly broad knowledge targets and outcome measures can make it challenging to apply research findings to practical settings. This limitation may be generalizable to other fields beyond math games, as it highlights the importance of clearly defining knowledge targets and outcome measures to ensure valid and reliable research findings. Overall, clarity and specificity in the types of knowledge targeted and outcome measures used in math game research are essential for ensuring the validity, comparability, generalizability, and practicality of research findings (Tobin & Begley, 2004).

In Chapter 4, although we aimed to develop a scale through a process of rigorous testing to establish its reliability and validity, it is possible that the scale items could be further improved and revised. To do so, it is better for future research to include focus groups or interviews with teachers who frequently implement games in their classrooms to gather feedback on the scale items. Additionally, the scale might be administered to a larger sample and repeat the validation process to ensure that it continues to meet reliability and validity criteria. By incorporating feedback and continually improving the scale, the usefulness and accuracy of measuring the construct of interest would be increased.

In the study of Chapter 4 that explored the relationship between game-based pedagogy use, perceived availability of school resources, and teacher facilitation of learning in GBL, the findings provided evidence of relationships between these variables. However, it is not clear whether low or high game-based pedagogy use, or perceived availability of school resources directly caused an increase or decrease in teachers' scaffolding practices in GBL environments. Further, the direct and indirect effects of game-based pedagogy usage and available school resources on teacher scaffolding use showed weak and non-significant in a correlational design might be due to the complexity of the relationship between these variables, limitations of self-report measures, or the presence of confounding variables. Future research should employ more comprehensive measures and involve and examine specific variables in more detail. For example, future studies could employ a mixed-methods approach that combines self-report measures with observational data or interviews to obtain a more in-depth understanding of teachers' scaffolding practices. In terms of specific variables, future studies could explore the impact of teacher training and professional development or prior gaming experiences on scaffolding practices in GBL environments, or the influence of contextual factors such as school policies or curriculum requirements.

Another consideration for the results of Chapter 4, is that social desirability can sometimes affect the data reported on self-report scales because people may tend to answer questions in a way that is socially acceptable or desirable, rather than being completely honest (Grimm, 2010). Individuals may adjust their responses to portray themselves in a positive light, alternatively, they may over-report positive behaviors or characteristics to appear more favorable (Grimm, 2010). Thus, social desirability bias can affect the validity and reliability of self-report measures, as it can lead to inaccurate or biased responses that do not accurately reflect the participant's true thoughts, feelings, or behaviors (Schwarz, 2007). Therefore, the use of self-report scales may limit the validity of the findings.

We note that sample size in Chapter 5 can affect the generalizability of the results regarding the issue of unequal sample sizes between the two teacher groups. Therefore, the small sample size may limit the generalizability of the findings. In addition, other factors may affect the relationship between TPACK-G and scaffolding use in GBL environments, such as teachers' attitudes towards technology, teacher characteristics, and student characteristics. As noted by Hsu et al., 2017, teachers' attitudes towards games have been found to have a significant impact on their acceptance and use of games in the classroom. Similarly, according to Lai et al. (2017), teacher characteristics, such as experience, professional development, and pedagogical beliefs, can influence the implementation of GBL. Lastly, student characteristics, such as prior knowledge and motivation, can also affect the effectiveness of scaffolding in GBL environments (Shute & Zapata-Rivera, 2008; Vandercruysse & Elen, 2017). Therefore, it is essential to consider these factors when examining the relationship between TPACK-G and scaffolding use in GBL environments. This can be done by incorporating measures that assess these factors, such as other constructs such as teachers' beliefs about games or attitudes towards games.

Based on the outcomes of this dissertation, several future directions for research can be identified. Firstly, future studies should focus on conducting more game-based research to investigate the influence of different pedagogical approaches on learning outcomes to compare its effectiveness on different types of knowledge that games aim to teach. Secondly, the scale used to measure scaffolding practices in GBL should be further revised and improved through teacher feedback and continued validation with larger sample sizes or use this scale as an observational or check list tool for teachers to improve their scaffolding practices. Thirdly, to address the limitations of self-report measures, other data collection methods could be integrated into future studies. Fourthly, future research should consider the generalizability of findings by addressing factors such as teacher attitudes towards games and beliefs about games, teacher characteristics, and student characteristics. Lastly, an intervention program for teachers to improve their TPACK-G and scaffolding practices during GBL could be designed and implemented as an effective way to support teacher professional development. Overall, this dissertation offers valuable insights into the design and implementation of game-based learning and highlights several avenues for future research to improve its effectiveness and impact.

Concluding Remarks

Game-based learning has been identified as a promising approach to increase student engagement, motivation, and achievement across various subjects. However, it is crucial to understand the factors that contribute to its effectiveness to successfully integrate GBL into the classroom. This dissertation aims to lay the groundwork for future research on the factors related to both games and teachers to determine the effectiveness of GBL. The studies discussed in this thesis will facilitate further research and inform teacher training and professional development programs, aiding the design and implementation of GBL interventions in actual classrooms, considering both game and teacher factors. By leveraging technology and pedagogy, game-based learning has the potential to enhance student learning outcomes and support the development of 21st-century skills, such as critical thinking, problem-solving, and collaboration.

References

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., De Freitas, S., Louchart, S., et al. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology, 46*(2), 391–411. https://doi.org/10.1111/bjet.12113

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research–A systematic review of recent trends. *Computers & Education, 114*, 255–273. https://doi.org/10.1016/j.compedu.2017.07.004

Chan, J. Y.-C., Closser, A. H., Ngo, V., Smith, H., Liu, A. S., & Ottmar, E. (2023). Examining shifts in conceptual knowledge, procedural knowledge and procedural flexibility in the context of two game-based technologies. *Journal of Computer Assisted Learning*, 1– 16. https://doi.org/10.1111/jcal.12798

Chung-Yuan, H., Meng-Jung, T., Yu-Hsuan, C., & Liang, J. C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Journal of Educational Technology & Society, 20*(1), 134.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86*(1), 79–122. DOI: 10.3102/0034654315582065

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*(2), 661-686. https://doi.org/10.1016/j.compedu.2012.03.004

Crooks, N. M., & Alibali, M. W. (2014). Defining and measuring conceptual knowledge in mathematics. *Developmental Review*, *34*(4), 344–377. https://doi.org/10.1016/j.dr.2014.10.001

Dubé, A. K., Kacmaz, G., Wen, R., Alam, S. S., & Xu, C. (2020). Identifying quality educational apps: Lessons from 'top' mathematics apps in the Apple App store. *Education and Information Technologies*, *25*, 5389-5404. https://doi.org/10.1007/s10639-020-10234-z

Felt, L. J., & Robb, M, B. (2016). *Technology addiction: concern, controversy, and finding balance*. Common Sense Media. https://www.commonsensemedia.org/sites/default/files/research/report/csm_2016_technology_addiction_research_brief_0.pdf

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning*, *29*(3), 207-219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Grimm, P. (2010). *Social desirability bias.* Wiley International Encyclopedia of Marketing.

Hsu, C.-Y., Liang, J.-C., Chai, C.-S., & Tsai, C.-C. (2013). Exploring preschool teachers' technological pedagogical content knowledge of educational games. *Journal of Educational Computing Research*, *49*(4), 461–479. https://doi.org/10.2190/EC.49.4.c

Hsu, C.-Y., Liang, J.-C., Chuang, T.-Y., Chai, C.-S., & Tsai, C.-C. (2021). Probing in-service elementary school teachers' perceptions of TPACK for games, attitudes towards games, and actual teaching usage: a study of their structural models and teaching experiences. *Educational Studies*, *47*(6), 734–750. https://doi.org/10.1080/03055698.2020.1729099

Hsu, C.-Y., Tsai, M.-J., Chang, Y.-H., & Liang, J.-C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Educational Technology & Society*, *20*(1), 134–143. https://drive.google.com/file/d/18vyoGmOMq6rkrshWRnp4hzH-TcBfczR1/view

Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*, 1729–1743. https://doi.org/10.1016/j.compedu.2008.05.004

Lai, C., Li, X., & Wang, Q. (2017). Students' perceptions of teacher impact on their self-directed language learning with technology beyond the classroom: Cases of Hong Kong and US. *Educational Technology Research and Development*, *65*, 1105-1133. https://doi.org/10.1007/s11423-017-9523-4

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Outhwaite, L. A., Faulder, M., Gulliford, A., & Pitchford, N. J. (2019). Raising early achievement in math with interactive apps: A randomized control trial. *Journal of Educational Psychology, 111*(2), 284. https://doi.org/10.1037/edu0000286

Rikkers, W., Lawrence, D., Hafekost, J., & Zubrick, S. R. (2016). Internet use and electronic gaming by children and adolescents with emotional and behavioural problems in Australia – results from the second Child and Adolescent Survey of Mental Health and Wellbeing. *BMC Public Health*, *16*, 1-16. https://doi.org/10.1186/s12889-016-3058-1

Schwarz, N. (2007). Cognitive aspects of survey methodology. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *21*(2), 277-287. https://doi.org/10.1002/acp.1340

Shute, V. J., & Zapata-Rivera, D. (2008). Adaptive technologies. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communication and technology* (3rd ed., pp. 277–294). New York, NY: Taylor and Francis.

Tobin, G. A., & Begley, C. M. (2004). Methodological rigour within a qualitative framework. *Journal of Advanced Nursing*, *48*(4), 388-396. https://doi.org/10.1111/j.1365-2648.2004.03207.x

Vandercruysse, S., & Elen, J. (2016). Towards a game-based learning instructional design model focusing on integration. *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 17-35). doi:10.1007/978-3-319-39298-1_2.

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60* (1), 412–425. https://doi.org/10.1016/j.compedu.2012.07.018

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–89. DOI: 10.3102/0034654312436980

Bibliography

Abdul Jabbar, A. I., & Felicia, P. (2015). Gameplay engagement and learning in game-based learning: A systematic review. *Review of Educational Research, 85*(4), 740-779. https://doi.org/10.3102/0034654315577210

All, A., Castellar, E. P. N., & Van Looy, J. (2016). Assessing the effectiveness of digital game-based learning: Best practices. *Computers & Education, 92*, 90-103. https://doi.org/10.1016/j.compedu.2015.10.007

Amory, A., Naicker, K., Vincent, J., & Adams, C. (1999). The use of computer games as an educational tool: Identification of appropriate game types and game elements. *British Journal of Educational Technology, 30*(4), 311–321. https://doi.org/10.1111/1467-8535.00121

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin*, *103*(3), 411. DOI:10.1037/0033-2909.103.3.411

Anderson, L. W. (2005). Objectives, evaluation, and the improvement of education. *Studies in Educational Evaluation, 31*(2-3), 102-113. https://doi.org/10.1016/j.stueduc.2005.05.004

Angelova, M., Gunawardena, D., & Volk, D. (2006). Peer teaching and learning: Co-constructing language in a dual language first grade. *Language and Education, 20*(3), 173–190. https://doi.org/10.1080/09500780608668722

Anghileri, J. (2006). Scaffolding practices that enhance mathematics learning. *Journal of Mathematics Teacher Education, 9*, 33-52. https://doi.org/10.1007/s10857-006-9005-9

Annetta, L. A. (2008). Video games in education: Why they should be used and how they are being used. *Theory Into Practice, 47*(3), 229–239. https://doi.org/10.1080/00405840802153940

Aoki, H., Kim, J., & Lee, W. (2013). Propagation & level: Factors influencing in the ICT composite index at the school level. *Computers & Education, 60*(1), 310-324. https://doi.org/10.1016/j.compedu.2012.07.013

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., De Freitas, S., Louchart, S., Suttie, N., Berta, R., & De Gloria, A. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology*, *46*(2), 391-411. https://doi.org/10.1111/bjet.12113

Awang, Z. (2014). *A handbook on SME: For academicians and practitioners*. MPWS Rich Resources.

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology*, *29*(3), 344-370. https://doi.org/10.1016/j.cedpsych.2003.09.002

Azevedo, R., & Hadwin, A. F. (2005). Scaffolding self-regulated learning and metacognition – implications for the design of computer-based scaffolds. *Instructional Science, 33*(5–6), 367–379. https://doi.org/10.1007/s11251-005-1272-9

Azevedo, R., Moos, D. C., Greene, J. A., Winters, F. I., & Cromley, J. G. (2008). Why is externally facilitated regulated learning more effective than self-regulated learning with hypermedia? *Educational Technology Research and Development*, *56*, 45-72. https://doi.org/10.1007/s11423-007-9067-0

Baek, Y. K. (2008). What hinders teachers in using computer and video games in the classroom? Exploring factors inhibiting the uptake of computer and video games. *Cyberpsychology & Behavior, 11*(6), 665–671. https://doi.org/10.1089/cpb.2008.0127

Bai, H., Pan, W., Hirumi, A., & Kebritchi, M. (2012). Assessing the effectiveness of a 3-D instructional game on improving mathematics achievement and motivation of middle school students. *British Journal of Educational Technology, 43*(6), 993–1003. https://doi.org/10.1111/j.1467-8535.2011.01269.x

Bakker, M., van den Heuvel-Panhuizen, M., & Robitzsch, A. (2015). Effects of playing mathematics computer games on primary school students' multiplicative reasoning ability. *Contemporary Educational Psychology, 40*, 55–71. https://doi.org/10.1016/j.cedpsych.2014.09.001

Ball, C., Huang, K.-T., Cotten, S. R., & Rikard, R. V. (2020). Gaming the SySTEM: The relationship between video games and the digital and STEM divides. *Games and Culture, 15*(5), 501-528. https://doi.org/10.1177/1555412018812513

Baroody, A. J., Feil, Y., & Johnson, A. R. (2007). An alternative reconceptualization of procedural and conceptual knowledge. *Journal for Research in Mathematics Education, 38*(2), 115–131. https://doi.org/10.2307/30034952

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70*, 65-79. https://doi.org/10.1016/j.compedu.2013.08.003

Becker, H. J. (1994). How exemplary computer-using teachers differ from other teachers: Implications for realizing the potential of computers in schools. *Journal of Research on*

Computing in Education, 26(3), 291-321. https://doi.org/10.1080/08886504.1994.10782093

Becker, J. M., Klein, K., & Wetzels, M. (2012). Hierarchical latent variable models in PLS-SEM: guidelines for using reflective-formative type models. *Long Range Planning, 45*(5-6), 359-394. https://doi.org/10.1016/j.lrp.2012.10.001

Becker, J. M., Ringle, C. M., Sarstedt, M., & Völckner, F. (2015). How collinearity affects mixture regression results. *Marketing Letters, 26,* 643-659. https://doi.org/10.1007/s11002-014-9299-9

Becker, K. (2007). Digital game-based learning once removed: Teaching teachers. *British Journal of Educational Technology, 38(*3), 478-488. https://doi.org/10.1111/j.1467-8535.2007.00711.x

Bell, A., & Gresalfi, M. (2017). The role of digital games in a classroom ecology: Exploring instruction with video games. In M.F. Young, & S.T. Slota (Eds.). *Exploding the castle: Rethinking how video games and game mechanics can shape the future of education*, (pp. 67-92). Charlotte, NC: Information Age, Inc.

Belland, B. R. (2010). Portraits of middle school students constructing evidence-based arguments during problem-based learning: the impact of computer-based scaffolds. *Educational Technology Research and Development, 58*(3), 285–309. https://doi.org/10.1007/s11423-009-9139-4

Belland, B. R. (2013). Scaffolding: Definition, current debates, and Future Directions. *Handbook of Research on Educational Communications and Technology*, 505–518. https://doi.org/10.1007/978-1-4614-3185-5_39

Belland, B. R., Burdo, R., & Gu, J. (2015). A blended professional development program to help a teacher learn to provide one-to-one scaffolding. *Journal of Science Teacher Education, 26*(3), 263–289. https://doi.org/10.1007/s10972-015-9419-2

Belland, B. R., & Drake, J. (2013). Toward a framework on how affordances and motives can drive different uses of scaffolds: theory, evidence, and design implications. *Educational Technology Research and Development, 61*(6), 903–925. https://doi.org/10.1007/s11423-013-9313-6

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2011). Problem-based learning and argumentation: testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instructional Science, 39*(5), 667–694. https://doi.org/10.1007/s11251-010-9148-z

Bennett, F. (2002). The Future of Computer Technology in K-12 Education. *Phi Delta Kappan, 83*(8), 621–625. https://doi.org/10.1177/003172170208300811

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin, 107(*2), 238 –246. https://doi.org/10.1037/0033-2909.107.2.238

Bentler, P. M., & Bonett, D. G. (1980). Significance tests and goodness of fit in the analysis of covariance structures. *Psychological Bulletin, 88*(3), 588 606. https://doi.org/10.1037/0033-2909.88.3.588.

Beserra, V., Nussbaum, M., & Grass, A. (2017). Using a fine-grained multiple-choice response format in educational drill-and-practice video games. *Interactive Learning Environments, 25*(6), 717–732. https://doi.org/10.1080/10494820.2016.1172244

Bingimlas, K. A. (2009). Barriers to the successful integration of ICT in teaching and learning environments: A review of the literature. *Eurasia Journal of Mathematics, Science and Technology Education, 5(*3), 235-245. https://doi.org/10.12973/ejmste/75275

Bisanz, J., & LeFevre, J.-A. (1990). Strategic and nonstrategic processing in the development of mathematical cognition. In D. F. Bjorklund (Ed.), *Children's strategies: Contemporary views of cognitive development* (pp. 213–244). Lawrence Erlbaum Associates, Inc.

Blumberg, F. C., Deater-Deckard, K., Calvert, S. L., Flynn, R. M., Green, C. S., Arnold, D., & Brooks, P. J. (2019). Digital games as a context for children's cognitive development: Research recommendations and policy considerations. *Social Policy Report, 32*(1), 1–33. http://dx.doi.org/10.1002/sop2.3.

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein. (2011). Introduction to meta-analysis. John Wiley & Sons.

Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2014). Comprehensive meta-analysis (version 3). Englewood, NJ: Biostat.

Bourgonjon, J., & Hanghøj, T. (2011, October). What does it mean to be a game literate teacher? Interviews with teachers who translate games into educational practice. In *Proceedings of the 5th European Conference on Games Based Learning* (pp. 67-73). Reading: Academic.

Bourgonjon, J., De Grove, F., De Smet, C., Van Looy, J., Soetaert, R., & Valcke, M. (2013). Acceptance of game-based learning by secondary school teachers. *Computers & Education, 67*, 21-35. https://doi.org/10.1016/j.compedu.2013.02.010

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., et al. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education, 94,* 178–192. https://doi.org/10.1016/j.compedu.2015.11.003

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research–A systematic review of recent trends. *Computers & Education, 114*, 255–273. https://doi.org/10.1016/j.compedu.2017.07.004

Breien, F. S., & Wasson, B. (2020). Narrative categorization in digital game-based learning: Engagement, motivation & learning. *British Journal of Educational Technology, 52*(1), 91–111. https://doi.org/10.1111/bjet.13004

Brezovszky, B., McMullen, J., Veermans, K., Hannula-Sormunen, M. M., Rodríguez-Aflecht, G., Pongsakdi, N., Laakkonen, E., & Lehtinen, E. (2019). Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge. *Computers & Education, 128*, 63–74. https://doi.org/10.1016/j.compedu.2018.09.011

Bruner, J. (1985). Child's Talk: Learning to Use Language. *Child Language Teaching and Therapy*, *1*(1), 111–114. https://doi.org/10.1177/026565908500100113

Bruner, J. (1985). *Vygotsky: A historical and conceptual perspective. Culture, communication, and cognition: Vygotskian perspectives*. London, UK: Cambridge University Press.

Buabeng-Andoh, C. (2021). Exploring university students' intention to use mobile learning: A research model approach. *Education and Information Technologies, 26*(1), 241 256. https://doi.org/10.1007/s10639-020-10267-4

Calantone, R. J. (2014). Common beliefs and reality about PLS: Comments on Rönkkö and Evermann (2013). *Organizational Research Methods, 17*(2), 182-209. https://doi.org/10.1177/10944281145269

Callaghan, M. N., & Reich, S. M. (2018). Are educational preschool apps designed to teach? An analysis of the app market. *Learning, Media and Technology, 43*(3), 280-293. ttps://doi.org/10.1080/17439884.2018.1498355

Cayton-Hodges, G. A., Feng, G., & Pan, X. (2015). Tablet-based math assessment: What can we learn from math apps? *Journal of Educational Technology & Society, 18(*2), 3-20. http://www.jstor.org/stable/jeductechsoci.18.2.3

Cazden, C. B. (1983). Peekaboo as an instructional model: Discourse development at home and at school. In B. Bain (Ed.), *The sociogenesis of language and human conduct* (pp. 33–58). Springer. https://doi.org/10.1007/978-1-4899-1525-2_3

Cenfetelli, R. T., & Bassellier, G. (2009). Interpretation of formative measurement in information systems research. *MIS quarterly*, 689-707. https://doi.org/10.2307/20650323

Chai, C. S., Ng, E. M., Li, W., Hong, H. Y., & Koh, J. H. (2013). Validating and modelling technological pedagogical content knowledge framework among Asian preservice teachers. *Australasian Journal of Educational Technology, 29*(1). https://doi.org/10.14742/ajet.174

Chan, J. Y.-C., Closser, A. H., Ngo, V., Smith, H., Liu, A. S., & Ottmar, E. (2023). Examining shifts in conceptual knowledge, procedural knowledge and procedural flexibility in the context of two game-based technologies. *Journal of Computer Assisted Learning,* 1– 16. https://doi.org/10.1111/jcal.12798

Chang, M., Evans, M. A., Kim, S., Norton, A., & Samur, Y. (2015). Differential effects of learning games on mathematics proficiency. *Educational Media International, 52* (1), 47–57. https://doi.org/10.1080/09523987.2015.1005427

Charsky, D., & Ressler, W. (2011). “Games are made for fun”: Lessons on the effects of concept maps in the classroom use of computer games. *Computers & Education, 56*(3), 604-615. https://doi.org/10.1016/j.compedu.2010.10.001

Chee, Y. S (2016). *Games-To-Teach or Games-To-Learn: Unlocking the Power of Digital Game-Based Learning Through Performan*ce. Singapore: Springer Singapore.

Chen, C. H., & Law, V. (2016). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. *Computers in Human Behavior, 55*, 1201-1212. https://doi.org/10.1016/j.chb.2015.03.010

Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning, 19*(3), 347–359. https://doi.org/10.1046/j.0266-4909.2003.00036.x

Chin, W. W. (1998). The partial least squares approach to structural equation modelling. *Modern Methods for Business Research, 295*(2), 295-336.

Cho, E. (2016). Making reliability reliable: A systematic approach to reliability coefficients. *Organizational Research Methods, 19(*4), 651-682. https://doi.org/10.1177/1094428116656239

Cho, K.-L., & Jonassen, D. H. (2002). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research and Development, 50(*3), 5–22. https://doi.org/10.1007/bf02505022

Choi, J.-I, & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational Technology Research and Development, 43(*2), 53–69. https://doi.org/10.1007/bf02300472

Chung-Yuan, H., Meng-Jung, T., Yu-Hsuan, C., & Liang, J. C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Journal of Educational Technology & Society, 20*(1), 134.

Clark, D. B., Nelson, B. C., Chang, H. Y., Martinez-Garza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring Newtonian mechanics in a conceptually integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States. *Computers & Education, 57*(3), 2178-2195. https://doi.org/10.1016/j.compedu.2011.05.007

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research, 86*(1), 79–122. https://doi.org/10.3102/0034654315582065

Clark, R. E. (2007). Learning from serious games? Arguments, evidence, and research suggestions. *Educational Technology, 47(*3), 56–59. https://www.jstor.org/stable/44429512

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd Edition). Hillsdale, NJ: Lawrence Earlbaum Associates.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: teaching the crafts of reading, writing and mathematics. In L. Resnick (Ed.), *Knowing, Learning and Instruction: Essays in honor of Robert Glaser* (pp. 453–494). Routledge.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education, 59*(2), 661-686. https://doi.org/10.1016/j.compedu.2012.03.004

Conole, G., Dyke, M., Oliver, M., & Seale, J. (2004). Mapping pedagogy and tools for effective learning design. *Computers & Education, 43*(1–2), 17–33. https://doi.org/10.1016/j.compedu.2003.12.018

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16(*3), 297-334. https://doi.org/10.1007/BF02310555

Crooks, N. M., & Alibali, M. W. (2014). Defining and measuring conceptual knowledge in mathematics. *Developmental Review, 34*(4), 344–377. https://doi.org/10.1016/j.dr.2014.10.001

Davis, E. A., & Linn, M. C. (2000). Scaffolding students' knowledge integration: prompts for reflection in KIE. *International Journal of Science Education, 22*(8), 819–837. https://doi.org/10.1080/095006900412293

Dawson, C., & Rakes, G. C. (2003). The influence of principals' technology training on the integration of technology into schools. *Journal of Research on Technology in Education, 36*(1), 29-49. https://doi.org/10.1080/15391523.2003.10782401

De Witte, K., & Rogge, N. (2014). Does ICT matter for effectiveness and efficiency in mathematics education? *Computers & Education, 75*, 173-184. https://doi.org/10.1016/j.compedu.2014.02.012

Deci, E. L., Koestner, R., & Ryan, R. M. (2001). Extrinsic rewards and intrinsic motivation in education: Reconsidered once again. *Review of Educational Research, 71* (1), 1–27. https://doi.org/10.3102/00346543071001001

Deen, M., Van den Beemt, A., & Schouten, B. (2015). The differences between problem-based and drill and practice games on motivations to learn. *International Journal of Gaming and Computer-Mediated Simulations, 7*(3), 44–59.

Dewey, J. (1938). *Experience and education.* New York: Simon and Schuster.

Dhir, S., & Shukla, A. (2018). The influence of personal and organisational characteristics on employee engagement and performance. *International Journal of Management Concepts and Philosophy, 11*(2), 117-131. https://doi.org/10.1504/IJMCP.2018.092321

Dijkstra, T. K., & Henseler, J. (2015). Consistent and asymptotically normal PLS estimators for linear structural equations. *Computational Statistics & Data Analysis, 81*, 10-23. https://doi.org/10.1016/j.csda.2014.07.008

Driscoll, M. P. (1994). *Psychology of learning for instruction.* Allyn & Bacon.

Duarte, P. A. O., & Raposo, M. L. B. (2010). A PLS model to study brand preference: An application to the mobile phone market. In *Handbook of partial least squares methods* (pp. 449-485). Berlin Heidelberg: Springer.

Dubé, A. K., & Keenan, A. (2016). Are games a viable home numeracy practice? In B. Blevins-Knabe & A. M. B. Austin (Eds.), *Early childhood mathematics skill development in the home environment* (pp. 165–184). Springer.

Dubé, A. K., & Wen, R. (2022). Identification and evaluation of technology trends in K-12 education from 2011 to 2021. *Education and Information Technologies, 27*(2), 1929-1958. https://doi.org/10.1007/s10639-021-10689-8

Dubé, A. K., Alam, S. S., Xu, C., Wen, R., & Kacmaz, G. (2019a). Tablets as elementary mathematics education tools: Are they effective and why. *Mathematical learning and cognition in early childhood: Integrating interdisciplinary research into practice*, (pp. 223–248). Cham: Springer.

Dubé, A. K., Kacmaz, G., Wen, R., Alam, S. S., & Xu, C. (2020). Identifying quality educational apps: Lessons from 'top' mathematics apps in the Apple App store. *Education and Information Technologies*, *25*, 5389-5404. https://doi.org/10.1007/s10639-020-10234-z

Eastwood, J. L., & Sadler, T. D. (2013). Teacher' implementation of a game-based biotechnology curriculum. *Computers & Education, 66,* 11-24. https://doi.org/10.1016/j.compedu.2013.02.003

Ellis, M. W., & Berry, R. Q., III (2005). The paradigm shifts in mathematics education: Explanations and implications of reforming conceptions of teaching and learning. *Mathematics Educator,* 15(1).

Esposito Vinzi, V., Chin, W. W., Henseler, J., & Wang, H. (2010). *Handbook of partial least squares*. Springer Handbooks of Computational Statistics Series. Vol. II. Heidelberg: Springer.

Fabian, K., Topping, K. J., & Barron, I. G. (2016). Mobile technology and mathematics: Effects on students' attitudes, engagement, and achievement. *Journal of Computers in Education, 3(*1), 77–104. https://doi.org/10.1007/s40692-015-0048-8

Federation of Academic Scientists. (2016). *Harnessing the power of video games for learning*. Retrieved March 30, 2023, from https://www.informalscience.org/sites/default/files/Summit_on_Educational_Games.pd

Felt, L. J. & Robb, M. B. (2016). *Technology addiction: Concern, controversy, and finding balance.* San Francisco, CA: Common Sense Media.

Fisher, C. (2017) *Designing games for children: Developmental, usability, and design considerations for making games for kids*. New York: Focal Press.

Fleer, M. (1992). Identifying teacher–child interaction which scaffolds scientific thinking in young children. *Science & Education, 76*, 373–397.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39-50. https://doi.org/10.1177/002224378101800104

Foster, A., & Shah, M. (2015). The play curricular activity reflection discussion model for game-based learning. *Journal of Research on Technology in Education, 47*(2), 71–88. https://doi.org/10.1080/15391523.2015.967551

Frenzel, A. C., Goetz, T., Pekrun, R., & Watt, H. M. (2010). Development of mathematics interest in adolescence: Influences of gender, family, and school context. *Journal of Research on Adolescence, 20*(2), 507–537. https://doi.org/10.1111/j.1532-7795.2010.00645.x

Garcia, D., MacDonald, S., & Archer, T. (2015). Two different approaches to the affective profiles model: median splits (variable-oriented) and cluster analysis (person-oriented). *PeerJ*, *3*, e1380. 10.7717/peerj.1380

Garland, R. (1991). The mid-point on a rating scale: Is it desirable. *Marketing bulletin*, *2*(1), 66-70.

Garson, G. D. (2012). Structural equation modeling. Asheboro, NC.

Gaskins, I. W., Rauch, S., Gensemer, E., Cunicelli, E., O'hara, C., Six, L. & Scott, T. (1997). Scaffolding the development of intelligence among children who are delayed in learning to read. In K. Hogan & M. Pressley (Eds.), *Scaffolding student learning: Instructional approaches and issues* (pp. 43–73). Brookline Books.

Ge, X., & Ifenthaler, D. (2018). Designing engaging educational games and assessing engagement in game-based learning. In *Gamification in Education: Breakthroughs in Research and Practice* (pp. 1-19). IGI Global.

Gee, J. P. (2008). Learning and Games. In *The Ecology of Games: Connecting Youth, Games, and Learning*. MIT Press. doi: 10.1162/dmal.9780262693646.vii

Gil-Flores, J., Rodríguez-Santero, J., & Torres-Gordillo, J. J. (2017). Factors that explain the use of ICT in secondary-education classrooms: The role of teacher characteristics and school infrastructure. *Computers in Human Behavior, 68,* 441-449. https://doi.org/10.1016/j.chb.2016.11.057

Gillies, R. M. (2008). The effects of cooperative learning on junior high school students' behaviours, discourse and learning during a science-based learning activity. *School Psychology International, 29*(3), 328–347. https://doi.org/10.1177/0143034308093673

Gillies, R. M., & Boyle, M. (2006). Ten australian elementary teachers' discourse and reported pedagogical practices during cooperative learning. *Elementary School Journal, 106*(5), 429–452. https://doi.org/10.1086/505439

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29*(3), 207-219. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Granott, N. (2005). Scaffolding dynamically toward change: Previous and new perspectives. *New Ideas in Psychology, 23*(3), 140-151. https://doi.org/10.1016/j.newideapsych.2006.07.002

Grimm, P. (2010). *Social desirability bias.* Wiley International Encyclopedia of Marketing.

Groff, J. S., Howells, C., & Cranmer, S. (2010). *The impact of console games in the classroom: Evidence from schools in Scotland* (pp. 1–94). https://www.nfer.ac.uk/media/1788/futl25.pdf

Haataja, E., Moreno-Esteva, E. G., Salonen, V., Laine, A., Toivanen, M., & Hannula, M. S. (2019). Teacher's visual attention when scaffolding collaborative mathematical problem-solving. *Teaching and Teacher Education, 86*, 102877. https://doi.org/10.1016/j.tate.2019.102877

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. https://doi.org/10.1080/10508406.2010.508029

Hair J.F., Anderson R.E., Tatham R.L., & Black W.C., (1998). *Multivariate Data Analysis.* Prentice-Hall: New Jersey

Hair Jr, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2021). *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*. Sage Publications.

Hair Jr, J. F., Matthews, L. M., Matthews, R. L., & Sarstedt, M. (2017). PLS-SEM or CB-SEM: updated guidelines on which method to use. *International Journal of Multivariate Data Analysis, 1*(2), 107-123. https://doi.org/10.1504/IJMDA.2017.087624

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. *Journal of Marketing Theory and Practice, 19*(2), 139-152. https://doi.org/10.2753/MTP1069-6679190202

Hair, J. F., Ringle, C. M., & Sarstedt, M. (2013). Partial least squares structural equation modeling: Rigorous applications, better results and higher acceptance. *Long Range Planning, 46*(1-2), 1-12. https://doi.org/10.1016/j.lrp.2013.01.001

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review, 31*(1), 2-24. https://doi.org/10.1108/EBR-11-2018-0203

Hair, J.F., Hult, G.T.M., Ringle, C.M. and Sarstedt, M. (2017a), *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, Sage, Thousand Oaks, CA.

Hakkarainen, K. (2004). Pursuit of explanation within a computer-supported classroom. *International Journal of Science Education, 26*(8), 979–996. https://doi.org/10.1080/1468181032000354

Hanghøj, T., & Brund, C. E. (2011). Teachers and serious games: Teacher's roles and positionings in relation to educational games. In S. Egenfeldt-Nielsen, B. Meyer, & B. H. Sørensen (Eds.), *Serious games in education: A global perspective* (pp. 125–136). Aarhus: Aarhus Universitetsforlag.

Hannafin, M., Land, S., & Oliver, K. (1999). Open-ended learning environments: Foundations, methods, and models. In C. M. Reigeluth (Ed.), *Instructional-design Theories and Models: A New Paradigm of Instructional Theory, Volume II* (pp. 115–140). Lawrence Erlbaum Associates.

Haruehansawasin, S., & Kiattikomol, P. (2018). Scaffolding in problem-based learning for low-achieving learners. *The Journal of Educational Research, 111*(3), 363–370. https://doi.org/10.1080/00220671.2017.1287045

Hattie, J. (2009). *Visible learning: A synthesis of over meta-analyses relating to achievement.* London: Routledge.

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching, 24*(4), 291–307. https://doi.org/10.1002/tea.3660240404

Hayak, M., & Avidov-Ungar, O. (2020). The integration of digital game-based learning into the instruction: Teachers' perceptions at different career stages. *TechTrends, 64,* 887-898. https://doi.org/10.1007/s11528-020-00503-6

Hébert, C., Jenson, J., & Fong, K. (2018). Challenges with measuring learning through digital gameplay in K-12 classrooms. *Media and Communication, 6*(2), 112–125. https://doi.org/10.17645/mac.v6i2.1366

Hedges, L. V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational Statistics, 6,* 107–112. https://doi.org/10.3102/10769986006002107

Helle, L., Tynjälä, P., Olkinuora, E., & Lonka, K. (2007). 'Ain't nothin' like the real thing'. Motivation and study processes on a work-based project course in information systems design. *British Journal of Educational Psychology, 77*(2), 397–411. https://doi.org/10.1348/000709906x105986

Henseler, J. (2014, May). Assessing and testing the goodness-of-fit of PLS path models. In *The 3rd Annual Conference of the Dutch/Flemish Classification Society (Vereniging voor Ordinatie en Classificatie-VOC)*.

Henseler, J., Dijkstra, T. K., Sarstedt, M., Ringle, C. M., Diamantopoulos, A., Straub, D. W., Ketchen Jr., D.J., Hair, J, F., Hult M., Tomas G., & Calantone, R. J. (2014). Common beliefs and reality about PLS: Comments on Rönkkö and Evermann (2013). *Organizational Research Methods, 17*(2), 182-209. https://doi.org/10.1177/1094428114526928

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science, 43(*1), 115–135 https://doi.org/10.1007/s11747-014-0403-8

Hidi, S. (2006). Interest: A unique motivational variable. *Educational Research Review, 1*(2), 69–82. https://doi.org/10.1016/j.edurev.2006.09.001

Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in “educational” apps: *Lessons from the science of learning. Psychological Science in the Public Interest, 16*(1), 3–34. https://doi.org/10.1177/1529100615569721

Hmelo, C., & Day, R. (1999). Contextualized questioning to scaffold learning from simulations. *Computers & Education, 32*(2), 151–164. https://doi.org/10.1016/s0360-1315(98)00062-1

Hoffmann, A. O., & Birnbrich, C. (2012). The impact of fraud prevention on bank-customer relationships: An empirical investigation in retail banking. *International Journal of Bank Marketing, 30*(5), 390-407. https://doi.org/10.1108/02652321211247435

Hogan, T. P., Benjamin, A., & Brezinski, K. L. (2000). Reliability methods: A note on the frequency of use of various types. *Educational and Psychological Measurement, 60*(4), 523-531. https://doi.org/10.1177/0013164002197069

Holman, B. (2018). In defense of meta-analysis. *Synthese, 196*(8), 3189–3211. https://doi.org/10.1007/s11229-018-1690-2

Honey, M. A., & Hilton, M. L. (2011). *Learning science through computer games.* National Academies Press, Washington, DC.

Hooper, D., Coughlan, J., & Mullen, M. (2008, June). Evaluating model fit: A synthesis of the structural equation modelling literature. In A. Brown (Ed.), *Proceedings of the 7th European Conference on Research Methodology for Business and Management Studies* (pp. 195–200). Regent's College, London, United Kingdom.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277–1288. https://doi.org/10.1177/10497323052766

Hsu, C. Y., Liang, J. C., & Su, Y. C. (2015). The role of the TPACK in game-based teaching: Does instructional sequence matter? *The Asia-Pacific Education Researcher, 24*, 463-470. https://doi.org/10.1007/s40299-014-0221-2

Hsu, C. Y., Liang, J. C., & Tsai, M. J. (2020). Probing the structural relationships between teachers' beliefs about game-based teaching and their perceptions of technological pedagogical and content knowledge of games. *Technology, Pedagogy and Education, 29(*3), 297-309. https://doi.org/10.1080/1475939X.2020.1752296

Hsu, C.-Y., Liang, J.-C., Chai, C.-S., & Tsai, C.-C. (2013). Exploring preschool teachers' technological pedagogical content knowledge of educational games. *Journal of Educational Computing Research, 49*(4), 461–479. https://doi.org/10.2190/EC.49.4.c

Hsu, C.-Y., Liang, J.-C., Chuang, T.-Y., Chai, C.-S., & Tsai, C.-C. (2021). Probing in-service elementary school teachers' perceptions of TPACK for games, attitudes towards games, and actual teaching usage: a study of their structural models and teaching experiences. *Educational Studies, 47*(6), 734–750. https://doi.org/10.1080/03055698.2020.1729099

Hsu, C.-Y., Tsai, M.-J., Chang, Y.-H., & Liang, J.-C. (2017). Surveying in-service teachers' beliefs about game-based learning and perceptions of technological pedagogical and content knowledge of games. *Educational Technology & Society, 20(*1), 134–143. https://www.jstor.org/stable/jeductechsoci.20.1.134

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal*, *6*(1), 1-55.

Hughes, C. (2015). The transition to school. *Psychologist*, *28*(9), 714-717.

Huizenga, J., Admiraal, W., Akkerman, S., & ten Dam, G. (2009). Learning History by playing a mobile city game. *Journal of Computer Assisted Learning, 25*, 332–344.

Inan, F. A., & Lowther, D. L. (2010). Factors affecting technology integration in K-12 classrooms: A path model. *Educational Technology Research and Development*, *58*, 137-154. https://doi.org/10.1007/s11423-009-9132-y

Jackson, S. L., Krajcik, J., & Soloway, E. (1998). The design of guided learning-adaptable scaffolding in interactive learning environments. In C.-M. Karat, A. Lund, J. Coutaz, & J. Karat (Eds.), *Proceedings of CHI 98: Human factors in computing systems* (pp. 187–194). Reading, MA: Addison-Wesley

Jadallah, M., Anderson, R. A., Nguyen-Jahiel, K., Miller, B. W., Kim, I.-H, Kuo, L.-J, Dong, T., & Wu, X. (2011). Influence of a teacher's scaffolding moves during child-led small-group discussions. *American Educational Research Journal, 48*(1), 194–230. https://doi.org/10.3102/0002831210371498

Johnston, E., Olivas, G., Steele, P., Smith, C., & Bailey, L. (2018). Exploring pedagogical foundations of existing virtual reality educational applications: A content analysis study. *Journal of Educational Technology Systems, 46(*4), 414–439. https://doi.org/10.1177/0047239517745560

Kacmaz, G., & Dube, A. K. (In preparation). Comparing and Validating the Three-Measurement Models of Teacher Scaffolding Questionnaire during Game-based Learning and Relationship with its Antecedents. *Learning Environments Research.*

Kangas, M., Koskinen, A., & Krokfors, L. (2017). A qualitative literature review of educational games in the classroom: the teacher's pedagogical activities. *Teachers and Teaching, 23(*4), 451-470. http://dx.doi.org/10.1080/13540602.2016.1206523

Kao, G. Y. M., Chiang, C. H., & Sun, C. T. (2017). Customizing scaffolds for game-based learning in physics: Impacts on knowledge acquisition and game design creativity. *Computers & Education, 113,* 294-312. https://doi.org/10.1016/j.compedu.2017.05.022

Kapp, K. M. (2012). *The gamification of learning and instruction: Game-based methods and strategies for training and education*. San Francisco: Pfeiffer.

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. Ferdig (Ed.), *Handbook of Research on Effective Electronic Gaming in Education* (pp. 1–32). New York: IGI Global.

Ke, F. (2019). Mathematical problem solving and learning in an architecture-themed epistemic game. *Educational Technology Research & Development, 67*(5), 1085–1104. https://doi.org/10.1007/s11423-018-09643-2

Kebritchi, M., & Hirumi, A. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*, 1729–1743. https://doi.org/10.1016/j.compedu.2008.05.004

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education, 55*(2), 427–443. https://doi.org/10.1016/j.compedu.2010.02.007

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education, 8(*1), 13–24. https://doi.org/10.1016/j.iheduc.2004.12.001

Kiili, K., Ketamo, H., Koivisto, A., & Finn, E. (2014). Studying the user experience of a tablet-based math game. *International Journal of Game-Based Learning (IJGBL), 4*(1), 60–77. http://doi.org/10.4018/IJGBL.2014010104

Kim, M. C., & Hannafin, M. J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers & Education, 56*(2), 403-417. https://doi.org/10.1016/j.compedu.2010.08.024

King, A. (1998). Transactive peer tutoring: Distributing cognition and metacognition. *Educational Psychology Review, 10*(1), 57–74. https://doi.org/10.1023/a:1022858115001

Kirriemuir, J., & McFarlane, A. (2004). *Literature review in games and learning*. Futurelab. Retrieved March 30, 2023, from http://www.futurelab.org.uk/resources/documents/lit_reviews/Games_Review.pdf.

Kline, R. B. (2011). *Principles and practice of structural equation modeling,* (3rd ed.). New York: Guilford Press

Kock, N. (2015). Common method bias in PLS-SEM: A full collinearity assessment approach. *International Journal of e-Collaboration, 11(*4), 1–10. http://doi.org/10.4018/ijec.2015100101

Koedinger, K. R., & Aleven, V. (2016). An interview reflection on “Intelligent tutoring goes to school in the big city.” *International Journal of Artificial Intelligence in Education, 26*(1), 13–24. https://doi.org/10.1007/s40593-015-0082-8

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70. https://www.learntechlib.org/primary/p/29544/.

Koh, J. H. L., Chai, C. S., & Tsai, C. C. (2014). Demographic factors, TPACK constructs, and teachers' perceptions of constructivist oriented TPACK. *Journal of Educational Technology & Society*, *17*(1), 185-196.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: putting learning by design(tm) into practice. *The Journal of the Learning Sciences, 12*(4), 495–547. https://doi.org/10.1207/s15327809jls1204_2

Konstantinidou, E., & Scherer, R. (2022). Teaching with technology: A large-scale, international, and multilevel study of the roles of teacher and school characteristics. *Computers & Education,* 179, 104424. https://doi.org/10.1016/j.compedu.2021.104424

Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of intelligent tutoring systems: A meta-analytic review. Review of Educational Research, 86(1), 42–78. https://doi.org/10.3102/0034654315581420

Lai, C., Li, X., & Wang, Q. (2017). Students' perceptions of teacher impact on their self-directed language learning with technology beyond the classroom: Cases of Hong Kong and US. *Educational Technology Research and Development, 65*, 1105-1133. https://doi.org/10.1007/s11423-017-9523-4

Lajoie, S. P. (2005). Extending the Scaffolding Metaphor. *Instructional Science, 33*(5–6), 541–557. https://doi.org/10.1007/s11251-005-1279-2

Lajoie, S. P., Guerrera, C., Munsie, S. D, & Lavigne, N. C. (2001). Constructing knowledge in the context of BioWorld. *Instructional Science, 29*(2), 155–186. https://doi.org/10.1023/a:1003996000775

Lamb, R., Antonenko, P., Etopio, E., & Seccia, A. (2018). Comparison of virtual reality and hands on activities in science education via functional near infrared spectroscopy. *Computers & Education, 124*, 14-26. https://doi.org/10.1016/j.compedu.2018.05.014

Larkin, K. (2015). "An app! An app! My kingdom for an app": An 18-month quest to determine whether apps support mathematical knowledge building. *Digital games and mathematics learning: Potential, promises and pitfalls*, 251-276.

Lee, H.-S., Linn, M. C., Varma, K., & Liu, O. L. (2010). How do technology-enhanced inquiry science units impact classroom learning? *Journal of Research in Science Teaching, 47*(1), 71–90. https://doi.org/10.1002/tea.20304

Lee, J., Andrade, S., Negotie, A., Li, C., Aruliah, R., Wood, E., & June. (2019). Do math apps "teach" numeracy skills to young children? In *paper presented at the 2019 the Mathematical Cognition and Learning Society Conference, Ottawa.*

Lee, K. T. (2002). Effective teaching in the information era: Fostering an ICT-based integrated learning environment in schools. *Asia-Pacific Journal of Teacher Education & Development*, *5*(1), 21-45.

Lee, M. H., & Tsai, C. C. (2010). Exploring teachers perceived self-efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web. *Instructional Science*, *38*, 1-21. doi:10.1007/s11251-008-9075-4.

Leerkes, E. M., Blankson, A. N., O'Brien, M., Calkins, S. D., & Marcovitch, S. (2011). The relation of maternal emotional and cognitive support during problem solving to pre-academic skills in preschoolers. *Infant and Child Development, 20,* 353–370. doi:10.1002/icd.728

LeFevre, J. A., Fast, L., Skwarchuk, S. L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., et al. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development, 81(*6), 1753–1767. https://doi.org/10.1111/j.1467-8624.2010.01508.x

Lenhart, A., Smith, A., Anderson, M., Duggan, M., & Perrin, A. (2015). *Teens, technology and friendships.* Pew Research Center. Retrieved March 30, 2023, from http://www.pewinternet.org/2015/08/06/teens-technology-and-friendships/.

Li, D. D., & Lim, C. P. (2008). Scaffolding online historical inquiry tasks: A case study of two secondary school classrooms. *Computers & Education, 50*(4), 1394–1410. https://doi.org/10.1016/j.compedu.2006.12.013

Li, S. C. S., & Huang, W. C. (2016). Lifestyles, innovation attributes, and teachers' adoption of game-based learning: Comparing non-adopters with early adopters, adopters and likely adopters in Taiwan. *Computers & Education, 96,* 29-41. https://doi.org/10.1016/j.compedu.2016.02.009

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis*. SAGE publications, Inc.

Lohmöller, JB. (1989). Predictive vs. Structural Modeling: PLS vs. ML. In *Latent variable path modeling with partial least squares* (pp. 199-226). New York: Springer.

Maertens, B., De Smedt, B., Sasanguie, D., Elen, J., & Reynvoet, B. (2016). Enhancing arithmetic in pre-schoolers with comparison or number line estimation training: Does it matter? *Learning and Instruction, 46*, 1–11. https://doi.org/10.1016/j.learninstruc.2016.08.004

Maloch, B. (2002). Scaffolding student talk: One teacher's role in literature discussion groups. Reading Research Quarterly, 37(1), 94–112. https://doi.org/10.1598/RRQ.37.1.4

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science, 5*(4), 333–369. https://doi.org/10.1016/S0364-0213(81)80017-1

Margulieux, L. E., & Catrambone, R. (2021). Scaffolding problem solving with learners' own self explanations of subgoals. *Journal of Computing in Higher Education, 33,* 499-523. https://doi.org/10.1007/s12528-021-09275-1

Mayer, R. E. (2014). *Computer games for learning: An evidence-based approach*. MIT Press.

Mayer, R. E. (2014b). *Computer games for learning: An evidence-based approach.* Cambridge, MA: MIT Press

Mayring, P. (2004). Qualitative content analysis*. A Companion to Qualitative Research*, *1*(2), 159–176.

Mccall, J. (2011). *Gaming the Past: Using Video Games to Teach Secondary History*. Routledge, Taylor & Francis Group.

McDonald, R. P. (1970). The theoretical foundations of principal factor analysis, canonical factor analysis, and alpha factor analysis. *British Journal of Mathematical and Statistical Psychology, 23*(1), 1-21. https://doi.org/10.1111/j.2044-8317.1970.tb00432.x

McEwen, R. N., & Dubé, A. K. (2015). Engaging or distracting: children's tablet computer use in education. *Journal of Educational Technology & Society, 18*(4), 9.

McEwen, R., & Dubé, A. K. (2016). Intuitive or idiomatic: An interdisciplinary study of child-tablet computer interaction. *Journal of the Association for Information Science and Technology, 67*(5), 1169–1181. https://doi.org/10.1002/asi.23470

McLaren, B. M., Adams, D. M., Mayer, R. E., & Forlizzi, J. (2017). A computer-based game that promotes mathematics learning more than a conventional approach. *International*

Journal of Game-Based Learning (IJGBL), 7(1), 36–56. http://doi.org/10.4018/IJGBL.2017010103

McManis, L. D., & Gunnewig, S. B. (2012). Finding the education in educational technology with early learners. *Young Children, 67*(3), 14–24.

McNeill, K. L., & Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain-specific and domain-general knowledge in writing arguments to explain phenomena. *The Journal of the Learning Sciences, 18*(3), 416–460. https://doi.org/10.1080/10508400903013488

Meade, A. W. & Craig, S. B. (2012). Identifying careless responses in survey data. *Psychological Methods, 17*(3), 437–455. DOI: 10.1037/a0028085

Mermelshtine, R. (2017). Parent–child learning interactions: A review of the literature on scaffolding. *British Journal of Educational Psychology, 87*(2), 241-254. https://doi.org/10.1111/bjep.12147

Mermelshtine, R., & Barnes, J. (2016). Maternal responsive–didactic caregiving in play interactions with 10-month-olds and cognitive development at 18 months. *Infant and Child Development, 25*(3), 296–316. doi:10.1002/icd.1961

Mertzman, T. (2008). Individualising scaffolding: teachers' literacy interruptions of ethnic minority students and students from low socioeconomic backgrounds. *Journal of Research in Reading, 31*(2), 183–202. https://doi.org/10.1111/j.1467-9817.2007.00356.x

Miller, S. P., & Hudson, P. J. (2007). Using evidence-based practices to build mathematics competence related to conceptual, procedural, and declarative knowledge. *Learning*

*Disabilities Research & Practice, 22(*1), 47–57. https://doi.org/10.1111/j.1540-5826.2007.00230.x

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108(*6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mohan, M. M., Upadhyaya, P., & Pillai, K. R. (2020). Intention and barriers to use MOOCs: An investigation among the post graduate students in India. Education and Information Technologies, 25(6), 5017–5031. https://doi.org/10.1007/s10639-020-10215-2

Molenaar, I., Roda, C., van Boxtel, C., & Sleegers, P. (2012). Dynamic scaffolding of socially regulated learning in a computer-based learning environment. *Computers & Education*, *59*(2), 515-523. https://doi.org/10.1016/j.compedu.2011.12.006

Montano, D. E., & Kasprzyk, D. (2015). Theory of reasoned action, theory of planned behavior, and the integrated behavioral model. *Health behavior: Theory, research and practice*, *70*(4), 231.

Muhonen, H., Rasku-Puttonen, H., Pakarinen, E., Poikkeus, A. M., & Lerkkanen, M. K. (2016). Scaffolding through dialogic teaching in early school classrooms. *Teaching and Teacher Education, 55*, 143-154. https://doi.org/10.1016/j.tate.2016.01.007

Mulaik, S. A., James, L. R., Van Alstine, J., Bennett, N., Lind, S., & Stilwell, C. D. (1989). Evaluation of goodness-of-fit indices for structural equation models. *Psychological Bulletin, 105*(3), 430 – 445. https://doi.org/10.1037/0033-2909.105.3.430

Naser, K., & Hassan, Y. (2013). Determinants of corporate social responsibility reporting: Evidence from an emerging economy. *Journal of Contemporary Issues in Business Research, 2*(3), 56–74.

Neitzel, C., & Stright, A. D. (2003). Mothers' scaffolding of children's problem solving: Establishing a foundation of academic self-regulatory competence. *Journal of Family Psychology, 17*(1), 147– 159. doi:10.1037/0893-3200.17.1.147

Neitzel, C., & Stright, A. D. (2004). Parenting behaviours during child problem solving: The roles of child temperament, mother education and personality, and the problem-solving context. *International Journal of Behavioral Development, 28*(2), 166–179. doi:10.1080/ 01650250344000370

Nikou, S. (2019). Factors driving the adoption of smart home technology: An empirical assessment. *Telematics and Informatics, 45*(101283), 1–12. https://doi.org/10.1016/j.tele.2019.101283

Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in Health Sciences Education, 15*, 625-632. https://doi.org/10.1007/s10459-010-9222-y

Nousiainen, T., Kangas, M., Rikala, J., & Vesisenaho, M. (2018). Teacher competencies in game-based pedagogy. *Teaching and Teacher Education, 74,* 85-97. https://doi.org/10.1016/j.tate.2018.04.012

O'Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: Evidence from the computer games literature. *Curriculum Journal, 16*(4), 455–474. https://doi.org/10.1080/09585170500384529

O'Rourke, E., Andersen, E., Gulwani, S., & Popovic, Z. (2015, April 18–23). A framework for automatically generating interactive instructional scaffolding. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems* (pp. 1545–1554).

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), 50–70. http://dx.doi.org/10.14221/ajte.2017v42n10.4

OECD (2020). *OECD Economic Outlook Volume Issue 1: Preliminary Version.* Retrieved September 15, 2020, from https://www.oecd.org/economy/greece-economic-snapshot/.

Oh, S., & Jonassen, D. H. (2007). Scaffolding online argumentation during problem solving. *Journal of Computer Assisted Learning, 23(*2), 95–110. https://doi.org/10.1111/j.1365-2729.2006.00206.x

Ok, M. W., Kim, M. K., Kang, E. Y., & Bryant, B. R. (2016). How to find good apps: An evaluation rubric for instructional apps for teaching students with learning disabilities. *Intervention in School and Clinic, 51*(4), 244–252. https://doi.org/10.1177/105345121558917

Oksanen, K., Lainema, T., & Hämäläinen, R. (2017). Learning from Social Collaboration: A Paradigm Shift in Evaluating Game-Based Learning. In R. Zheng & M. Gardner (Eds.), *Handbook of Research on Serious Games for Educational Applications* (pp. 41-65). IGI Global. https://doi.org/10.4018/978-1-5225-0513-6.ch003.

Olney, I., Herrington, J. & Verenikina, I. (2008) *iPods in early childhood: Mobile technologies and storytelling.* In: Proceedings ASCILITE 2008 - Hello! Where are you in the Landscape of Educational Technology? Melbourne, Australia pp. 696-700.

Ormrod, J. E. (1995). *Educational psychology: Principles and applications.* Merrill.

Osburn, H. G. (2000). Coefficient alpha and related internal consistency reliability coefficients. *Psychological Methods, 5*(3), 343–355. https://doi.org/10.1037/1082-989X.5.3.343

Outhwaite, L. A., Faulder, M., Gulliford, A., & Pitchford, N. J. (2019). Raising early achievement in math with interactive apps: A randomized control trial. *Journal of Educational Psychology, 111*(2), 284. https://doi.org/10.1037/edu0000286

Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2017). Closing the gap: Efficacy of a tablet intervention to support the development of early mathematical skills in UK primary school children. *Computers & Education, 108*, 43-58. https://doi.org/10.1016/j.compedu.2017.01.011

Ozgur, H. (2020). Relationships between teachers' technostress, technological pedagogical content knowledge (TPACK), school support and demographic variables: A structural equation modeling. *Computers in Human Behavior, 112,* 106468. https://doi.org/10.1016/j.chb.2020.106468

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction, 1*(2), 117–175. https://doi.org/10.1207/s1532690xci0102_1

Pan, Y., & Ke, F. (2023). Effects of game-based learning supports on students' math performance and perceived game flow. *Educational Technology Research and Development*, 1-21. https://doi.org/10.1007/s11423-022-10183-z

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018). The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece. *Education and Information Technologies, 23*(5), 1849–1871. https://doi.org/10.1007/s10639-018-9693-7

Papastergiou, M. (2009). Exploring the potential of computer and video games for health and physical education: A literature review. *Computers & Education, 53*(3), 603-622. https://doi.org/10.1016/j.compedu.2009.04.001

Pata, K., Sarapuu, T., & Lehtinen, E. (2005). Tutor scaffolding styles of dilemma solving in network-based role-play. *Learning and Instruction, 15*(6), 571-587. https://doi.org/10.1016/j.learninstruc.2005.08.002

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *The Journal of the Learning Sciences, 13*(3), 423–451. https://doi.org/10.1207/s15327809jls1303_6

Pedersen, S., & Liu, M. (2002). The transfer of problem-solving skills from a problem-based learning environment. *Journal of Research on Technology in Education, 35*(2), 303–320. https://doi.org/10.1080/15391523.2002.10782388

Pei-Wen, T., Jennifer, I. O. P. L., Chien-Hui, Y., & Vivian, H. H. C. (2012). Reconceptualizing pedagogical usability of and teachers' roles in computer game-based learning in school. *Educational Research and Reviews, 7*(20), 419-429. https://doi.org/10.5897/ERR11.072

Pentimonti, J. M., & Justice, L. M. (2010). Teachers' use of scaffolding strategies during read alouds in the preschool classroom. *Early Childhood Education Journal, 37*(4), 241–248. https://doi.org/10.1007/s10643-009-0348-6

Perini, S., Luglietti, R., Margoudi, M., Oliveira, M., & Taisch, M. (2018). Learning and motivational effects of digital game-based learning (DGBL) for manufacturing education–The Life Cycle Assessment (LCA) game. *Computers in Industry, 102*, 40-49. https://doi.org/10.1016/j.compind.2018.08.005

Peterson, R. A., & Kim, Y. (2013). On the relationship between coefficient alpha and composite reliability. *Journal of Applied Psychology, 98,* 194 –198. http://dx.doi.org/10.1037/a0030767

Pifarre, M., & Cobos, R. (2010). Promoting metacognitive skills through peer scaffolding in a CSCL environment. *International Journal of Computer-Supported Collaborative Learning, 5*(2), 237–253. https://doi.org/10.1007/s11412-010-9084-6

Pitchford, N. J. (2015). Development of early mathematical skills with a tablet intervention: A randomized control trial in Malawi. *Frontiers in Psychology, 6*, 485. https://doi.org/10.3389/fpsyg.2015.00485

Plass, J. L., O'Keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., et al. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology, 105*(4), 1050. https://doi.org/10.1037/a0032688

Prensky, M. (2001). Digital Natives, Digital Immigrants Part 1. *On the Horizon, (9)*5,1-6. https://doi.org/10.1108/10748120110424816

Puntambekar, S., & Hübscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist, 40*(1), 1–12. https://doi.org/10.1207/s15326985ep4001_1

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching, 42*(2), 185–217. https://doi.org/10.1002/tea.20048

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*(3), 337–386. https://doi.org/10.1207/s15327809jls1303_4

Raphael, L. M., Pressley, M., & Mohan, L. (2008). Engaging instruction in middle school classrooms: An observational study of nine teachers. *Elementary School Journal, 109*(1), 61–81. https://doi.org/10.1086/592367

Reiser, B. J., & Tabak, I. (2014). Scaffolding. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 44-62). Cambridge University Press.https://doi.org/10.1017/CBO9781139519526.005

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning sciences*, *13*(3), 273-304. https://doi.org/10.1207/s15327809jls1303_2

Riconscente, M. M. (2013). Results from a controlled study of the iPad fractions game Motion Math. *Games and Culture, 8*(4), 186–214. https://doi.org/10.1177/15554120134968

Rideout, V., & Robb, M. B. (2019). *The Common sense census: Media use by tweens and teens, 2019.* San Francisco: Common Sense Media. Retrieved March 30, 2023, from https://www. commonsensemedia.org/sites/default/files/uploads/research/2019-census-8-to-18-key-findings-updated.pdf.

Rienties, B., Giesbers, B., Tempelaar, D., Lygo-Baker, S., Segers, M., & Gijselaers, W. (2012). The role of scaffolding and motivation in CSCL. *Computers & Education, 59(*3), 893-906. https://doi.org/10.1016/j.compedu.2012.04.010

Rikkers, W., Lawrence, D., Hafekost, J., & Zubrick, S. R. (2016). Internet use and electronic gaming by children and adolescents with emotional and behavioural problems in

Australia – results from the second Child and Adolescent Survey of Mental Health and Wellbeing. *BMC Public Health, 16*, 1-16. https://doi.org/10.1186/s12889-016-3058-1

Ringle, C. M., Wende, S., & Becker, J. M. (2015). SmartPLS 3. Bonningstedt: SmartPLS. Retrieved from https://www.smartpls.com/

Rittle-Johnson, B. (2006). Promoting transfer: effects of self-explanation and direct instruction. *Child Development, 77,* 1–15. doi:10.1111/j.1467-8624.2006.00852.x.

Rittle-Johnson, B. (2017). Developing mathematics knowledge. *Child Development Perspectives, 11*(3), 184–190. https://doi.org/10.1111/cdep.12229

Rittle-Johnson, B., & Siegler, R. S. (1998). The relation between conceptual and procedural knowledge in learning mathematics: A review. In C. Donlan (Ed.), *The development of mathematical skills* (pp. 75–110). London: Psychology Press.

Rittle-Johnson, B., Schneider, M., & Star, J. R. (2015). Not a one-way street: Bidirectional relations between procedural and conceptual knowledge of mathematics. *Educational Psychology Review, 27*(4), 587–597. https://doi.org/10.1007/s10648-015-9302-x

Rittle-Johnson, B., Siegler, R. S., & Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: an iterative process. *Journal of Educational Psychology, 93,* 346–362. doi:10.1037//0022-0663.93.2.346.

Rittle-Johnson, B., Siegler, R. S., & Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: An iterative process. *Journal of Educational Psychology, 93*(2), 346–362. https://doi.org/10.1037/0022-0663.93.2.346

Rubens, W., Emans, B., Leinonen, T., Skarmeta, A. G., & Simons, R.-J. (2005). Design of web-based collaborative learning environments. Translating the pedagogical learning principles to human computer interface. *Computers & Education, 45*(3), 276–294. https://doi.org/10.1016/j.compedu.2005.04.008

Rutherford, T., Farkas, G., Duncan, G., Burchinal, M., Kibrick, M., Graham, J., et al. (2014). A randomized trial of an elementary school mathematics software intervention: Spatial-temporal math. *Journal of Research on Educational Effectiveness, 7*(4), 358–383. https://doi.org/10.1080/19345747.2013.856978

Şahin, F., Doğan, E., İlic, U., & Şahin, Y. L. (2021). Factors influencing instructors' intentions to use information technologies in higher education amid the pandemic. *Education and Information Technologies*, *26*, 4795-4820. https://doi.org/10.1007/s10639-021-10497-0

Sánchez-Mena, A., Martí-Parreño, J., & Aldás-Manzano, J. (2017). The Effect of Age on Teachers' Intention to Use Educational Video Games: A TAM Approach. *Electronic Journal of E-Learning*, *15*(4), 355-366.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*(3), 345–372. https://doi.org/10.1002/sce.10130

Sarstedt, M., Hair Jr, J. F., Cheah, J. H., Becker, J. M., & Ringle, C. M. (2019). How to specify, estimate, and validate higher-order constructs in PLS-SEM. *Australasian Marketing Journal, 27*(3), 197-211. https://doi.org/10.1016/j.ausmj.2019.05.003

Saxena, M. (2010). Reconceptualising teachers' directive and supportive scaffolding in bilingual classrooms within the neo-Vygotskyan approach. *Journal of Applied Linguistics & Professional Practice*, *7*(2), 163-184.

Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development, 50*(3), 77–96. https://doi.org/10.1007/bf02505026

Schacter, J., Shih, J., Allen, C. M., DeVaul, L., Adkins, A. B., Ito, T., et al. (2016). Math shelf: A randomized trial of a prekindergarten tablet number sense curriculum. *Early Education & Development, 27*(1), 74–88. https://doi.org/10.1080/10409289.2015.1057462

Scherer, R., Siddiq, F., & Tondeur, J. (2020). All the same or different? Revisiting measures of teachers' technology acceptance. *Computers & Education, 143*, 103656. https://doi.org/10.1016/j.compedu.2019.103656

Schwarz, N. (2007). Cognitive aspects of survey methodology. Applied Cognitive Psychology: *The Official Journal of the Society for Applied Research in Memory and Cognition, 21*(2), 277-287. https://doi.org/10.1002/acp.1340

Segars, A. H., & Grover, V. (1998). Strategic information systems planning success: an investigation of the construct and its measurement. *MIS quarterly*, 139-163. https://doi.org/10.2307/249393

Shaffer, D. W., Squire, K. R., Halverson, R., & Gee, J. P. (2005). Video games and the future of learning. *Phi Delta Kappan, 87(*2), 105-111. https://doi.org/10.1177/003172170508700205

Shah, M. (2019). Scaffolding and Assessing Teachers' Examination of Games for Teaching and Learning. *Game-based assessment revisited*, 185-210.

Shah, M. & Foster, A. (2015). Developing and assessing teachers' knowledge of game-based learning. *Journal of Technology and Teacher Education, 23*(2), 241-267. https://www.learntechlib.org/primary/p/147391/.

Shamon, H., & Berning, C. C. (2020). Attention Check Items and Instructions in Online Surveys with Incentivized and Non-Incentivized Samples: Boon or Bane for Data Quality? *Survey Research Methods, 14*(1), 55-77. DOI/10.18148/srm/2020.v14i1.7374

Sharma, P., & Hannafin, M. J. (2007). Scaffolding in technology-enhanced learning environments. *Interactive Learning Environments, 15*(1), 27-46. https://doi.org/10.1080/10494820600996972

Sherin, B., Reiser, B. J., & Edelson, D. (2004). Scaffolding analysis: Extending the scaffolding metaphor to learning artifacts. *Journal of the Learning Sciences, 13*(3), 387–421. https://doi.org/10.1207/s15327809jls1303_5

Shin, N., Sutherland, L. M., Norris, C. A., & Soloway, E. (2012). Effects of game technology on elementary student learning in mathematics. *British Journal of Educational Technology, 43(*4), 540–560. https://doi.org/10.1111/j.1467-8535.2011.01197.x

Shute, V. J., D'Mello, S., Baker, R., Cho, K., Bosch, N., Ocumpaugh, J., Ventura., Matthew & Almeda, V. (2015). Modeling how incoming knowledge, persistence, affective states, and in-game progress influence student learning from an educational game. *Computers & Education*, *86*, 224-235. https://doi.org/10.1016/j.compedu.2015.08.001

Shute, V. J., & Ke, F. (2012). Games, learning, and assessment. In *Assessment in Game-Based Learning* (pp. 43–58). New York: Springer.

Shute, V., Rahimi, S., Smith, G., Ke, F., Almond, R., Dai, C. P., Kuba, R., Liu, Z.,Yang, X., & Sun, C. (2021). Maximizing learning without sacrificing the fun: Stealth assessment, adaptivity and learning supports in educational games. *Journal of Computer Assisted Learning*, *37*(1), 127-141. https://doi.org/10.1111/jcal.12473

Shute, V. J., & Zapata-Rivera, D. (2008). Adaptive technologies. In J. M. Spector, M. D. Merrill, J. J. G. van Merriënboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communication and technology* (3rd ed., pp. 277–294). New York, NY: Taylor and Francis.

Silliman, E. R., Bahr, R., Beasman, J., & Wilkinson, L. C. (2000). Scaffolds for learning to read in an inclusion classroom. *Language, Speech, and Hearing Services in Schools*, *31*(3), 265-279.

Silliman, E., & Wilkinson, L. C. (1994). Discourse scaffolds for classroom intervention. In *Language Learning Disabilities in School-Age Children and Adolescents*, ed. G. Wallach and K. Butler. New York: Pearson Higher Education.

Silseth, K. (2012). The multivoicedness of game play: Exploring the unfolding of a student's learning trajectory in a gaming context at school. *International Journal of Computer-Supported Collaborative Learning,* 7, 63-84. https://doi.org/10.1007/s11412-011-9132-x

Simms, L. J. (2008). Classical and modern methods of psychological scale construction. *Social and Personality Psychology Compass, 2*(1), 414-433. https://doi.org/10.1111/j.1751-9004.2007.00044.x

Smith, B. K., & Reiser, B. J. (2005). Explaining behavior through observational investigation and theory articulation. *The Journal of the Learning Sciences, 14*(3), 315-360. https://doi.org/10.1207/s15327809jls1403_1

Soper, D. (2018) A-Priori sample size calculator for structural equation models [Software].

Soper, D. S. (2021). A-priori sample size calculator for structural equation models [Software]. https://www. danielsoper.com/statcalc

Spencer-Smith, G., & Hardman, J. (2014). The impact of computer and mathematics software usage on performance of school leavers in the Western Cape Province of South Africa: a comparative analysis. *International Journal of Education and Development using ICT*, *10*(1).

Spires, H. A. (2015). Digital game-based learning. *Journal of Adolescent & Adult Literacy, 59*(2), 125–130. https://doi.org/10.1002/jaal.424

Stegenga, J. (2011). Is meta-analysis the platinum standard of evidence? *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences, 42*(4), 497-507. https://doi.org/10.1016/j.shpsc.2011.07.003

Stieler-Hunt, C., & Jones, C. M. (2015). Educators who believe: understanding the enthusiasm of teachers who use digital games in the classroom. *Research in Learning Technology,* 23. https://doi.org/10.3402/rlt.v23.26155

Stone, C. A. (1998). The metaphor of scaffolding: Its utility for the field of learning disabilities. *Journal of Learning Disabilities, 31*(4), 344-364. https://doi.org/10.1177/002221949803100404

Stright, A. D., Herr, M. Y., & Neitzel, C. (2009). Maternal scaffolding of children's problem solving and children's adjustment in kindergarten: Hmong families in the United States. *Journal of Educational Psychology, 101*(1), 207–218. doi:10.1037/a0013154

Su, Y., & Klein, J. (2010). Using scaffolds in problem-based hypermedia. *Journal of Educational Multimedia and Hypermedia*, *19*(3), 327-347.

Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction, 28*, 100457. https://doi.org/10.1016/j.lcsi.2020.100457

Sung, H.-Y., & Hwang, G.-J. (2013). A collaborative game-based learning approach to improving students' learning performance in science courses. *Computers & Education, 63,* 43–51. https://doi.org/10.1016/j.compedu.2012.11.019

Tabak, I. (2004). Synergy: A complement to emerging patterns of distributed scaffolding. The Journal of the Learning Sciences, 13(3), 305–335. https://doi.org/10.1207/s15327809jls1303_3

Tabak, I., & Kyza, E. A. (2018). Research on scaffolding in the learning sciences: A methodological perspective. In *International Handbook of the Learning Sciences* (pp. 191-200). Routledge.

Takeuchi, L. M., & Vaala, S. (2014). Level up Learning: A National Survey on Teaching with Digital Games. In *Joan Ganz Cooney Center at Sesame Workshop.*

Tay, J., Goh, Y. M., Safiena, S., & Bound, H. (2022). Designing digital game-based learning for professional upskilling: A systematic literature review. *Computers & Education,* 104518. https://doi.org/10.1016/j.compedu.2022.104518

Tenenhaus, M., Vinzi, V. E., Chatelin, Y. M., & Lauro, C. (2005). PLS path modeling. *Computational Statistics & Data analysis, 48*(1), 159-205. https://doi.org/10.1016/j.csda.2004.03.005

Tobias, S. E., & Fletcher, J. D. (2011). *Computer games and instruction*. IAP Information Age Publishing.

Tobias, S., Fletcher, J. D., & Wind, A. P. (2013). Game-based learning. In J. M. Spector, M. D. Merrill, J. Elen & M. J. Bishop (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 485–503). Springer, New York, NY. https://doi.org/10.1007/97-1-4614-3185-5_38

Tobin, G. A., & Begley, C. M. (2004). Methodological rigour within a qualitative framework. *Journal of Advanced Nursing, 48*(4), 388-396. https://doi.org/10.1111/j.1365-2648.2004.03207.x

Tokarieva, A. V., Volkova, N. P., Harkusha, I. V., & Soloviev, V. N. (2019). Educational digital games: models and implementation. *Educational Dimension, 1,* 5-26. https://doi.org/10.31812/educdim.v53i1.3872

Tourangeau, R., Rips, L. J., & Rasinski, K. (2000). *The psychology of survey response*. Cambridge: Cambridge University Press

Troussas, C., Krouska, A., & Sgouropoulou, C. (2020). Collaboration and fuzzy-modeled personalization for mobile game-based learning in higher education. *Computers & Education, 144*, 103698. https://doi.org/10.1016/j.compedu.2019.103698

Tzuo, P.-W., Ling, J. I. O. P., Yang, C.-H., & Chen, V. H.-H. (2012). Reconceptualizing pedagogical usability of and teachers' roles in computer game-based learning in school. *Educational Research and Reviews,7*, 419–429. DOI: 10.5897/ERR11.072

Urbach, N., & Ahlemann, F. (2010). Structural equation modeling in information systems research using partial least squares. *Journal of Information Technology Theory and Application (JITTA)*, *11*(2), 2.

Ustunel, H. H., & Tokel, S. T. (2018). Distributed scaffolding: Synergy in technology-enhanced learning environments. *Technology, Knowledge, and Learning, 23*(1), 129–160. https://doi.org/10.1007/s10758-017-9299-y

Valdez, A., Trujillo, K., & Wiburg, K. (2013). Math Snacks: Using animations and games to fill the gaps in mathematics. *Journal of Curriculum and Teaching, 2*(2), 154–161. http://dx.doi.org/10.5430/jct.v2n2p154

van Aalst, J., & Truong, M. S. (2011). Promoting knowledge creation discourse in an asian primary five classrooms: Results from an inquiry into life cycles. *International Journal of Science Education, 33*(4), 487–515. https://doi.org/10.1080/09500691003649656

Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review, 22*, 271-296. https://doi.org/10.1007/s10648-010-9127-6

van den Heuvel-Panhuizen, M., Kolovou, A., & Robitzsch, A. (2013). Primary school students' strategies in early algebra problem solving supported by an online game. *Educational Studies in Mathematics, 84*(3), 281–307. https://doi.org/10.1007/s10649-013-9483-5

van der Ven, F., Segers, E., Takashima, A., & Verhoeven, L. (2017). Effects of a tablet game intervention on simple addition and subtraction fluency in first graders. *Computers in Human Behavior, 72*, 200–207. https://doi.org/10.1016/j.chb.2017.02.031

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *EDUCAUSE review, 41*(2), 16.

Vandercruysse, S., & Elen, J. (2016). Towards a game-based learning instructional design model focusing on integration. *Instructional Techniques to Facilitate Learning and Motivation of Serious Games* (pp. 17-35). doi:10.1007/978-3-319-39298-1_2.

Vandercruysse, S., Vandewaetere, M., Cornillie, F., & Clarebout, G. (2013). Competition and students' perceptions in a game-based language learning environment. *Educational Technology Research and Development, 61*(6), 927-950. https://doi.org/10.1007/s11423-013-9314-5

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist, 46(*4), 197–221. https://doi.org/10.1080/00461520.2011.611369

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge–a review of the literature. *Journal of Computer Assisted Learning, 29*(2), 109-121. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Vygotsky, L. S. (1986). *Thought and Language. (A.Kozulin, Ed.)* Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind in society: Development of higher psychological processes.* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.) Cambridge, MA: Harvard University Press.

Waiyakoon, S., Khlaisang, J., & Koraneekij, P. (2015). Development of an instructional learning object design model for tablets using game-based learning with scaffolding to enhance mathematical concepts for mathematic learning disability students. *Procedia-Social and Behavioral Sciences, 174*, 1489-1496. https://doi.org/10.1016/j.sbspro.2015.01.779

Wang, S. Y., Chang, S. C., Hwang, G. J., & Chen, P. Y. (2018). A microworld-based role-playing game development approach to engaging students in interactive, enjoyable, and effective mathematics learning. *Interactive Learning Environments, 26*(3), 411–423. https://doi.org/10.1080/10494820.2017.1337038

Ward Jr, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association*, *58*(301), 236-244.

Wasko, M. M., & Faraj, S. (2005). Why should I share? Examining social capital and knowledge contribution in electronic networks of practice. *MIS quarterly,* 35-57. https://doi.org/10.2307/25148667

Watson, W. R., Mong, C. J., & Harris, C. A. (2011). A case study of the in-class use of a video game for teaching high school history. *Computers & Education, 56*(2), 466-474. https://doi.org/10.1016/j.compedu.2010.09.007

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind.* Cambridge, MA: Harvard University Press.

Westland, J. C. (2010). Lower bounds on sample size in structural equation modeling. *Electronic Commerce Research and Applications, 9*(6), 476–487. https://doi.org/10.1016/j.elerap.2010.07.003

Wiburg, K., Chamberlin, B., Valdez, A., Trujillo, K., & Stanford, T. (2016). Impact of Math Snacks games on students' conceptual understanding. *Journal of Computers in Mathematics and Science Teaching, 35*(2), 173–193. https://eric.ed.gov/?id=EJ1095367

Williamson, B. (2009). *Computer games, schools, and young people: A report for educators on using games for learning*. Bristol: Futurelab.

Wilson, C. D., Reichsman, F., Mutch-Jones, K., Gardner, A., Marchi, L., Kowalski, S., Lord, T., & Dorsey, C. (2018). Teacher implementation and the impact of game-based science curriculum materials. *Journal of Science Education and Technology, 27*, 285–305. https://doi.org/10.1007/s10956-017-9724-y

Wood, D., & Middleton, D. (1975). A study of assisted problem-solving. *British Journal of Psychology, 66(*2), 181-191. https://doi.org/10.1111/j.2044-8295.1975.tb01454.x

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wood, D., Wood, H., & Middleton, D. (1978). An experimental evaluation of four face-to-face teaching strategies. *International Journal of Behavioral Development, 1*(2), 131-147. https://doi.org/10.1177/016502547800100203

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60 (*1), 412–425. https://doi.org/10.1016/j.compedu.2012.07.018

Wouters, P., Van Nimwegen, C., Van Oostendorp, H., & Van Der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*(2), 249. https://doi.org/10.1037/a0031311

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching, 38*(7), 821-842. https://doi.org/10.1002/tea.1033

Wu, W. H., Chiou, W. B., Kao, H. Y., Hu, C. H. A., & Huang, S. H. (2012). Re-exploring game-assisted learning research: The perspective of learning theoretical bases.

Computers & Education, 59(4), 1153–1161. https://doi.org/10.1016/j.compedu.2012.05.003

Wu, W. H., Hsiao, H. C., Wu, P. L., Lin, C. H., & Huang, S. H. (2012). Investigating the learning-theory foundations of game-based learning: A meta-analysis. *Journal of Computer Assisted Learning, 28*(3), 265–279. https://doi.org/10.1111/j.1365-2729.2011.00437.x

Wu, Y.-T., & Anderson, O. R. (2015). Technology-enhanced stem (science, technology, engineering, and mathematics) education. *Journal of Computers in Education, 2*(3), 245–249. https://doi.org/10.1007/s40692-015-0041-2

Yang, K.-H., Chu, H.-C., & Chiang, L.-Y. (2018). Effects of a progressive prompting-based educational game on second graders' mathematics learning performance and behavioral patterns. *Educational Technology & Society, 21*(2), 322–334. https://drive.google.com/file/d/1US7WBesZnvT8Qh_NCSl7yGdtDPn-kFMz/view

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. https://doi.org/10.1186/s41039-019-0100-9

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–89. https://doi.org/10.3102/0034654312436980

Yu, F. Y., Tsai, H. C., & Wu, H. L. (2013). Effects of online procedural scaffolds and the timing of scaffolding provision on elementary Taiwanese students' question-generation in a science class. *Australasian Journal of Educational Technology, 29*(3). https://doi.org/10.14742/ajet.197

Yu, Z., Gao, M., & Wang, L. (2021). The effect of educational games on learning outcomes, student motivation, engagement and satisfaction. *Journal of Educational Computing Research, 59*(3), 522–546. https://doi.org/10.1177/0735633120969214

Appendix A (Manuscript 1 materials)

Summary of the search process with Prisma Flow Diagram

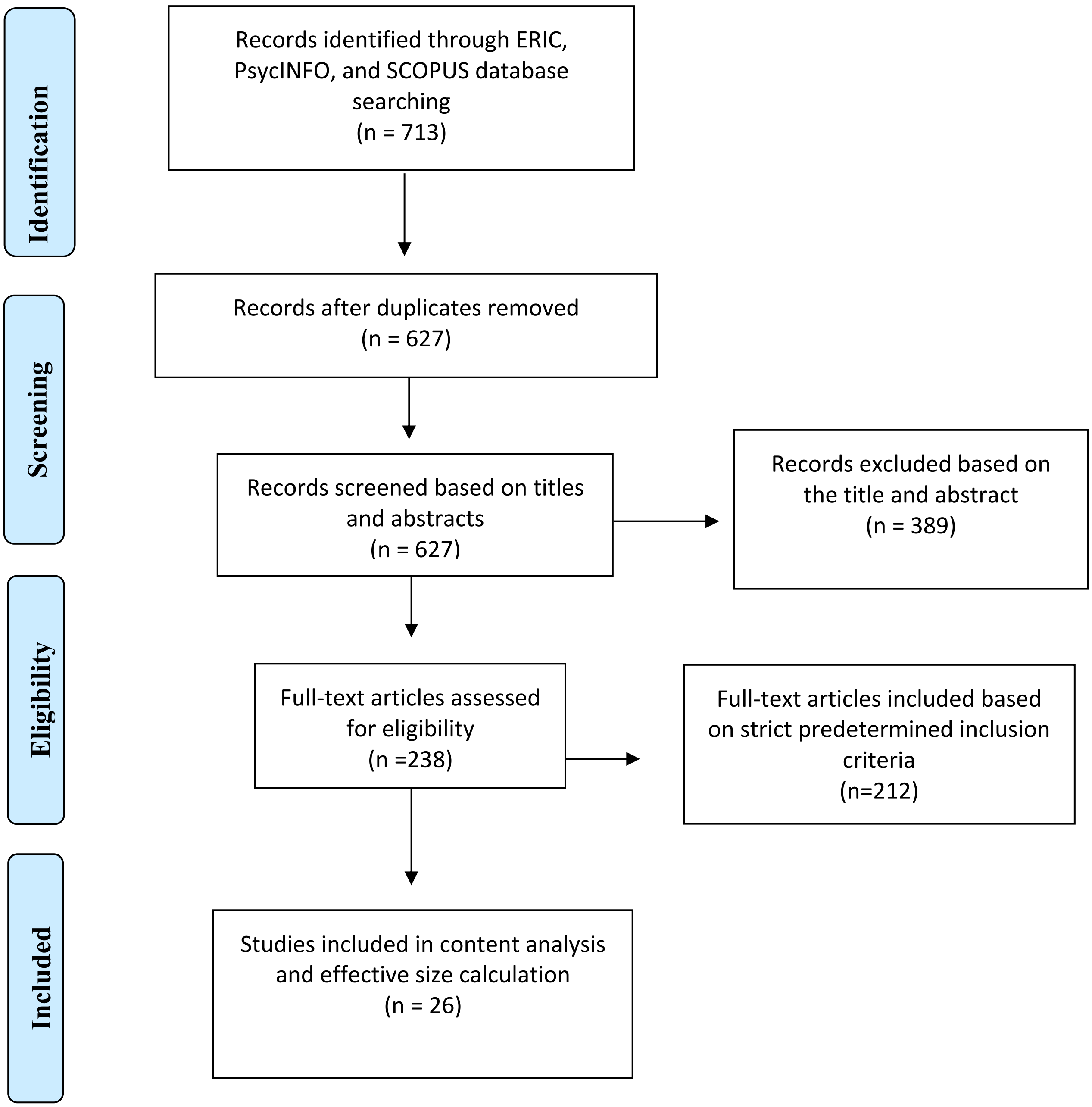


Table 1

Direct Instruction Games' Sub-Groups, Individual Outcomes and Effect Sizes, Overall Effect Size of the Study, Relative Weights of Studies in Each Study, and Summary Effect Size of the Approach

Types of Math Knowledge	Study	Sub-Groups	Outcome Measures	Effect Size	Overall Effect Size	Relative Weight
Factual Knowledge	Plass et al. 2013	*Fear Factor* Game Intervention Group	Math Fluency	0.341	0.341	10.88
	Foster and Shah 2015	*Dimension M* Game Intervention Group	Knowledge of Algebra, Roots and Numbers	1.033	1.033	7.97
	Besserra et al. 2017	Group 1: Multiple Choice Math Game	Knowledge of Arithmetic	0.701	1.047	9.41
		Group 2: Fine-Grained Multiple-Choice Game Group		1.428		
	O'Rourke et al. 2017	*Dr Kawashima's Brain* Training Game Intervention Group	Basic Number Facts	0.389	0.389	10.96
	Van der Ven et al. 2017	Tablet Game Intervention Group	Accuracy on Arabic Digits in Addition	0.462	0.343	9.63
			Accuracy on Arabic Digits in Subtraction	0.172		
			Accuracy on Arabic Dots in Addition	0.257		
			Accuracy on Dots in Subtraction	0.452		
			Efficiency on Arabic Digits in Addition	0.338		
			Efficiency on Arabic Digits in Subtraction	0.297		
			Efficiency on Arabic Dots in Addition	0.306		
			Efficiency on Dots in Subtraction	0.461		
Factual & Conceptual Knowledge	Outhwaite et al. 2017	Group 2: 13-week Game Intervention Group	Math Concepts	1.862	1.052	11.03
			Math Curriculum Knowledge	1.518		
		Group 3: 13-week Game Intervention Group -low achievers	Math Concepts	1.421		
			Math Curriculum Knowledge	1.945		
	Outhwaite et al. 2019	Group 1: Game Intervention Group	Fluency in Facts	0.081	0.048	11.67
			Fluency in Concepts	0.042		
			Math reasoning	0.055		
			Problem Solving	0.060		

		Group 2: Time-equivalent Game Intervention Group	Fluency in Facts	0.011		
			Fluency in Concepts	0.020		
			Math reasoning	0.094		
			Problem Solving	0.023		
	Pitchford 2015	Group 1: Standard Math Tablet *One Billion* Game Intervention Group	Math Curriculum Knowledge	0.132	0.637	10.95
			Math Concepts	0.302		
		Group 2: Standard Math Tablet *One Billion* Intervention Group	Math Curriculum Knowledge	1.090		
			Math Concepts	0.619		
		Group 3: Standard Math Tablet *One Billion* Intervention Group	Math Curriculum Knowledge	1.683		
			Math Concepts	0.159		
Factual & Procedural Knowledge	Shin et al. 2012	*Skills Arena* Game Intervention Group	Basic Arithmetic Operations	0.136	0.278	7.03
			Advanced Arithmetic Operations	0.419		
Factual, Procedural & Conceptual Knowledge	Maertans et al. 2016	Group 1: *Comparison* Game Group	Give a number (% correct)	0.011	0.050	10.48
			Connecting (% correct)	0.387		
			Non-symbolic comparison (% correct)	0.275		
			Symbolic comparison (%correct)	0.589		
			Non-symbolic NLE	0.356		
			Symbolic NLE	-0.187		
			Arithmetic Problems	0.173		
			Addition Operations	0.125		
		Group 2: *Number Line* Game Group	Give a number (% correct)	0.275		
			Connecting (% correct)	0.211		
			Non-symbolic comparison (% correct)	-0.052		
			Symbolic comparison (%correct)	0.340		
			Non-symbolic NLE	-0.778		
			Symbolic NLE	-1.069		
			Arithmetic Problems	0.097		
			Addition Operations	0.004		
Summary effect size					0.510	

Table 2

Experiential Learning' Games' Sub-Groups, Individual Outcomes and Effect Sizes, Overall Effect Size of the Study, Relative Weights of Studies in Each Study, and Summary Effect Size of the Approach

	Study	Sub-Groups	Outcome Measures	Effect Size	Overall Effect Size	Relative Weight
Conceptual Knowledge	Bai et al. 2012	*Dimension M* Game Intervention Group	Algebra Concepts	0.739	0.739	15.44
	Rutherford et al. 2014	Group 1: *ST Math Game* Cohort 1	Math Proficiency	0.076	0.106	17.13
		Group 2: *ST Math Game* Cohort 2		0.172		
	McLaren et al. 2017	*Decimal Point* Game Intervention Group	Knowledge of Decimals	0.838	0.838	12.97
	Papadakis et al. 2018	Group 1: Computer-based Game Intervention Group	Math Ability	0.079	0.185	15.67
		Group 2: Tablet-based Game Intervention Group		0.298		
Procedural & Conceptual Knowledge	Ke 2019	*E Rebuild* Game Intervention Group	Problem Solving Skills	0.975	0.668	9.14
			Mental Rotation	0.362		
Factual, Procedural & Conceptual Knowledge	Kebritchi et al. 2010	*Dimension M* Game Intervention Group	Knowledge of Pre-Algebra and Algebra	0.847	0.847	13.56
	Bakker et al. 2015	Group 1: Grade 2 Math Tablet Games Intervention Group	Knowledge Test	0.037	0.225	16.09
			Skills Test	0.231		
			Insight Test	0.007		
		Group 2: Grade 3 Math Tablet Games Intervention Group	Knowledge Test	0.242		
			Skills Test	0.058		
			Insight Test	0.00		
Summary effect size					0.461	

Table 3

Discovery Learning Games' Sub-Groups, Individual Outcomes and Effect Sizes, Overall Effect Size of the Study, Relative Weights of Studies in Each Study, and Summary Effect Size of Approach

Types of Math Knowledge	Study	Sub-Groups	Outcome Measures	Effect Size	Overall Effect Size	Relative Weight
Procedural & Conceptual Knowledge	Van Den Heuvel-Panhuiz et al. 2013	Group 1: *Hit the Target* Grade 5 Game Intervention	Early Algebra Knowledge	0.285	0.378	35.14
		Group 2: *Hit the Target* Grade 6 Game Intervention		0.302		
		Group 3: *Hit the Target* Grade 6 Game Intervention		0.544		
	Yeh et al. 2019	Math Island Game Intervention Group	Arithmetic Operations	0.362	0.288	28.69
			Conceptual Understanding	0.069		
			World-Problem Solving	0.433		
Factual & Procedural Knowledge	Brezovszky et al. 2019	Group 1: *Number Navigation* Grade 4 Game Intervention Group	Arithmetic Fluency	0.262	0.057	36.17
			Correct Solutions	0.189		
			Multi operational solutions	0.017		
			Pre-Algebra Knowledge	- 0.599		
		Group 2: *Number Navigation* Grade 5 Game Intervention Group	Arithmetic Fluency	0.076		
			Correct Solutions	0.024		
			Multi operational solutions	0.048		
			Pre-Algebra Knowledge	0.000		
		Group 3: *Number Navigation* Grade 6 Game Intervention Group	Arithmetic Fluency	0.128		
			Correct Solutions	0.167		
			Multi operational solutions	0.012		
			Pre-Algebra Knowledge	0.166		
Summary effect size					0.735	

Table 4

Constructivist Games' Sub-Groups, Individual Outcomes and Effect Sizes, Overall Effect Size of the Study, Relative Weights of Studies in Each Study, and Summary Effect Size of Approach

Types of Math Knowledge	Study	Sub-Groups	Outcome Measures	Effect Size	Overall Effect Size	Relative Weight
Conceptual Knowledge	Valdez et al. 2013	Group 1: *Math Snacks* Grade 6 Game Intervention Group	Number Line, Ratio and Proportion Concepts	0.049	0.053	38.49
		Group 2: *Math Snacks* Grade 7 Game Intervention Group		0.062		
	Wiburg et al. 2016	*Math Snacks* Game Intervention Group	Ratios, Fractions and Decimals	0.290	0.290	45.04
	Wang et al. 2018	*Speedy World* Game Intervention Group	Conceptions of Speed	0.346	0.346	16.47
Summary effect size					0.208	

Table 5

Unclassified/Other Games' Sub-Groups, Individual Outcomes and Effect Sizes, Overall Effect Size of the Study, Relative Weights of Studies in Each Study, and Summary Effect Size of Approach

Types of Math Knowledge	Ped. Approaches	Study	Sub-Groups	Outcome Measures	Effect Size	Overall Effect Size	Relative Weight
Conceptual Knowledge	Embodied Cognition	Risconscente 2013	Group 1: *Motion Math* Schools 1 Game Intervention	Fractions	0.158	0.196	27.88
			Group 2: *Motion Math* Schools 2 Game Intervention		0.235		
	Not Clear	Chang et al. 2015	Group 1: *The Math App* Grade 6 Game Intervention	Fractions and Measurement	0.056	0.321	34.61
			Group 2: *The Math App* Grade 7 Game Intervention		0.483		
			Group 3: *The Math App* Grade 8 Game Intervention		0.233		
	Montessori Approach	Schacter 2016	*Math Shelf* Game Intervention Group	Number Sense	0.739	0.739	37.51

Appendixes B (Manuscript 2 materials)

Figure 1

Six-dimension TSQ-GBL (Model 1)' Outer Loadings, Path Coefficients, and r^2 Results

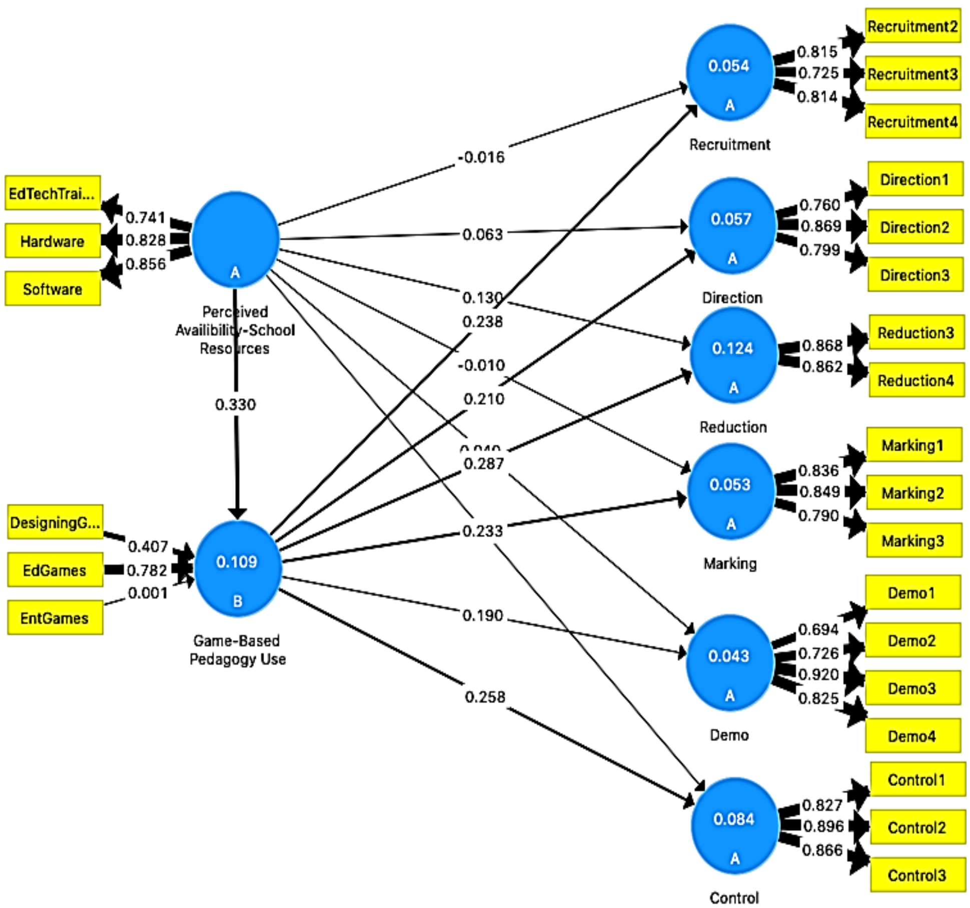


Figure 2

Three-dimension TSQ-GBL (Model 2)' Outer Loadings, Path Coefficients, and r^2 Results

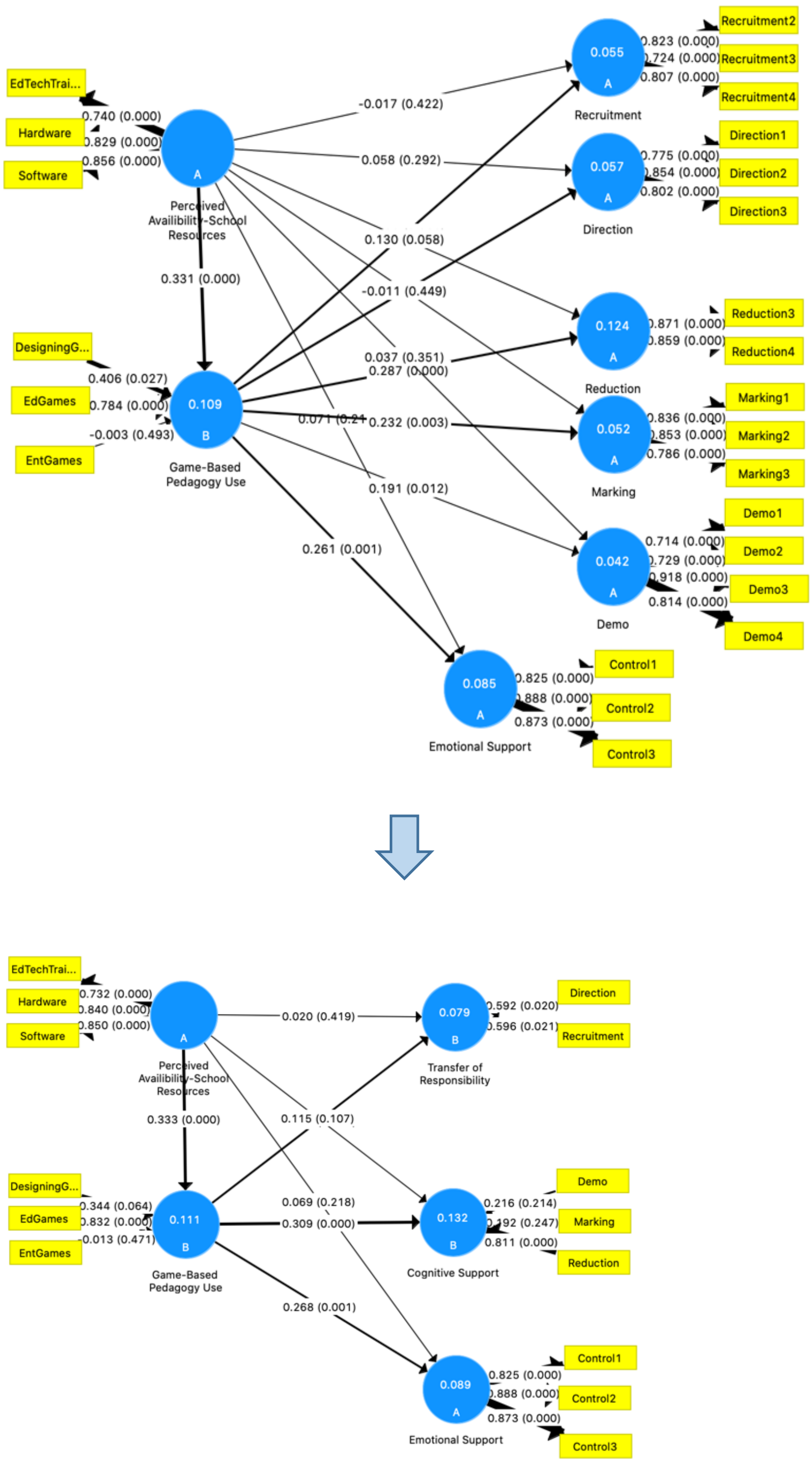
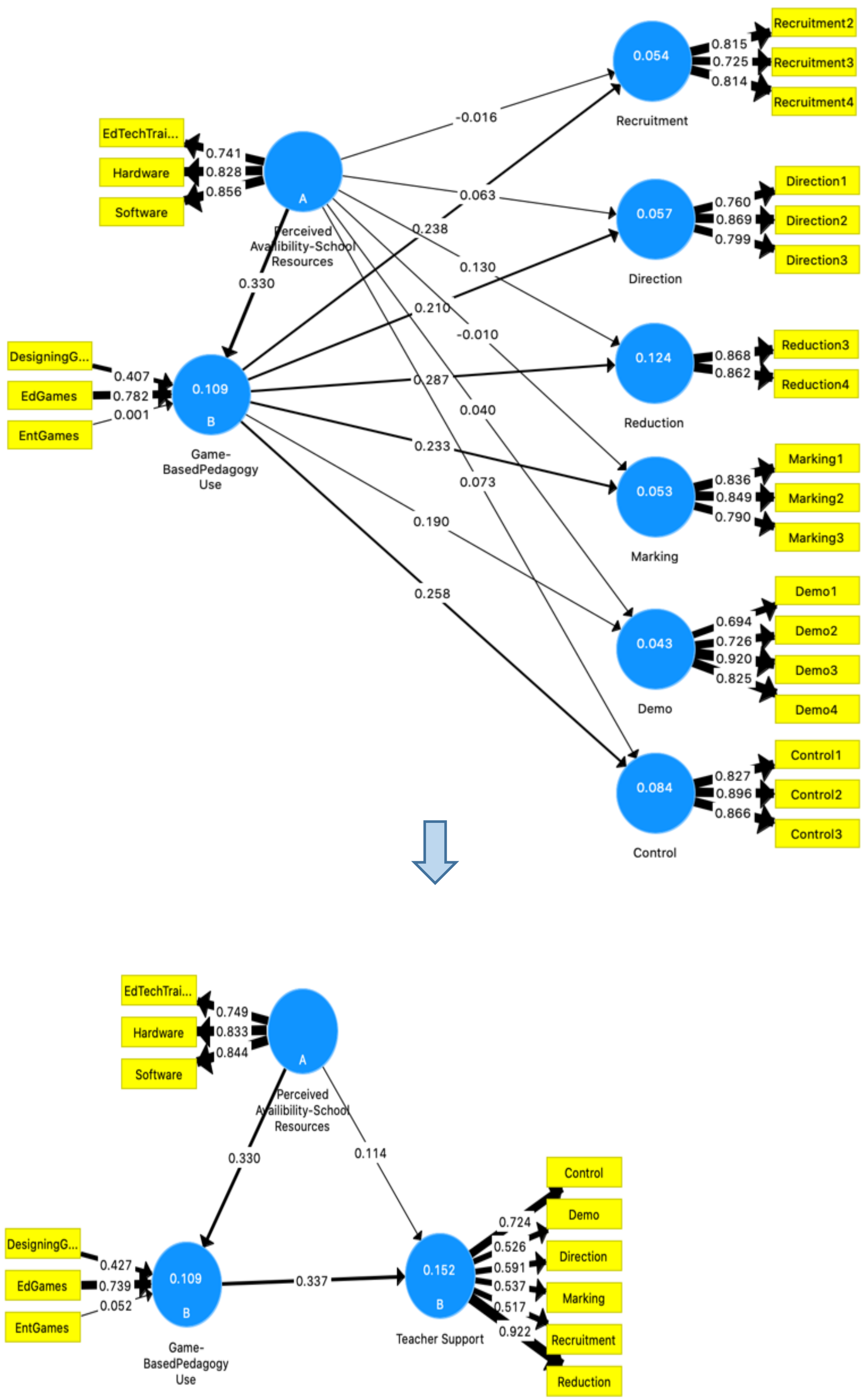


Figure 3

Single/uni-dimension TSQ-GBL (Model 3)' Outer Loadings, Path Coefficients, and r^2 Results



Appendixes C (Manuscript 3 materials)

TPACK-G

Game Knowledge

1. I can learn digital learning games easily.
2. I have the technical skills to play (most) digital learning games effectively.
3. I can quickly understand the rules while playing digital learning games.
4. I can familiarize myself with the game interface.

Game Content Knowledge

1. I can identify whether the subject knowledge is applied in digital learning games.
2. I can identify whether the core concepts of the subject matter knowledge are displayed in the digital learning games.
3. I can tell whether the digital learning games represent the targeted subject knowledge.

Game Pedagogical Knowledge

1. I know how to select appropriate digital learning games according to my students' learning process or needs.
2. I know how to use the characteristics of digital learning games to support teaching.
3. I know the relevant instructional strategies of digital learning games.
4. I know how to integrate digital learning games into my teaching.

Technological, Pedagogical, and Content Knowledge-Games

1. I can use appropriate digital learning games to display the subject I teach.
2. I know how to extract essential information in digital learning games to enhance teaching.

3. I know how to use digital learning games to help students achieve learning objectives in multiple ways.
4. I can select digital learning games to use in my classroom that enhances what I teach, how I teach and what students learn.
5. I can teach lessons that combine the subject I teach, the methods (scaffolding practices) I use to teach, and digital learning games.

TSQ-GBL

Cognitive Support

Reduction

1. I make the gameplay easier by explaining the difficulty levels clearly
2. I clarify complex game rules/concepts by breaking or dividing them into small pieces.
3. I help students by setting small and concrete goals, such as completing certain levels.
4. I give students extra time so they can master complex game concepts or levels.

Marking

1. I highlight key game design features, game rules or elements in the game.
2. I underline key learning content or concepts in the game.
3. I stress recognizing and linking crucial information during gameplay.

Demo

1. I explicitly demonstrate how to play the game step-by-step.
2. I explicitly explain the key learning concepts/tasks involved in the game.
3. I explicitly explain or demonstrate game rules or additional gameplay strategies.
4. I explicitly show students each game feature/elements that provide help on complex levels.

Transfer of Responsibility

Recruitment

1. Before students start playing the game in class, I explain the game's learning goals to get them ready and interested to learn.
2. Before students start playing the game in class, I explain the game rules to get them ready and interested to learn.

Direction

1. I provide reminder prompts to students to keep them on task.
2. I provide confirmation prompts that students are heading in the right direction during gameplay to sustain their attention on the task.
3. I ask questions to my students to focus on their learning process.

Emotional Support

Control

1. When students get frustrated with the game, I help by providing gameplay suggestions or strategies.
2. When students get frustrated in the game, I help by providing learning suggestions or strategies.
3. When students get frustrated with the game, I help by providing emotional support or strategies.