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Review Article

Exploring Educational User Engagement: A Systematic Mapping of Serious Games with Gesture-based Interaction

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ABSTRACT

Integrating serious games in educational settings has emerged as a promising approach to enhance learning experiences. In serious games, gesture-based interactions, such as motion sensors and wearable devices, enhance intuitiveness and engagement. The lack of standardisation in educational user engagement evaluation methods for serious games and gesture-based interaction has been highlighted in multiple studies. Most standardisation splits the dimensions, complicating the evaluation process. A systematic mapping study was conducted to address this issue, examining serious games and gesture-based interaction in education from 2018 to 2024 across five electronic databases. Despite wide interest among authors, there has been a limited systematic effort to define the concepts. This paper contributes by identifying elements used in serious games and gesture-based interaction for education, analysing research approaches and contributions, and proposing design criteria for evaluating educational prototypes based on user engagement. The study addresses differing opinions among authors and suggests solutions to unify concepts related to user engagement. The paper recommends several guidelines for serious games and gesture-based interaction in education, along with instruments to enhance user engagement.

Keywords: Education, gesture-based interaction, serious games, user engagement

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INTRODUCTION

One of the current challenges in transferring educational materials to elementary school students is developing teaching methods

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that enhance engagement with both games and educational content. Traditional classroom teaching methods, manually conducted by teachers, persist in schools and often fail to cater to students with diverse learning styles and the study approaches of the new generation. Consequently, there is an urgent need for greater implementation of various technologies and available media channels to address this issue effectively.

User engagement is one of the most prominent qualities in digital games and human-computer interaction that deals with user behaviour. Studies on learning engagement have gained growing attention from academicians around the globe, but the focus has been limited, with engagement often viewed as a subcategory of motivation (Mazlan et al., 2019). In education, student engagement is a multifaceted construct that is often considered complex, encompassing three primary components, which are behavioural, emotional, and cognitive dimensions (Dubey et al., 2023).

Serious games are believed to bring enjoyment to learning activities and sessions, allowing users to engage and have an optimal learning experience (Castellano et al., 2021). A serious game can deliver optimal practice opportunities to individual learners, thereby potentially precluding the onset of boredom. These games have become a valuable platform in both commercial and academic settings, enriching learning through their design and development (Mohd et al., 2018). A serious game designed for both academic and commercial purposes could stimulate business management scenarios, engaging users in realistic challenges like financial planning and marketing strategies with immediate feedback. In an academic context, such a game could be used to complement traditional coursework, offering practical application of theoretical concepts dynamically and engagingly. Researchers are particularly interested in serious games because their characteristics can motivate, engage, and educate players, depending on the domain design (Johnson et al., 2017). Morganti et al. (2017) pointed out that serious games are often applied in three key areas to support energy efficiency efforts, which were environmental education, raising awareness and lastly encouraging environmentally friendly behaviours.

Gesture-based interaction with technology in education refers to a method where users interact with digital devices and applications through physical gestures rather than traditional input methods like keyboards or mice. This interaction utilises natural user interfaces (NUIs) such as motion sensors, cameras, or wearable devices to detect and interpret gestures made by the user's body movements or hand motions. In educational contexts, gesture-based interaction enhances engagement by providing a more intuitive and immersive learning experience. It can be employed in various educational applications, from virtual classrooms to interactive learning environments, fostering active participation and facilitating the acquisition of knowledge and skills through interactive and responsive technology. Technology is instrumental to online education and can provide many benefits, such as student engagement, when implemented in the educational realm (Torres et al., 2021).

In general, the use of technology and specialised hardware, both online and offline, offers an alternative to conventional learning methods, especially in contexts requiring social interaction restrictions, such as during the COVID-19 pandemic. This approach helps prevent boredom and ensures safe learning. Since the lockdown era of COVID-19, particularly in Malaysia, educational methods have increasingly become technology-based.

In recent years, systematic mapping has been broadly used by some researchers because the nature of the study can help researchers understand in more detail the connection of concepts used in their related study. According to Fernandez et al. (2011) A systematic mapping study offers a structured way to explore what research has been done on a specific topic, helping to highlight existing gaps and understand the scope of available studies.

This paper is organised into five main sections, corresponding to the research question. The first section discusses the related work on serious games with gesture-based interaction about education and user engagement. In the second section, the research methodology outlines the systematic mapping process. Meanwhile, the third section analyses the results from data extraction and study mapping. The fourth section is a discussion that builds on previous work to address the challenge of mapping questionnaires for children's education and introducing tools and instruments for measuring user engagement. Finally, the last section of the paper delves into the summary of the scientific contributions. This article aggregates publications from five popular database engines in research by covering works from 2018 to 2024.

RELATED WORK

In the modern era, the use of technology has significantly influenced various fields, with games gaining rapid popularity among researchers for their potential in education, training, and cognitive development. Games enable learners to simulate and experience real-life environments, enhancing cognitive understanding through user control. Research demonstrates that the power of games is their capacity for engagement, replayability, fun, enjoyment, cooperative social mechanics, etc. (Anvari et al., 2024; Brockmyer et al., 2009). Serious games, designed to achieve specific learning outcomes, make learning fun and engaging while fostering essential skills and knowledge. According to Katsaliaki and Mustafee (2012), serious games effectively promote knowledge acquisition and problem-solving skills, often outperforming traditional methods in terms of performance and retention. In education, serious games enhance teaching and learning experiences by creating engaging, interactive learning opportunities. They can supplement traditional teaching methods, offering students additional ways to engage with the subject matter. Wong et al. (2020) found that game-based approaches effectively capture children’s attention and sustain their interest, proving to be more effective than traditional methods. Serious games provide individualised practice without boredom, a challenge for conventional instruction methods (Ronimus et al., 2019).

Additionally, virtual reality in serious games aids in recalling outcomes, understanding skills, and visually recognising components (Checa et al., 2021). However, there is a need for frameworks and guidelines to effectively design and present educational materials through serious games.

Virtual reality serious games, for instance, have the potential to enhance student learning and satisfaction by offering a deeper understanding of the subject matter (Checa et al., 2021). The study conducted by Torres et al. (2021) effectively adapted virtual simulations and serious games for mental health education. Their approach involved presenting scenarios from a first-person perspective, enabling learners to freely navigate 3D environments using mouse or camera control buttons within the user interface. This research also demonstrated the capability to create realistic training scenarios, including opportunities for psychomotor skills development. Similarly, Johnson-Glenberg et al. (2020) utilised virtual simulation serious games in STEM education learning.

Gesture-based interaction utilises the physical movements of the hands, fingers, or other body parts to engage with digital devices and systems. This approach harnesses natural human gestures to create a more intuitive and seamless method for controlling and communicating with technology. It often involves touchless interfaces, allowing users to issue commands through hand movements. The diversity of interfaces used in gesture-based interaction introduces the use of multimodal interaction. Multimodal interaction, as described by Nigay and Coutaz (1993), enables users to employ various modalities, such as voice, gesture, and typing, to communicate with a computer. Besides, some of the gesture-based interactions use a modern ubiquitous approach. In modern ubiquitous environments, interaction incorporates hands-free and eyes-free input from different body parts. For example, the waist, the largest joint in the human body, can be actively controlled (Xu et al., 2021). Our hands, being highly expressive, are particularly effective for interacting with our environment (Khalaf et al., 2019). Notable gesture devices include Leap Motion, Microsoft's Kinect, and Intel's RealSense. Hand gestures have been explored in various educational contexts, such as interacting with jigsaw games and computational thinking concepts (Rubegni et al., 2022) and road safety education (Wan Husain et al., 2022). However, there has been limited exploration of user engagement and metrics in educational interactions. Technology plays a crucial role in online education and can significantly enhance student engagement when effectively implemented (Torres et al., 2021).

User engagement is one of the most prominent qualities in digital games and human-computer interaction that deals with user behaviour. Research indicates that some authors prefer using consistent dimensions for measuring user engagement, often overlooking alternative perspectives. Despite this reason, the discussion of the user engagement dimensions will be useful in helping the researchers to focus on suitable dimensions to be implemented in their research within the respective domain and field that they want to focus. In this paper, the dimensions of user engagement measurement will be discussed in detail.

RESEARCH METHODOLOGY

In this section, the systematic mapping study (SMS) includes the definition of research questions, conduct of search, screening of papers, keywording of abstracts, data extraction and mapping of the study as illustrated in Figure 1 (Ya'u et al., 2019).

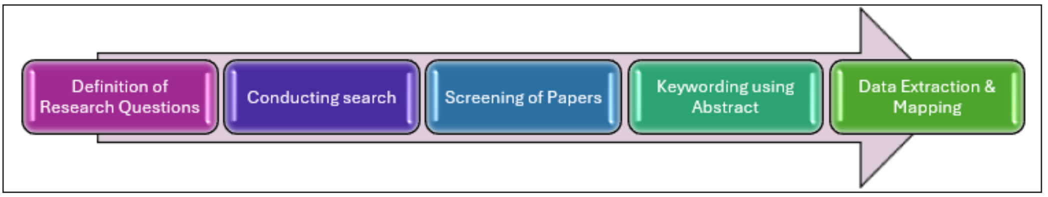


Figure 1. Systematic mapping process

Definition of Research Questions

In conducting the research, the research questions and objectives play important roles in constructing the analysis phase and the knowledge improvement flow. This SMS paper aims to answer the following questions:

RQ1 : What elements are used in serious games and gesture-based interaction for education?

RQ2 : What research approaches and contributions have the selected papers implemented (e.g. framework, method, tool)?

RQ3 : Which design criteria in serious games and gesture-based interaction are used to evaluate the education prototype and applications based on user engagement?

Conducting Search

According to Gusenbauer and Haddaway (2020), 14 databases can be used as principal search systems: ACM Digital Library, BASE, ClinicalTrials.gov, Cochrane Library, EbscoHost, OVID, ProQuest, PubMed, ScienceDirect, Scopus, TRID, Virtual Health Library, Web of Science, and Wiley Online Library. The research process for this paper was done by searching the materials in the Scopus, IEEE, ACM, Springer and Web of Science databases based on the research questions. The search strategy in searching the string used phrase searching.

Screening of Papers

The systematic mapping process adopted in this study was guided by a structured search strategy encompassing three sequential stages: pilot, primary, and snowballing searches designed to identify and select relevant literature for inclusion as shown in Figure 2.

Pilot Search Strategy

Implementing a pilot search strategy within search strings aims to optimise the retrieval of relevant results from selected online databases and is a well-established practice in systematic mapping research (Gusenbauer & Haddaway, 2020). This strategy helps avoid the misconception of studies conducted in various disciplines and approaches suggested by the researchers. Furthermore, implementing this strategy can reduce biased findings by relying on the trusted online databases. Due to the cumbersome nature of search engines such as Scopus and IEEE in controlling the search strings, five different searches were implemented based on the research by systematic mapping done by Ya'u et al. (2019). During this paper's initial search phase in systematic mapping, five online databases were chosen: Scopus, IEEE, ACM, Springer and Web of Science. The search string using the Boolean operator employed ("serious games" OR "serious game" OR "games" OR "serious gaming" OR "applied games") AND ("gesture interaction" OR "gesture-based interaction" OR "gesture based interaction" OR "natural interaction" OR "natural user interaction") AND ("education" OR "primary school education" OR "kid education"). The results of the search string are shown in Table 1. Overall, from the five trusted databases, 2705 related publications were retrieved.

Figure 2. Search strategy process

Table 1
Results of the pilot search in a trusted database

Database Name	Retrieve Paper
Scopus	52
IEEE	224
ACM	599
Springer	1804
Web of Science	26
Total	2705

Primary Search Strategy

It is inappropriate to evaluate all research papers using a uniform set of criteria, as some emphasise the introduction of novel techniques or findings with limited empirical validation, while others provide comprehensive discussions of conceptual frameworks. In the search strategy, to retrieve suitable sources is to play around with ambiguity, researchers find the technique to retrieve specific terms using Boolean operators very helpful. From that number of findings, the relevant research was narrowed down more specifically based on titles and keywords.

Snowballing Search

During the snowballing search, another cycle of searching was used. In this process, detailed checking was performed on the selected papers.

Inclusion and Exclusion Criteria

Articles using serious games and gesture-based interaction in the education field were included. Meanwhile, for the exclusion criteria, the following categories were excluded:

1. Studies that do not focus on serious games, gesture-based interaction, and education.
2. Short conference papers (less than four pages), opinion papers and work in progress reports.
3. Review papers and studies, such as surveys that do not have theoretical concepts, prototype testing and systematic literature review related to the topic.
4. Papers that are not written in the English language.

Keywording Using Abstract

In searching for keywords using the abstract, we executed the search from two different angles to focus on the topic in more detail. The criteria were narrowed down to increase focus on the topic selected. The selected papers were chosen by shortlisting the keywords used by these papers and by screening abstracts that contained the keywords.

Data Extraction and Mapping of Studies

The data extraction form was designed to contain the following information: study ID, date of the extraction, paper title, author(s), publication type/year, Source, study context, concept(s), area of focus and in answering the research question (Ya'u et al., 2019). In this paper, the data extraction focuses on study ID, paper title, authors, publication type/year, source, study context, concept(s), and area of focus. The sample of extraction is illustrated in Table 2.

After further screening and selection based on abstracts (63 papers) and lastly, for deep discussion, only 28 full-text papers were extracted. The summary of the extraction is shown in Figure 3.

Table 2
Sample of data extraction

StudyID	Database	Paper Title	Publication Year
1	SPRINGER	Digital game elements, user experience and learning: A conceptual framework	2018
2	SPRINGER	An immersive virtual-reality computer-assembly serious game to enhance autonomous learning	2021
3	SPRINGER	Exploring spiral narratives with immediate feedback in immersive virtual reality serious games for earthquake emergency training	2022
4	SPRINGER	Supporting struggling readers with digital game-based learning	2019
5	SPRINGER	The effects of touchless interaction on usability and sense of presence in a virtual environment	2022
6	SPRINGER	FunQ: Measuring the fun experience of a learning activity with adolescents	2021
7	SPRINGER	Educational games and the new forms of interactions	2019

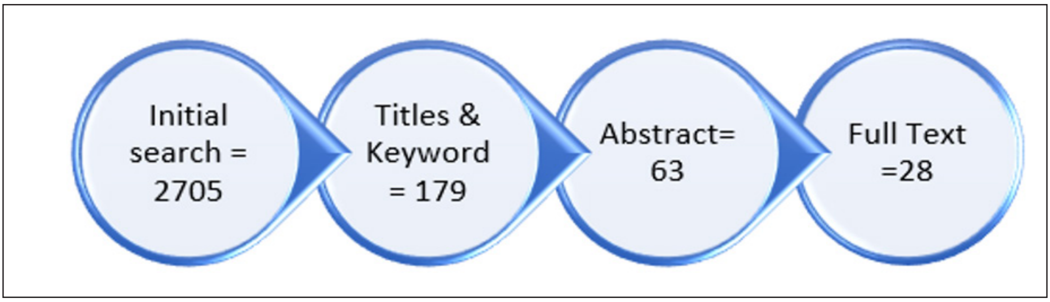


Figure 3. Primary search phase activities

DESCRIPTIVE ANALYSIS RESULT

The study population was categorised based on publication years and types, allowing for a comprehensive analysis of trends and variations over time. The literature search spanned from 2018 to December 2024, yielding retrieved papers distributed as follows: four papers from 2018, five papers from 2019, one paper from 2020, six papers from 2021, five papers from 2022, four papers from 2023 and three papers from 2024. Further details and visual representations can be found in Figure 4.

For the publication type, 28 articles were sourced from journals and conference proceedings, shown in Figure 5. Among these findings, 13 articles (46%) were retrieved from journals, while the remaining 15 articles (54%) were sourced from conference proceedings.

In addressing the research questions, the classification scheme revolves around three fundamental aspects: 1) Elements suitable for use in game design and interaction design within educational contexts, 2) Contribution facets, and 3) Evaluation criteria for measuring user engagement.

Elements of Serious Games and Gesture-Based Interaction in Education

The elements of serious games and gesture-based interaction for education were examined, keeping in mind their various goals within the field of education and non-education. The analysis indicates a predominant emphasis on the field of education, with a total of 20 papers, while 8 papers deviate from this focus, as detailed in Table 3.

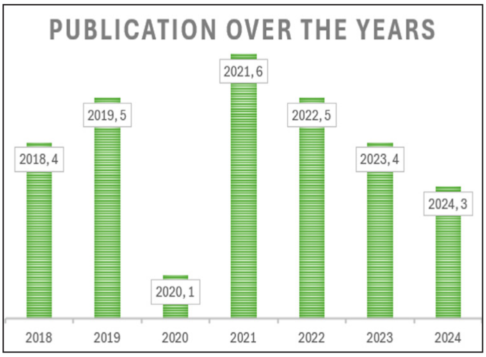


Figure 4. Publication over the years

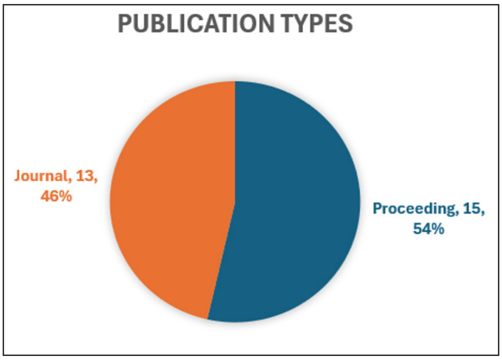


Figure 5. Publication type

Table 3
Distribution of selected studies according to education and non-education fields

Field	# Study	Paper
Education	20	Anvari et al. (2024); Chang and Tsai (2018); Checa et al. (2021); Chiu et al. (2018); de Paolis and de Luca (2022); Denden et al. (2018); Feng et al. (2022); Fernandes and Werner (2019); Holz et al. (2024); Johnson-Glenberg et al. (2020); Lombana et al. (2023); Munsinger and Quarles (2019); Nie et al. (2022); Ronimus et al. (2019); Rubegni et al. (2022); Shao et al. (2021); Tisza and Markopoulos (2021); Torres et al. (2021); Wan Husain et al. (2022); Zaina et al. (2019)
Non-Education	8	Alexiou and Schippers (2018); Bian et al. (2023); Holz et al. (2024); Krivich et al. (2023); Meena et al. (2019); Silva et al. (2024); Vellingiri et al. (2020); Xu et al. (2021)

In this systematic mapping research, three modalities were compared and analysed: serious games, gesture-based interaction and the hybridisation between gesture-based interaction and serious games. Overall, for the SMS, 17 elements reflect the analysis of approaches and contribution-based elements used in serious games, gesture-based interaction, and user engagement, as shown in Table 4. Based on the synthesis of the study, 13 key elements commonly identified in serious games include interaction, avatar, user control, feedback, narrative, scenario-based, reward, challenge, aesthetic, incremental learning, goal, accommodating learning style, and scaffolding. Meanwhile, for user engagement, the components involved are cognitive, emotional, performance and engagement. Therefore, the conclusions will be valuable for everyday life, especially as future educational standards increasingly emphasise the use of technology in learning environments.

Serious games integrate game elements not only for entertainment but also for educational, training, simulation, or real-world problem-solving purposes, enhancing engagement and efficacy in learning and problem-solving experiences. In addition to serious games, gesture-based interaction was examined as another technological context. Gesture-based interaction involves utilising body movements or gestures to interact with digital devices or systems, enabled by sensors, cameras, or other technologies that interpret and respond to these gestures. Such interfaces are utilised across various domains, such as gaming, virtual reality, augmented reality, and human-computer interaction. Here are four key elements associated with gesture-based interactions, which are interaction, avatar, user control and feedback, based on Table 4, which focuses on gesture. Additionally, elements lacking support from other research were excluded to prevent biases. According to the classification in Figure 6, the researchers have found that based on research question one (RQ1), the reviewed papers examined various elements, including narrative and scenario-based approaches (six papers each), feedback and user control (eight papers each), and the majority (fourteen papers) focusing on the use of avatars and interaction.

In summary, the most effective gameplay for users implemented in serious games and gesture-based interaction depends on the cognitive learning of the target users. Key elements of serious games depend on their goals and objectives. Design elements were retrieved based on pedagogy-driven SGs. In a pedagogy-driven approach, it highlights the main pedagogical and entertainment features, and their interrelation (Arnab et al., 2014). Based on SMS for educational user engagement, the selection of the game elements for further development is based on their consistent association with positive learning engagement from the prior study, based on 5 databases. Clearly, from the findings, we can see that the most important elements that connect serious games and gesture-based interactions are interaction elements throughout the games.

Table 4
Detailed analysis of approaches and contribution-based elements used in serious games, gesture-based interaction and user engagement

Authors/ Concept used/ Component involved	**Interaction**	**Avatar**	**User control**	**Feedback**	**Narrative**	**Scenario-base**	**Reward**	**Challenge**	**Aesthetic**	**Incremental learning**	**Goal**	**Accommodating learning style**	**Scaffolding**	**Cognitive**	**Emotional**	**Performance**	**Engagement**
Serious Game, Gesture-based Interaction																	
Checa et al. (2021)	✓		✓			✓					✓						
Rubegni et al. (2022)	✓	✓															
Nie et al. (2022)	✓	✓				✓				✓							
Shao et al. (2021)		✓			✓												
Wan Husain et al. (2022)	✓		✓			✓				✓		✓	✓				
Serious Game																	
Anvari et al. (2024)	✓	✓		✓			✓		✓								
Alexiou and Schippers (2018)			✓	✓	✓		✓	✓	✓		✓						
Bian et al. (2023)		✓		✓	✓			✓									
Chang and Tsai (2018)	✓																
Denden et al. (2018)	✓	✓		✓	✓	✓	✓					✓					
Feng et al. (2022)				✓	✓	✓											
Fernandes and Werner (2019)		✓															
Holz et al. (2024)	✓		✓	✓			✓		✓								
Krivich et al. (2023)		✓			✓												
Lombana et al. (2023)		✓	✓														✓
Meena et al. (2019)												✓					

Table 4 (*continued*)

Authors/ Concept used/ Component involved	Interaction	Avatar	User control	Feedback	Narrative	Scenario-base	Reward	Challenge	Aesthetic	Incremental learning	Goal	Accommodating learning style	Scaffolding	Cognitive	Emotional	Performance	Engagement
Ronimus et al. (2019)		✓					✓	✓		✓			✓	✓	✓	✓	
Silva et al. (2024)	✓																
Tisza and Markopoulo (2021)		✓	✓					✓									
Torres et al. (2021)	✓	✓				✓											
Xu et al. (2021)	✓			✓													
Yang et al. (2023)	✓																
Gesture based Interaction																	
de Paolis and de Luca (2022)	✓	✓	✓											✓	✓		
Zaina et al. (2019)	✓	✓	✓	✓													
Total	14	14	8	8	6	6	5	4	4	3	2	3	1	2	2	1	1

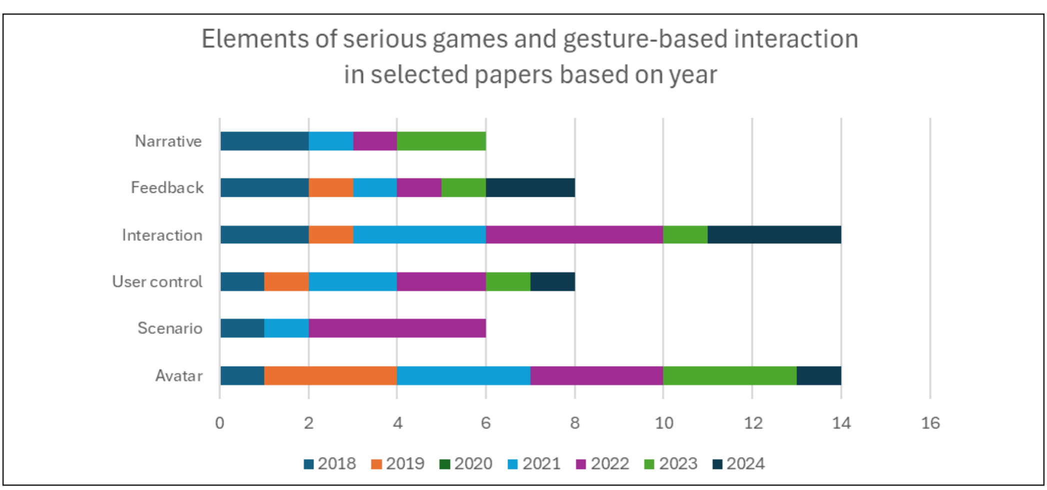


Figure 6. Elements of Serious Games and Gesture-Based Interaction in selected papers based on the year

Additionally, the use of avatars is another important element in the field of education. Moreover, the sixth element mentioned earlier plays the biggest role in promoting skill development and is thought to enhance user engagement.

Interaction

The interaction in educational perspective refers to how players and games engage, such as based on environments and setup of scenario, the characters use that guide to physical, cognitive and social development. A well-designed interaction system will help the game feel natural and easy to use, allowing players to stay focused and feel involved. The players must deal with the situation and implement interaction (Wan Husain et al., 2022). Research by Checa et al. (2021) It stresses that interaction techniques in virtual reality are divided into three basic forms: selection, manipulation, and locomotion. In this research, the user only had to focus on manipulating objects using a single mechanism to pick up and drop them and place these objects into position. The simple interaction in the game is by using a mouse and keyboard. Still, in high-level interaction design, the interaction can be controlled by a device that supports gestures, movement, etc. According to Yang et al. (2023) Integrating interactive elements allows users to engage more deeply with the website, resulting in a more memorable and enjoyable experience. Based on the study of 28 papers, most interaction elements were integrated with others, but a quick and different approach was implemented by Silva et al. (2024) was more focused on gesture interaction technique defined as: anticlockwise, clockwise, up, down, left, and right.

Avatar

Virtual characters and avatars are commonly some of the elements implemented in games with a specific purpose. Some authors mentioned that avatars are related to engagement (Ronimus et al., 2019), and some authors used the avatars as a feature, as they add value to the applications. Avatars in game design offer user satisfaction, which can result in gaining players' loyalty and increasing engagement. Rubegni et al. (2022) found that using avatars as the central point of interaction can be especially effective in capturing children's attention and encouraging their involvement. Their study also suggested that avatars have the potential to support the creation of more engaging and effective educational tools for young learners. In gesture interaction, the avatar and characters are used to control the game's movement and to perform an action (Zaina et al., 2019). In their research, the authors proved that avatars play an engaging role in helping children better remember what they've learned. Avatars can be used to represent players' selves in the game (Denden et al., 2018; Zaina et al., 2019). Avatar is an intermediary character to connect with the virtual world and pairs together with a scenario-based environment to represent the real-world environment, like the study by Nie et al. (2022), Shao et al. (2021) and Torres et al. (2021). In other words, these two important elements in games can bridge the content to deliver it to users more effectively and in an impactful manner. An avatar in the application can be represented in the virtual world by a simple cursor or more commonly by a hand or a whole-body avatar (Fernandes & Werner, 2019). The study by De Paolis and De Luca (2022) found that in their framework, which focuses on presence, immersion and interaction, proto presence is based on kinesthetic information about the relative position of the user's body, which allows advanced technology devices such as Leap Motion and Kinect to be implemented in more detail to bring more effective effects for the avatars.

Scenario-based

Scenario-based learning materials for the players are designed based on real-life situations (Wan Husain et al., 2022). In an easy explanation, the players tend to learn more when the game content is related to their everyday surroundings or real-life experiences. The scenario implements the facilitation of reflection-in-action, which is important to train individuals about behavioural responses (Feng et al., 2022). Scenario-based features can be divided into static and dynamic (Torres et al., 2021). Many researchers use static scenarios in which the structure design is not adjustable by the user (Denden et al., 2018; Feng et al., 2022; Nie et al., 2022; Torres et al., 2021). However, the dynamic scenario also exists, such as the research by Torres et al. (2021).

User Control

User control means the player can control the learning process. The player can repeat or continue the learning process (Feng et al., 2022) based on trial and error learning (Wan Husain et al., 2022). This situation gives an advantage to the player to revisit a scenario and give a different response to avoid errors or mistakes.

Feedback

Feedback is a game feature that directs learners to evaluate their performance, identify knowledge gaps, and obtain correct knowledge by receiving various forms of information (Feng et al., 2022). Meanwhile, research by Bian et al. (2023) mentioned that feedback helps players effectively perceive their feelings and performance during the game task; the system should be able to give players quantitative and visual feedback on how they are doing. Three types of stimulation are deployed with immediate feedback: image-based feedback, audio feedback, and text-based feedback. Feedback devices can influence the cognitive engagement of players, and qualities like immediacy, frequency, clarity and relevance can contribute to that (Alexiou & Schippers, 2018). Through this research, the relationship of the fragile feedback mechanisms can disrupt user engagement.

Therefore, designing or evaluating game-based learning applications needs to take feedback as an important element in educational platform games.

Narrative

The study by (Bian et al., 2023; Feng et al., 2022) used a narrative element, where the storyline followed a structured sequence of scenarios. Learners' actions determined the progression from one scenario to the next. This finding shows that narrative elements are also connected to scenario-based elements. Providing clear instructions and flow to the users allows the players to play more confidently and increases user engagement.

Contribution Facet

A contribution facet refers to any added value that has some impact on the research. For this study, contribution facets focus on the approaches and contributions of the selected papers, such as framework, tools, evaluation, metrics and models used in their research. The contribution facet study is described in detail in Table 5.

The researchers made numerous contributions in their work while developing quality research. According to Table 6, most contributions focused on the evaluation facet, with 13 papers dedicated to this area. Secondly, the findings were more focused on the framework with 7 papers. Then, it was followed by tools and metrics, each represented by 5 papers, and finally, models with 3 papers. Considering that the focus of the 28 papers lies in evaluation, the prevalent elements utilised are interaction, avatar, feedback, goal, challenge, accommodating learning style, scenario-based design, incremental learning, narrative, aesthetic and user control. Next, an examination of four papers within the framework studies revealed the implementation of 17 elements and concepts: goal, reward, feedback, challenge, narrative, aesthetic, scenario-based design, avatar, accommodating learning styles, interaction, user-centred design, behaviour-based approaches, cognitive elements, emotional factors, scaffolding, user control, and incremental learning. In the studies concerning tools, which were drawn from three papers, researchers predominantly employed 7 elements and concepts of serious games and gesture-based interaction: feedback, scenario-based design, avatar, interaction, cognitive elements, emotional factors, and user control. Meanwhile, in the model facet study, it's worth noting that no redundant concepts were integrated.

There is a different situation for the metric facet; the different criteria used need to be captured through the system settings and the observation methods. From the six extracted papers, a consensus emerged that time is a key factor in measuring various aspects, including interaction, fatigue, usability, behaviour, performance, and knowledge. These measurements are supplemented by factors such as the time taken, number of rotations, incorrect actions, task completion, and success rates.

Table 5
Contribution facet study

Category	Description
Framework	A framework is a structured approach or set of guidelines that provides a foundation for organising and solving complex problems.
Tool	A "tool" is an object or software application that is designed to perform a specific task or function, often making the task easier, more efficient, or more accurate.
Evaluation	Evaluation is the process of ensuring an algorithm achieves the objectives.
Metric	A "metric" is a quantifiable measurement or standard used to assess, evaluate, or express a particular attribute, performance, or characteristic of something. Metrics are used in various fields to track progress, compare results, make informed decisions, and understand the effectiveness of processes or systems. Metrics are valuable because they provide objective data that can be used for analysis and decision-making.
Model	A model can refer to various concepts depending on the context in which it is used.

Table 6
Contribution facet based on framework, tool, evaluation, metrics, and model

Contribution Facet	Framework	Tool	Evaluation	Metric	Model
Studies	Alexiou and Schippers (2018); Anvari et al. (2024); Bian et al. (2023); de Paolis and de Luca (2022); Denden et al. (2018); Wan Husain et al. (2022); Silva et al. (2024)	de Paolis et al. (2019); Silva et al. (2024); Torres et al. (2021); Xu et al. (2021); Yang et al. (2023)	Checa et al. (2021); de Paolis and de Luca (2022); Fernandes and Werner (2019); Holz et al. (2024); Lombana et al. (2023); Meena et al. (2019); Nie et al. (2022); Ronimus et al. (2019); Rubegni et al. (2022); Shao et al. (2021); Tisza and Markopoulos (2021); Xu et al. (2021); Zaina et al. (2019)	Chiu et al. (2018); Johnson-Glenberg et al. (2020); Munsinger and Quarles (2019); Vellingiri et al. (2020); Xu et al. (2021)	Feng et al. (2022); Lombana et al. (2023); Ronimus et al. (2019)
Count	7	5	13	5	3

The detailed analysis for the metric facet can be referred to in Table 7. According to Ya'u et al. (2019), engagement can be gauged through three main metrics: 1) exposure time extracted from game logs post-intervention, 2) active engagement time encompassing the duration users spend on learning tasks within the game, and 3) exclusion of time spent on other game features like avatar movement and pauses.

Table 7
Detailed analysis for the metric facet

Study ID/ metric	Time	Number of rotations	Number of wrong	Success rate	Completion task	Metric type
Chiu et al. (2018)	✓	✓	✓			Behavior
Johnson-Glenberg et al. (2020)	✓		✓			Knowledge
Munsinger and Quarles (2019)	✓				✓	Interaction, fatigue, usability
Vellingiri et al. (2020)	✓	✓		✓		Performance
Xu et al. (2021)	✓				✓	Usability
Yang et al. (2023)	✓					Emotion

Evaluation Used in Prototypes and Applications

Evaluation constitutes a pivotal phase in prototype and application development, ensuring alignment with user requirements, functionality, and delivering a positive user experience. The evaluation methods employed in both prototypes and applications in this study are summarised in Table 8.

Table 8
Evaluation used in prototypes and applications

Evaluation Types	Description
Usability	The ease with which users can interact with a product, system, or interface to achieve their goals effectively and efficiently while having a positive user experience.
Emotional and cognitive engagement	User engagement involves users' feelings, attitudes, and overall emotional response to a product or experience, as well as their intellectual or mental involvement with the product or content.
Interview	The technique for collecting data may be highly structured, resembling questionnaires, or highly unstructured, starting with general questions that allow the respondent to lead the way.
Heuristic	The method is used to review software and spot any issues related to how easy it is to use. It involves experts going through the interface and checking whether it follows well-known usability guidelines.
Performance testing	Performance testing to evaluate responsiveness, functionality and assess factors like loading times, response times, and overall system stability to ensure a smooth and efficient user experience.

Based on the analysis of the 13 papers presented in Table 9, it is evident that usability studies were the most employed evaluation method, utilised in six papers. Additionally, three studies assessed user engagement, incorporating both cognitive and emotional dimensions. Two papers adopted interview-based approaches, while one focused on user experience and another examined the aspect of fun in learning. Notably, the review highlights a limited exploration of the multifaceted dimensions of user engagement across the selected studies.

The data extraction results from our systematic mapping study offer a detailed and structured overview of the current research within the field. The analysis identified key elements, including dominant research components, commonly addressed contribution facets, and areas of user engagement that remain underexplored. These findings provide a clear picture of the existing knowledge base and highlight specific research gaps that need attention.

Table 9
Measurement tools for evaluating engagement

Paper	Tool Name	Evaluation Engagement Dimension/ Measurement
Checa et al. (2021)	Satisfaction questionnaire adapted from (Tcha-Tokey et al., 2016)	Usability
de Paolis and de Luca (2022)	Presence Questionnaire (PQ) for the evaluation adapted by combining the Usability Metric for User eXperience (UMUX) questionnaire, the System Usability Scale (SUS) and the presence questionnaire (PQ)	Cognitive, emotional
Fernandes and Werner (2019)	Heuristic	Usability
Holz et al. (2024)	User Experience Questionnaire (UEQ) (Schrepp et al., 2017), 13 questions from the Kids Game Experience Questionnaire KidsGEQ	User Experience
Lombana et al. (2023)	Not mentioned in detail	Engagement
Meena et al. (2019)	SUS, NASA	Usability, task workload
Nie et al. (2022)	Not mentioned in detail	Usability
Ronimus et al. (2019)	GraphoLearn engagement	Cognitive, Emotional, performance
Rubegni et al. (2022)	Not mentioned in detail	Interview with students
Shao et al. (2021)	Not mentioned in detail	Usability
Tisza and Markopoulos (2021)	FunQ	Fun experience learning
Xu et al. (2021)	NASA-TLX Hart and Staveland (1988), IPQ	Usability
Zaina et al. (2019)	Not mentioned in detail	Interview with teachers

DISCUSSION

Based on the findings, the different authors offer various perspectives, and some have made significant contributions in relating the theory and implementation. This paper also focuses on the dimension in measuring the theory used. In answering the research question, the study of serious games and gesture-based interaction was first mapped, and the patterns and modalities were explored in terms of action using the game elements. The studies by Nie et al. (2022), Shao et al. (2021) and Torres et al. (2021) agree that using an avatar would be the glue to connect players with a scenario-based environment and the control by users. These studies also indicate that using an avatar gives significance to the interaction.

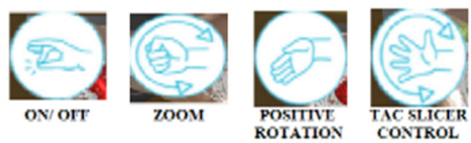
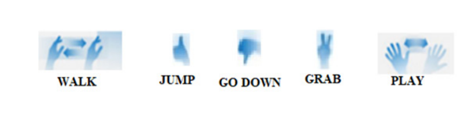
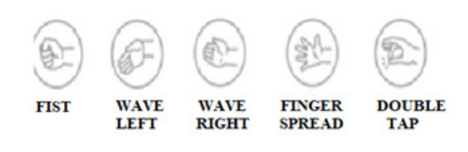
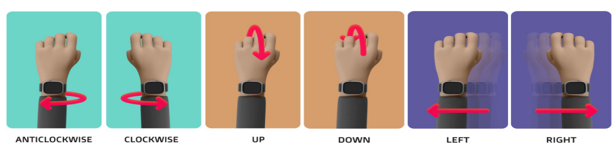
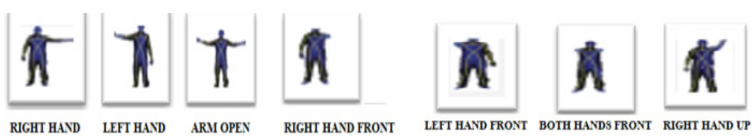
Avatar-based generally refers to interactions or experiences involving avatars, which are digital representations or characters representing users in a virtual environment. Avatars can take various forms, such as human-like figures, animals, or abstract representations, and they are commonly used in digital media, virtual reality video games, and online platforms. Avatar-based interactions are driven by the desire to create more personalised, engaging, and immersive digital experiences. It allows users to have a presence in virtual or online spaces, enhancing communication, collaboration, and overall user engagement. Advances in technology, such as motion tracking and facial expression recognition, contribute to making avatar-based experiences more realistic and interactive.

Based on the findings, it can be inferred that the utilisation of gestures in advanced technology for gaming typically ranges from four to seven gestures, while users with disabilities may employ a greater number of gestures. Feng et al. (2022) found a relationship between scenario-based learning with narrative, which is based on the user control elements. By adjusting the narrative, users can replay a scenario with instant feedback, encouraging reflection-in-action. This gives players the freedom to decide whether to repeat the task or move forward. Table 10 summarises the avatar action in controlling the virtual environment.

From the research approaches and contribution facets, the primary focus was on evaluation, as the major rules for the design and development of prototypes and frameworks need to be assessed in the final stage of development. Overall, both the evaluation facet and the contributions of the approach yielded the same result, emphasising three main attributes: avatar, interaction, and user control. This finding supports the discussion in research question one, which examined the elements used in serious games and gesture-based interaction for education.

In line with Mayer's proposition of teaching experience design, any teaching experience should undergo comparison using valid, reliable, objective, and referenced instruments alongside experimental control groups employing conventional teaching (Checa et al., 2021; Mayer, 2014). Research conducted by Chiu et al. (2018) introduces behaviour metrics for measuring gesture-based interaction, including completion time, number of rotations, and number of incorrect attachments per level, as these metrics are linked to task difficulty and player impulsivity.

Table 10
The avatar (interaction) action in controlling the virtual environment

Gesture used	Action using serious games elements
Four hand gestures	
Five hand gestures	
Five hand gestures	
Six hand gestures	
Seven basic gestures	

The authors also recommend additional metrics such as the number of rotations per successful attachment (calculated by dividing the number of rotations by the number of successful attachment attempts) and the average time spent between each rotation (calculated by dividing the total time taken to finish by the number of rotations).

Moreover, some research employs an authentication method to restrict access to the collected traces and results, ensuring that only authorised individuals can access them and safeguarding the learners' privacy. Additionally, the collected traces and generated reports are retained for a predetermined period (typically one academic year) before being automatically deleted. Furthermore, to enhance transparency in learning, students have the option to view their collected gaming behaviour traces.

Nevertheless, there is still a lack of a thorough theoretical understanding of how the different elements embedded in game design influence user engagement in learning, something this research set out to do. Based on previous empirical research by Alexiou and Schippers (2018), user engagement can be divided into four main dimensions: 1) openness to experience, which is crucial for user engagement and technology acceptance, encompassing traits such as imagination, sensitivity to aesthetics, curiosity, and independent thinking; 2) conscientiousness, referring to individuals' perseverance and dedication to their learning goals, which enhances performance and active learning; 3) goal orientation, which includes both learning goal orientation and performance goal orientation; and 4) sensation seeking and need for cognition, where behaviours can lead to a higher sense of control and mastery, fulfilling needs for competence and autonomy, and contributing to immersion and enjoyment. The model proposed by Alexiou and Schippers (2018) also suggests that player engagement is closely linked to the narrative, game mechanics, and aesthetics (user control). Together, these elements boost both emotional and cognitive involvement.

Quite a different study by de Paolis et al. (2019) focused on evaluating user experience. Although the focus of this research is user experience, the framework also uses the same game elements for user engagement, which are presence, immersion and interaction. According to Tisza and Markopoulos (2021), the concepts of experience and engagement represent distinct theoretical ideas and should not be treated as the same when examining users' subjective experiences. In response to this distinction, they developed the FunQ evaluation framework, which assesses six dimensions: Autonomy, Challenge, Delight, Immersion, Loss of Social Barriers, and Stress. Through a detailed systematic mapping, it is evident that these elements are interconnected and, when implemented together, can enhance game design and user engagement more effectively. Based on the existing mapping structure derived from selected papers across five database engines, an initial item pool of instruments was constructed, focusing on attributes and elements of gesture-based interaction and serious games. These instruments are designed to facilitate the more effective measurement of user engagement and usability. The final version for testing user engagement and usability incorporates seven attributes and elements of gesture-based interaction and serious games.

Methods for evaluating user engagement predominantly stem from the domain of human-computer interaction, particularly in education. User engagement stands as a crucial component within the fields of serious game development and interface design. Most papers extracted do not solely concentrate on user engagement but rather integrate it with usability and other aspects of interaction design. A compilation of instruments has been assembled to measure user engagement, drawing from 28 papers extracted from the five renowned databases. This compilation is presented in Table 11, covering various items such as avatar, narrative, user control, enjoyment, competence, immersion, scenario-based design, visual fidelity, learning goal and interaction.

A range of methodological approaches has been employed across studies to assess engagement and attitudes, each adapted to suit the characteristics of the target population.

Table 11
Measurement tool for evaluating user engagement based on systematic mapping

Elements	Instruments
Enjoyment Ronimus et al. (2019)	The following items measured emotional engagement: 1. I enjoy playing GL. 2. I would like to play GL even more. 3. It is fun to practice reading with GL. 4. I could play GL forever.
Lombana et al. (2023)	5. Playing GL makes me happy. 1. I enjoyed the game 2. I was trying my best in the game 3. It was easy to play the game 4. I liked the game graphics
User control (autonomy) Ronimus et al. (2019)	The following items were used to assess cognitive engagement: 1. I try my best when I play GL. 2. I choose my responses carefully. 3. I like it when a difficult task appears in the game. 4. I concentrate hard when I play.
Tisza and Markopoulos (2021)	5. I like to read even the difficult words in GL. 1. During the activity, I had the sense of controlling the activity. 2. During the activity, I knew what to do. 3. During the activity, I could do what I wanted. 4. During the activity, I could make some choices about the activity.
Interaction Rubegni et al. (2022)	Survey 1. How much did you enjoy playing the game? 2. Would you recommend it to other children? 3. Have you ever used a gesture-controlled game (e.g., Kinect or Wii-controlled games)? 4. Do you remember something about the game? Interview 1. What did you like about this game? 2. What did you not like about this game? 3. Do you remember something about the game? If yes, what?
Easy to use (Narrative) Feng et al. (2022)	1. The training storyline helped me to learn. 2. It was easy for me to understand the learning content. 3. It was easy for me to learn about what to do during and after earthquakes. 4. It was easy for me to remember what I had learned.
Competence (Self-efficacy) Feng et al. (2022)	1. I know what to do when facing an earthquake. 2. I can remain calm when facing an earthquake. 3. I have the confidence to deal with an earthquake alone. 4. I can come up with a plan for responses to an earthquake. 5. I can handle situations during an earthquake. 6. I can think of a solution if I am in trouble during an earthquake.
Scenario-based (attention) Feng et al. (2022)	1. It was easy for me to concentrate on my learning. 2. It was easy for me to stay focused on the task. 3. I felt the training was fun.

Table 11 *(continued)*

Elements	Instruments
Immersion de Paolis and de Luca (2022)	1. Were you able to anticipate what would happen next in response to the actions that you performed? 2. How completely were you able to actively survey or search the environment using vision? 3. How much delay did you experience between your actions and expected outcomes? 4. How quickly did you adjust to the virtual environment experience? 5. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience? 6. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?
Visual fidelity de Paolis and de Luca (2022)	1. How closely were you able to examine objects? 2. How well could you examine objects from multiple viewpoints?
Aesthetic (avatar) Shao et al. (2021)	Semi-structured interview: 1. Making an avatar with my own face makes me is more willing to tell stories and get very excited. 2. The character with a customised avatar is very attractive.
O'Brien et al. (2018)	1. This Application X was attractive. 2. This Application X was aesthetically appealing. 3. I liked the graphics and images of Application X. 4. Application X appealed to the visual senses. 5. The screen layout of Application X was visually pleasing.
Focus on the learning goal O'Brien et al. (2018)	1. I lost myself in this experience. 2. I was so involved in this experience that I lost track of time. 3. I blocked out things around me when I was using Application X. 4. When I was using Application X, I lost track of the world around me. 5. The time I spent using Application X just slipped away. 6. I was absorbed in this experience. 7. During this experience, I let myself go.

Feng et al. (2022) utilised a 7-point Likert scale extending from -3 for "totally disagree" to +3 for "totally agree", enabling a detailed gradient of agreement particularly suitable for adult or older participants. In contrast, Ronimus et al. (2019) designed an engagement measurement instrument specifically tailored for children, addressing both emotional and cognitive components. To ensure the statements were comprehensible to young respondents, the scale was piloted in advance. The assessment employed a visual format comprising five differently sized squares to indicate varying frequencies of engagement, ranging from "every time" to "never," thereby facilitating children's understanding through concrete visual representations. Similarly, Rubegni et al. (2022) adopted a 5-point scale ranging from 1 for "not at all" to 5 for "very much", supplemented by emoticons in a "smile-o-meter" format, a design inspired by (Denden et al., 2018). This visual enhancement supported younger participants in expressing affective responses more intuitively. Collectively, these approaches underscore the significance of employing developmentally appropriate and contextually relevant instruments when assessing engagement, particularly in child-centred research.

In conclusion, the discussion of our systematic mapping study has elucidated significant patterns and gaps within the existing research landscape. Through our analysis, we identified prevalent methodologies, core thematic elements in serious games and gesture-based interaction, and underexplored topics that warrant further investigation, especially to measure user engagement. These findings provide a foundation for guiding future research efforts and fostering more targeted and impactful studies. By addressing the identified research gaps and leveraging the emerging trends, researchers can contribute to a more comprehensive understanding of the field.

CONCLUSION

This paper focused on identifying and theorising the relationship between elements of serious games, gestural interaction, and user engagement within the education domain from 2018 to 2024. The analysis encompassed three main aspects: 1) the elements utilised in serious games and gesture-based interaction for educational purposes, 2) the research methodologies and contributions implemented in the selected, and 3) the design criteria employed in serious games and gesture-based interaction to evaluate educational prototypes and applications based on user engagement. User engagement and usability questionnaires were collected and synthesised to enhance the development and efficacy of educational apps for students. Consequently, this paper aimed to condense the key design elements essential for measuring user engagement, providing a comprehensive measurement tool tailored to the educational domain. Furthermore, the findings offer insights and guidelines for industry practitioners involved in measuring user engagement using this tool. Future research should aim to build on these findings, employing rigorous methodologies and fostering interdisciplinary collaboration to further enhance the depth and breadth of knowledge in this domain.

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REFERENCES

Alexiou, A., & Schippers, M. C. (2018). Digital game elements, user experience and learning: A conceptual framework. *Education and Information Technologies, 23*(6), 2545-2567. https://doi.org/10.1007/s10639-018-9730-6

Anvari, S. S., Hammer, J., & Wehbe, R. R. (2024). "More than just a game, it's an app that builds awareness around mental health": Mental health stigma reduction using games for change. *Proceedings of the ACM on Human-Computer Interaction, 8*(CHI PLAY), Article 316. https://doi.org/10.1145/3677090

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., de Freitas, S., Louchart, S., Suttie, N., Berta, R., & de Gloria, A. (2014). 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

Bian, Y., Zhou, C., Zhang, Y., Liu, J., Sheng, J., & Liu, Y. J. (2023). Focus on cooperation: A face-to-face VR serious game for relationship enhancement. *IEEE Transactions on Affective Computing, 15*(3), 913-928. https://doi.org/10.1109/TAFFC.2023.3306198

Brockmyer, J. H., Fox, C. M., Curtiss, K. A., McBroom, E., Burkhart, K. M., & Pidruzny, J. N. (2009). The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology, 45*(4), 624-634. https://doi.org/10.1016/j.jesp.2009.02.016

Chang, C. K., & Tsai, Y. T. (2018). Pair-programming curriculum development of motion-based game for enhancing computational thinking skills. *Proceedings of the 2018 7th International Congress on Advanced Applied Informatics (IIAI-AAI)*, 284-287. https://doi.org/10.1109/IIAI-AAI.2018.00061

Checa, D., Miguel-Alonso, I., & Bustillo, A. (2023). Immersive virtual-reality computer-assembly serious game to enhance autonomous learning. *Virtual Reality, 27*(4), 3301-3318. https://doi.org/10.1007/s10055-021-00607-1

Chiu, P. T., Wauck, H., Xiao, Z., Yao, Y., & Fu, W. T. (2018). Supporting spatial skill learning with gesture-based embodied design. *Proceedings of the 2018 International Conference on Intelligent User Interfaces*, 67-71. https://doi.org/10.1145/3172944.3172994

de Paolis, L. T., & de Luca, V. (2022). The effects of touchless interaction on usability and sense of presence in a virtual environment. *Virtual Reality, 26*, 1551-1571. https://doi.org/10.1007/s10055-022-00647-1

de Paolis, L. T., de Luca, V., & Paladini, G. I. (2019). Touchless navigation in a multimedia application: The effects perceived in an educational context. In L. T. de Paolis & P. Bourdot (Eds.), *Augmented reality, virtual reality, and computer graphics* (Vol. 11614, pp. 348-367). Springer. https://doi.org/10.1007/978-3-030-25999-0_30

Denden, M., Tlili, A., Essalmi, F., & Jemni, M. (2018). Implicit modelling of learners' personalities in a game-based learning environment using their gaming behaviours. *Smart Learning Environments, 5*, Article 29. https://doi.org/10.1186/s40561-018-0078-6

Dubey, P., Pradhan, R. L., & Sahu, K. K. (2023). Underlying factors of student engagement to e-learning. *Journal of Research in Innovative Teaching and Learning, 16*(1), 17-36. https://doi.org/10.1108/JRIT-09-2022-0058

Feng, Z., González, V. A., Mutch, C., Amor, R., & Cabrera-Guerrero, G. (2023). Exploring spiral narratives with immediate feedback in immersive virtual reality serious games for earthquake emergency training. *Multimedia Tools and Applications, 82*(1), 125-147. https://doi.org/10.1007/s11042-022-13306-z

Fernandes, F., & Werner, C. (2019). Towards immersive learning in object-oriented paradigm: A preliminary study. *Proceedings of the 2019 21st Symposium on Virtual and Augmented Reality (SVR)*, 59-68. https://doi.org/10.1109/SVR.2019.00026

Fernandez, A., Insfran, E., & Abrahão, S. (2011). Usability evaluation methods for the web: A systematic mapping study. *Information and Software Technology, 53*(8), 789-817. https://doi.org/10.1016/j.infsof.2011.02.007

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (Advances in psychology, Vol. 52, pp. 139-183). North-Holland. https://doi.org/10.1016/S0166-4115(08)62386-9

Holz, H., Beuttler, B., Löfflad, D., & Ninaus, M. (2024). Developing a group-based literacy screening for German pre-readers: A digital, game-based approach. *Proceedings of the ACM on Human-Computer Interaction, 8*(MHCI), Article 251. https://doi.org/10.1145/3676496

Johnson-Glenberg, M. C., Ly, V., Su, M., Zavala, R. N., Bartolomeo, H., & Kalina, E. (2020). Embodied agentic STEM education: Effects of 3D VR compared to 2D PC. *Proceedings of the 6th International Conference of the Immersive Learning Research Network (iLRN)*, 24-30. https://doi.org/10.23919/iLRN47897.2020.9155155

Krivich, E., Mõttus, M., & Bauters, M. (2023). Comparing psychophysiological responses to vicarious pain experience elicited by videos featuring either humans or avatars. *ACM International Conference Proceeding Series*, 334-339. https://doi.org/10.1145/3616961.3617801

Lombana, D. A. B., Ventura, R. B., Chen, Y. T., & Porfiri, M. (2023). Educating youth about human impact on freshwater ecosystems using an online serious game. *IEEE Transactions on Games, 15*(4), 590-602. https://doi.org/10.1109/TG.2022.3185959

Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 43-71). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.005

Meena, Y. K., Cecotti, H., Wong-Lin, K. F., & Prasad, G. (2019). Design and evaluation of a time adaptive multimodal virtual keyboard. *Journal on Multimodal User Interfaces, 13*(4), 343-361. https://doi.org/10.1007/s12193-019-00293-z

Munsinger, B., & Quarles, J. (2019). Augmented reality for children in a confirmation task: Time, fatigue, and usability. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology (VRST)*. https://doi.org/10.1145/3359996.3364274

Nie, J., Zhao, Y., Yao, B., Xu, Z., Chen, J., Yu, C., Hansen, P., Liu, J., Wang, J., Yan, G., Yao, C., Zhou, L., Ying, F., Liang, X., & Wang, G. (2022). SignFind: A synchronised sign language and Chinese character teaching game for Chinese deaf children using gesture recognition. *Proceedings of the CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/3491101.3519697

O'Brien, H. L., Cairns, P., & Hall, M. (2018). A practical approach to measuring user engagement with the refined User Engagement Scale (UES) and new UES short form. *International Journal of Human-Computer Studies, 112*, 28-39. https://doi.org/10.1016/j.ijhcs.2018.01.004

Ronimus, M., Eklund, K., Pesu, L., & Lyytinen, H. (2019). Supporting struggling readers with digital game-based learning. *Educational Technology Research and Development, 67*(3), 639-663. https://doi.org/10.1007/s11423-019-09658-3

Rubegni, E., Gentile, V., Malizia, A., Sorce, S., & Kargas, N. (2022). Child–display interaction: Lessons learned on touchless avatar-based large display interfaces. *Personal and Ubiquitous Computing, 26*(3), 667-680. https://doi.org/10.1007/s00779-020-01451-x

Schrepp, M., Hinderks, A., & Thomaschewski, J. (2017). Design and evaluation of a short version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence, 4*(6), 103-108. https://doi.org/10.9781/ijimai.2017.09.001

Shao, B., Zhang, Y., Wang, Q., Xu, X., Zhou, Y., Feng, G., & Lv, F. (2021). StoryIcon: A prototype for visualising children's storytelling. *ACM International Conference Proceeding Series*, 152-157. https://doi.org/10.1145/3490355.3490377

Silva, L., Soares, F., Felix, J., Cardoso, L., Aranha, R. V., & Nascimento, T. H. (2024). Gesture recognition in smartwatches using LSTM for interaction in low-cost virtual environments. *ACM International Conference Proceeding Series*, 284-288. https://doi.org/10.1145/3691573.3691615

Tcha-Tokey, K., Christmann, O., Loup-Escande, E., & Richir, S. (2016). Proposition and validation of a questionnaire to measure the user experience in immersive virtual environments. *International Journal of Virtual Reality, 16*(1), 33-48. https://doi.org/10.20870/IJVR.2016.16.1.2880

Tisza, G., & Markopoulos, P. (2023). FunQ: Measuring the fun experience of a learning activity with adolescents. *Current Psychology, 42*, 1936-1956. https://doi.org/10.1007/s12144-021-01484-2

Torres, A., Kapralos, B., da Silva, C., Peisachovich, E., & Dubrowski, A. (2021). A scenario editor to create and modify virtual simulations and serious games for mental health education. *2021 12th International Conference on Information, Intelligence, Systems and Applications (IISA)*. https://doi.org/10.1109/IISA52424.2021.9555531

Vellingiri, S., McMahan, R. P., & Prabhakaran, B. (2020). SCeVE: A component-based framework to author mixed reality tours. *ACM Transactions on Multimedia Computing, Communications, and Applications, 16*(2), Article 52. https://doi.org/10.1145/3377353

Wan Husain, W. S., Wan Shamsuddin, S. N., & Rahim, N. (2022). A conceptual framework for road safety education using serious games with a gesture-based interaction approach. *Pertanika Journal of Science and Technology, 30*(1), 621-640. https://doi.org/10.47836/pjst.30.1.34

Xu, X., Li, J., Yuan, T., He, L., Liu, X., Yan, Y., Wang, Y., Shi, Y., Mankoff, J., & Dey, A. K. (2021). HulaMove: Using commodity IMU for waist interaction. *Proceedings of the CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/3411764.3445182

Ya'u, B. I., Salleh, N., Nordin, A., Alwan, A. A., Idris, N. B., & Abas, H. (2019). A systematic mapping study on cloud-based mobile application testing. *Journal of Information and Communication Technology, 18*(4), 485-527.

Yang, S., Gao, Z., Mogavi, R. H., Hui, P., & Braud, T. (2023). Tangible Web: An interactive immersion virtual reality creativity system that travels across reality. *Proceedings of the ACM Web Conference 2023*, 3915-3922. https://doi.org/10.1145/3543507.3587432

Zaina, L., Castro, E., Martinelli, S., & Sakata, T. (2019). Educational games and the new forms of interactions. *Smart Learning Environments, 6*, Article 12. https://doi.org/10.1186/s40561-019-0099-9