Paper Title A Systematic Review of Data Collection and Analysis Methods in K–12 Educational Games

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Session Title Looking Back to Move Forward: Reviews on Advanced Technologies for Learning (Table 5)

Session Type Roundtable Presentation

Presentation Date 4/14/2024

Presentation Location Philadelphia, Pennsylvania

Descriptors Computers and Learning, Data Analysis, Video Games

Methodology Conceptual/Theoretical

Unit SIG-Advanced Technologies for Learning

DOI https://doi.org/10.3102/2110403

A Systematic Review of Data Collection and Analysis Methods in K-12 Educational Games

Abstract: This paper reports on systematic literature review that examined learning theories and data collection and analysis methods used to study game-based learning in research on educational digital games for K-12 populations. Through electronic database, hand, and ancestral searches, we identified 25 empirical studies (29 educational games) published in peer-review journals that report evidence of how students learn through in-game and out-of-game data collection and analysis methods. Taking an approach to game-based learning as identity-driven and situated, we found that while games do not take such an approach to game-based learning, games tend to collect data on players' social interactions and collaborative experiences. The review also highlighted the opportunity for providing real-time feedback and data to players during gameplay.

1. Objectives

Educational digital games for K-12 learners provide dynamic and engaging disciplinary learning experiences (Inocencio et al., 2018), fostering knowledge and skill development and influencing attitudes (Petri & von Wangenheim, 2016). For K-12 students well-chosen educational games can be highly beneficial. However, researchers must convincingly demonstrate the learning outcomes achieved by students through gameplay (Petri & von Wangenheim, 2017).

Properly gathered and analyzed data is crucial in evaluating the impact of digital educational games and gaming environments (Dehghanzadeh et al., 2023; Novia et al., 2021). It provides valuable insights into students' learning processes, engagement, and performance within game-based learning environments (Alonso-Fernández et al., 2019a; Wang et al., 2021). However, despite existing literature on gamification and evaluating educational games (Dehghanzadeh et al., 2023; Inocencio et al., 2018; Novia et al., 2021; Petri & von Wangenhelm, 2017; Alonso-Fernández et al., 2019a), the use of data and analysis as evidence for students' learning and engagement in educational games remains underexplored. Particularly, there is a need to synthesize the best approaches to analyze gameplay data, especially in multiplayer, collaborative games targeting diverse, minoritized youth.

Currently, we are designing a multiplayer digital game for middle youth to learn data science through interactions with the game's context and generated data. Our interest lies in exploring how other games and designers use data to enhance players' learning experiences in the game world. Therefore, the primary objective of this systematic literature review is to delve into the utilization of in-game and out-of-game data collection and analysis methods in understanding players' engagement and learning in educational games. Our research questions are:

RQ1. What learning theories do researchers use to analyze learning in games? Have any taken a situative approach to game design?

RQ2: How are researchers collecting and analyzing game data to study game-based learning?

2. A Situated Approach to Game-based Learning

Traditional approaches in game design for learning often blend behaviorist, cognitivist, and constructivist elements to create engaging educational experiences (Plass et al., 2015). However, our research team takes a different perspective towards game-based learning as situated in context (Greeno, 1998) and identity-driven (Gee, 2000). Situated learning in games involves active engagement with the game's context, often in a community of practice (Lave & Wenger, 1991) of other players, and the development and application of knowledge in problem-solving and real-world scenarios. An approach to game-based learning as identity-driven recognizes the diverse problem-solving roles that players take on and the enactment of various identities through practices with material and ideational resources to aid them in solving in-game problems (Nasir, 2002).

This review extends previous work by investigating empirical studies on integrating educational games and measuring gameplay performance and learning outcomes. Existing reviews highlight in-game data collection and analysis methods but have not identified suitable technologies for evaluating learning through engagement and participation. We broaden the scope by including non-academic disciplines for K-12 students, such as life skills, emergency rescue, and self-protection. Additionally, we focus on researcher-designed and pre-existing educational games, ensuring a consistent analysis of gameplay data and chosen methods.

3. Methods and Data Sources

3.1 Search

In this literature review, we followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) to guide the literature review. Fig. 1 provides an overview of the study search and article eligibility/selection procedures. We used the terms "educational game," "data," "data analysis," "collaborative," "game and learning," "game analytics," "logfile," and "engagement" to search for articles with full-text access in the databases ERIC, IEEE, and ACM. The initial search yielded 731 articles, which underwent deduplication, resulting in 452 remaining articles.

This literature review included articles that met the following criteria: (1) participants within K-12 educational settings or games targeting K-12 students, (2) focused on electronic games (excluding physical games or those requiring specialized technology like AR/VR), (3) related to researcher-designed educational games or the use of pre-existing games for educational purposes, (4) empirical and related to game data analysis or learning outcomes, and (5) written in English.

After reviewing the 452 remaining articles, we excluded articles for the following reasons: published before 2013 (23 articles), unrelated to the topic (250 articles), participants not within the K-12 educational setting or games not targeting K-12 students (33 articles), and studies that were not empirical (100 articles). This resulted in 46 articles, for which we downloaded the full articles for further review and coding.

Furthermore, we conducted an ancestral search of the reference lists from seven prior reviews of gamification learning. Additionally, Google Scholar was utilized to identify additional relevant items. A total of 76 potential articles were identified. We excluded articles unrelated to the topic (23 articles), participants not within the K-12 educational setting or games not targeting K-12 students (17 articles), educational games involving additional devices (eight articles), educational games that were not digital (seven articles), commercial non-educational games (two articles), studies not in English (six articles), and duplicate studies (eight articles).

Additionally, we manually searched specific journals where educational game studies are published (*Games Learning and Society, Games and Culture, Games: Research and Practice, Computers and Education,* and *British Journal of Educational Technology*). From the 17 articles found, we excluded articles without K-12 participants or that did not target K-12 students (five articles) and unrelated to the topic (four articles). Thus, we added 10 articles for further review.

From the 61 articles that were thoroughly analyzed we excluded articles for the following reasons: not related to the topic (11 articles), participants not in K-12 (7 articles), educational games involving additional devices (two articles), not empirical studies (9 articles), or duplicate studies (7 articles). Ultimately, 25 articles met all the criteria and were included in this review.

3.2 Coding

We coded 25 full-text articles based on study characteristics (author, year of publication, country origin), participants (grade, N, local, and any other demographic description provided), data (gameplay duration, type of data collected, type of methods used to analyze data), and game characteristics (description of the educational game, including disciplinary content and game type [e.g., multiplayer or single-player, gameworld], learning theory, how researchers report on or use evidence of players' learning). Although the research team has carefully discussed the findings, additional rounds of coding by team members and the calculation of an interrater to be sure where the reliability scores are in progress.

4. Findings

In Table 1, we present individual study descriptions for the 25 studies (29 educational games) included in this review. Studies are listed alphabetically, and descriptive information for each study includes: (a) authors and year published, (b) the name of the educational games, (c) the thematic content of the educational games, (d) number of participants, (e) participants' grade level and (f) the evidence of players' learning.

The review covered various countries and educational game content, such as science, math, language, art, and life skills. Participants' ages ranged from elementary to high school, including learners with disabilities. In-game data collection methods involved task completion time, gameplay duration, and interactions with game elements, including collaboration with non-player characters. Statistical, quantitative, and qualitative analysis provided insights into players' in-game performance and learning patterns, often compared with out-of-game data collected through interviews and pre-post content assessments.

However, of the papers we found, games were primarily single-player games or evaluated as single-player games and used in school settings, with gameplay sections lasting 15 to 50 minutes. Studies and games did not attend to player identities (i.e., report on demographic variables) and did not show learners the in-game data (something that is of particular interest to the research team in designing a data science game). However, many of the games in our review collected data to evaluate participation in social interactions.

4.1 RQ1 Findings (Learning Theories)

Regarding learning theories, we found that researchers primarily use behaviorist and cognitive views of learning. None of the studies using gameplay analytics took a situative view of learning. However,

Two studies (Monterrat et al., 2017; Westera et al., 2014) focus on behaviorism, evaluating players' behavior change and strategy adjustments after facing challenges.

Five studies incorporated cognitivist elements, measuring students' cognitive growth through pre-test and post-test assessments (Khan et al., 2017; Alonso-Fernandez et al., 2019). Additionally, two studies validated players' cognitive process using task completion time data (Gonzalez-Arroyo et al., 2022; Alonso-Fernandez et al., 2019), while one study used thematic analysis to visualize cognitive processing (Barcomb et al., 2020).

Most games used a constructivist approach, emphasizing social interaction and collaborative learning experiences. Seventeen studies demonstrated players' improvement after game implementation. Nine studies used thematic analysis on interview data to highlight learning through collaboration and problem-solving. Sixteen studies analyzed in-game data to examine collaborative problem-solving interactions, fostering collective understanding among students. Twelve studies used pre- and post-tests to evaluate attitude change related to collaborative learning experiences and social interactions on students' learning and attitude towards game content.

4.2 RQ2. Data Collection and Analysis Methods to Study Game-Based Learning

Five studies in this review focus on in-game data collection, tracking gameplay duration, analyzing overall task completion time, tracking each task completion time, seeking assistance, and studying students' interactions with game elements.(Alonso-Fernandez et al., 2019; Kang et al., 2017; Serrano-Laguna et al., 2014; Gonzalez-Arroyo et al., 2022). Researchers use statistical analysis to evaluate players' in-game performance, identify learning patterns, and assess their application of real-life knowledge to solve in-game challenges, providing valuable insights into how players apply their knowledge in practice.(Alonso-Fernandez et al., 2019; Kang et al., 2017).

Additionally, researchers use quantitative and qualitative analysis to interpret players' attitudes and learning outcomes through out-of-game data. Interviews and thematic analysis capture players' responses, while pre & post-tests evaluated content understanding and improvements

(Slattery et al., 2023; Haruna et al., 2018; Gonzalez et al., 2014). Video observation and web-based qualitative analysis explore emotions and in-game strategy discussions (Khan et al., 2017; Gonzalez et al., 2014), while questionnaires with quantitative analysis summarize player feedback (Haruna et al., 2018; Arias et al., 2016).

By combining in-game and out-of-game data, researchers gained insights into players' gameplay, understanding of game design, and learning outcomes. Eighteen studies in this review merged in-game performance with out-of-game assessments or analysis of videos of out-of-game performance. Integrating in-game and out-of-game data analysis helped map connections between players' in-game performance and evidence of learning outcomes for content goals as measured by pretest and posttest comparisons, providing deeper insights and strategies to enhance students' educational game experiences.

5. Significance

This review highlights the need for educational games that approach learning from a situated, community of practice perspective and emphasize gameplay to build a community of players. Additionally, there is a notable gap in addressing the learning needs of minoritized populations in educational games. Most studies in our review did not report on demographic identities, and only one study focused on making the game engaging for both boys and girls based on their performance. Incorporating players' identities as a part of game data collection and analysis could open new understandings of game-based learning experiences, which could be used to make games more inclusive and engaging for all learners. Approaches to game-based learning that seek to foster communities of practice and engage player identities are necessary to build inclusive gaming experiences that empower players from diverse backgrounds and promote a sense of belonging.

Another significant finding from this review is the limited use of in-game data visualization and real-time feedback during gameplay. Providing players with in-game data can offer new ways for players to learn in context (Wilkerson & Polman, 2020). Access to players' own game data can facilitate reflection on their learning, supporting new forms of collaboration, progress tracking, and timely assistance when facing challenges. Our review suggests directions for collecting and analyzing in-game and out-of-game data to study situated learning: in-game performance, interactions, collaboration data, and pre & posttests data. These methods can inform the development of future educational games to enhance the gameplay experience and promote a deeper understanding of the game's content.

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Fig. 1. PRISMA flow diagram
Note. Adapted from Moher, Liberati, Tetzlaff, Altman, and PrismaGroup. (2009).

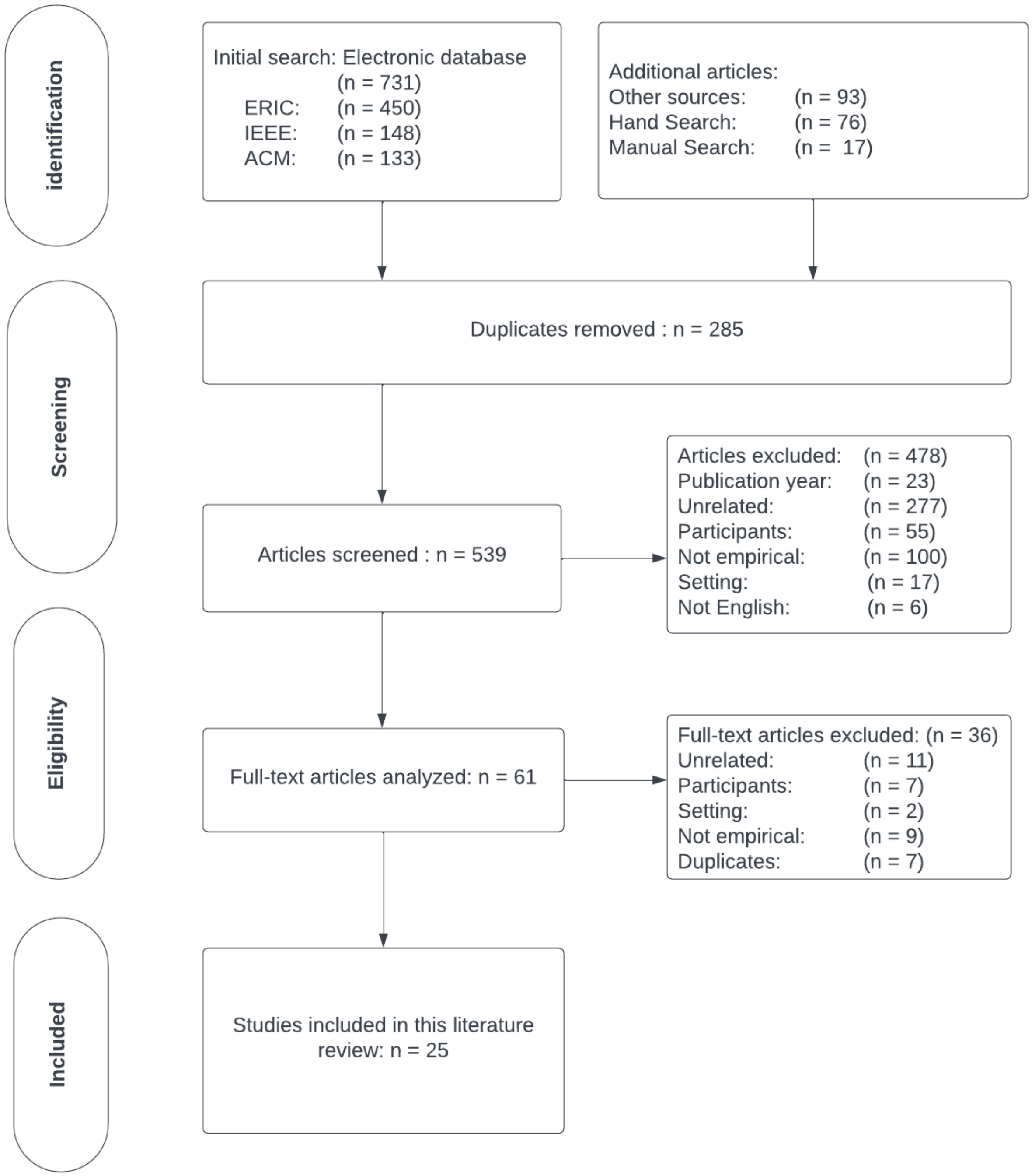

Table 1

Individual study descriptions

Study	Game Title	Game content	N	Grade	Data	Evidence of players learning
(Alonso-Fernandez et al., 2019)	Conectado	Mental health- increase bully and cyberbullying awareness	257	High school	In game & Out game	Post-test scores show an improved understanding of bullying and cyberbullying, correlated with game completion time, proving the effectiveness.
	Downtown	Life skill-training for players with intellectual disabilities	51	Adult	In game	The improved gameplay, from the initial to the final section, reveals enhanced understanding and strategic thinking skills fostered by players.
	First Aid Game	Physical health- instruct in cardiopulmonary resuscitation (CPR)	227	High school	In game & Out game	Post-test improvement, correlated with player interaction data, shows profound CPR understanding and practical application in students.
(Anderson et al., 2018)	Virulent	Biology - understanding the life cycle of a virus	84	4 to 9	In game & Out game	Students adeptly tackle in-game challenges independently or through peer discussions, applying acquired knowledge to real-life problem-solving.
(Arias et al., 2016)	Business Simulation Game	Business - practice business management and economics in simulation games with 33 different simulations	990	11 and 12	Out game	Students' higher post-test scores and increased confidence in real-time problem-solving demonstrate practical knowledge application. Collaborative group dynamics enrich learning.
(Barcomb et	Moodle	English - help	11	8 and 9	In	The students' improvement

al., 2020)	based English learning	players increase their accuracy in English pronunciation			game & Out game	in the pre-test to post-test and perceptions showcases enhanced word pronunciation understanding. Compelling evidence of active cognitive processing and practical application.
(Cicchino et al., 2015)	French and Indian War	History - understand the French and Indian War	600	6 to 8	Out game	Players' relevant intellectual activities show their understanding of historical context and their critical thinking, enhancing strategic gameplay. .
(Gonzalez et al., 2014)	Massively Multiplayer Online Role-Playing Game for Hospitalized children	Collaboration - Facilitating collaboration for hospitalized students in-game communication.	2	5 and 6	Out game	Post-test improvement and interactive problem-solving demonstrate progress in collaboration skills, fostering teamwork among players.
(Gonzalez-Arroyo et al., 2022)	Platform / Adventure game on math	Math- solve math questions practically	1	3	In game	Players' game completion and advanced performance align with the prediction model, indicating their understanding and practical application of math.
(Gresalfi et al., 2015)	Quest Atlantis	Math - learning math through engaging with non-player characters and solving quests.	19 (1st year) 22 (2nd year)	4 to 6	In game & Out game	Students skillfully analyze problems, utilize hints, and collaborate with group members to solve game tasks
(Hamari et al., 2016)	Quantum Spectre	Physics - puzzle-style game requires players to solve quests using physics	134	11	In game & Out game	The game's engaging nature positively impacts learning; students effectively apply class knowledge to solve in-game challenges.

	Spumone	Physics -. Students apply the game strategies based on course content	40	undergraduate	In game & Out game	Game engagement positively impacts learning; students apply class knowledge to solve challenges effectively, fostering their learning experiences.
(Haruna et al., 2018)	Adolescent sexual health education	Health - digital health game on Adolescent Sexual Health Literacy and how to improve students' understanding of sexual health behavior	120	6 to 10	Out game	Student's improvement in pre-test and post-test scores demonstrates enhanced content understanding through the game. The shift in attitudes towards sexual education showcases how the game fosters comfortable discussions and collaborations.
(Hulse et al., 2019)	From here to there! (FH2T)	Math - perceptual based interventions to introduce foundational algebraic concepts	185	elementary	In game & Out game	Students in the gamified learning environment demonstrate better math understanding than non-gamified students. Their effective application of knowledge in practical questions highlights cognitive processing.
(Hursen et al., 2019)	ClassDojo	Science - solve the puzzle for science problems using students' native language	16	4	In game & Out game	The students' and parents' positive attitude towards science gamification underscores effective learning and practical application. The game fosters a strong connection between classroom and real-world understanding, enhancing engagement and science comprehension.
(Kang et al., 2017)	Alien Rescue	Physics - problem-solving on quests using physics	202	6	In game	Students' interactions with in-game tools and sequential learning patterns show adeptness in critical thinking and

						problem-solving.
(Ke et al., 2014)	Scratch - based math design game	Math- foster positive mathematics dispositions and mathematics thinking	64	middle	In game & Out game	Students' positive attitude, enjoyment, and improved reasoning show enthusiasm for mathematics through gamification.
(Kerr et al., 2015)	Save Patch	Math - the understanding of fraction	62	6	In game & Out game	Students' reduced irrelevant behavior and faster question-solving in revisits indicate their understanding of fractions.
(Khan et al., 2017)	Patterns of Reactivity	Science- using videos and animation to help students understand and apply metal in real-time scenarios.	72	8	Out game	Through gamification, students enjoy the game while gaining a profound understanding and collaborating effectively.
(Kinnebrew et al., 2017)	SURGE Next	Physics - understanding the concepts of physics	68	8	In game & Out game	Gameplay behavior correlates with strategic planning and learning gains, showing students' adequate physics comprehension and critical thinking.
(Klimova et al.,2021)	Minecraft Education	Computer Science- understanding the concepts of programming	94	5 to 9	In game & Out game	Students' knowledge improvement after using Minecraft Education, particularly in subtopics like Loops, highlights compelling learning experiences.
(Monterrat et al., 2017)	Projet Voltaire	French- online learning environment to practice French spelling and grammatical	59	8 and 9	In game & Out game	Players utilize in-game characteristics, collaborate, and leverage strengths to solve challenges. The game fosters strategic thinking and teamwork, creating an engaging

		rules.				learning experience.
(Moon et al., 2020)	E-Rebuild	Math - 3D architecture game that allows players to construct a structure based on the given design requests and limited resources	32	6 to 8	In game & Out game	Most students' peer interactions are game-related, actively applying mathematical understanding to practical tasks.
(Nand et al., 2016)	JQuizShow	Math- In game the participants are offered cash prizes for correctly answering a series of multiple-choice questions as difficulties increase.	120	4 and 5	In game & Out game	Students' remarkable improvement in learning demonstrates their understanding of applying math knowledge independently and collaboratively.
(Rowe et al., 2017)	Zoombinis	Computer Science - award-winning game on computational thinking through solving puzzles.	80	Elementary and middle	In game & Out game	Students' gameplay behavior shows their deep understanding of computational thinking, problem-solving, and systematic testing, effectively tackling challenges.
(Serrano-Laguna et al., 2014)	The big Party	Life skill - teach persons with physical disabilities, habits, and daily skills in real life.	19	adult	In game	The stage trace highlights the improvement in player completion and time-performance correlation.
	Lost in	Programming-	37	Not	In	A high completion rate and

	Space <XML>	learn basic XML and DTD concepts		mention	game	students' improvement in question-solving with the instructor help show their understanding of concepts.
(Slattery et al., 2023)	Minecraft Education	Problem solving - players use building blocks to solve the challenge at each level.	173	3 to 7	Out game	Students' positive attitude towards using Minecraft for learning and problem-solving demonstrates their practical application of acquired knowledge and collaborative nature.
(Westera et al., 2014)	VIBOA environmental policy game	Science - solve environmental problems in an academic and methodological way	118	master	In game & Out game	Enhancing game behavior fosters engaging interactions, leading to successful solution exchanges among players.