Exploring the Role of Sound Design in Serious Games: Impact on User Experience and Learning Outcomes

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Abstract: Sound design plays an important role in serious games, influencing user experience and learning outcomes. However, deriving general principles and best practices remains challenging, as most literature relies on case-based studies in different application domains. Through a systematic review of the literature, 21 studies were analyzed to address two key questions: 1) what types of serious games and application domains incorporate sound design? and 2) what sound design strategies are implemented to enhance user experience and learning outcomes? The findings show that serious games have mainly focused on education, healthcare, and training, using sound to enhance motivation (50%), cognition (32%), and knowledge acquisition (18%). Furthermore, sound design strategies fulfill distinct roles: sound effects enhance feedback and engagement, background music influences motivation and cognitive processing, ambient sounds support navigation and emotional regulation, and dialogue facilitates knowledge acquisition. The findings highlight the need for further research to establish standardized sound design principles to optimize user experience and learning outcomes in serious games.

1 INTRODUCTION

Serious games are a category of video games developed for purposes beyond entertainment, including training, advertising, simulation, and education (Susi et al., 2007). They enable the creation of virtual environments that would be impractical due to time, cost, and safety constraints. These virtual spaces enable innovative exploration and learning experiences that transcend the physical world's limitations (Kaczmarczyk et al., 2016). For example, a serious game designed for firefighting training can effectively teach procedural skills by simulating dangerous scenarios that would be too risky or unethical to replicate in real life (Mystakidis et al., 2022).

Sound design has become a significant research topic in game design. Research shows that sound design in serious games significantly enhances user experience and learning outcomes. In particular, sound design can improve learning engagement and motivation (Kao et al., 2021; Yang et al., 2019; Ku et al., 2016; Barbosa and Nunes, 2015; Byun and Loh, 2015; Ke, 2008), provides critical support for visually impaired users (Radecki et al., 2020; Connors et al., 2014; Ferreira and Cavaco, 2014), improves learning performance (Ku et al., 2016; Schuurink et al., 2008), and reduces anxiety while improving auditory tolerance for people with autism spectrum disorder (ASD) (Johnston et al., 2022, 2020).

Despite evidence supporting the importance of sound design in serious games, guidelines for best practices and effective design strategies remain scarce. This study systematically reviews the literature on sound design impacts in serious games[1], addressing two main research questions:

RQ1: *What types of serious games and their application domains have been proposed to explore the impact of sound design?*

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[1] A systematic literature review methodology was chosen to provide a rigorous and transparent synthesis of existing studies, identifying patterns and gaps in sound design strategies with strong empirical evidence. Although this methodology offers a comprehensive view of academic research, it cannot capture industry practices that often remain unpublished due to commercial confidentiality. Therefore, while our review presents evidence-based findings, it may not fully represent the state-of-the-art in industrial applications.

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RQ2: *What sound design strategies have been implemented in serious games targeting impact on user experience and learning outcomes?*

The remainder of the paper is structured as follows. Section 2 outlines the methods used to review the literature on the impacts and outcomes of sound design in serious games. Section 3 presents the results of the review. Finally, Section 4 summarizes the findings of this work and provides directions for future research.

2 METHODOLOGY

The methodology comprises data collection and taxonomic mapping. Data collection involved searching scientific databases using predefined terms and selection criteria aligned with our research questions. The search was conducted on January 28, 2025. In the taxonomic mapping and categorization section, the selected studies were analyzed and classified into serious games, sound design, and the impact of their intersection. Figure 1 shows a graphical summary of the literature review process.

2.1 Data Collection

2.1.1 Databases Searched

The primary databases selected for this study, Web of Science and Scopus, cover our two key research domains: serious games and the impact of sound design. The interdisciplinary nature of the topic required databases with comprehensive coverage in education, information technology, medicine, psychology, and social sciences. Their indexing capabilities thoroughly cover relevant literature while providing manageable search results. Additional databases, including the Association for Computing Machinery (ACM), Ingentaconnect, the Institute of Electrical and Electronics Engineers (IEEE), Springer Nature, ScienceDirect, Wiley, and the Multidisciplinary Digital Publishing Institute (MDPI), were accessed through the Web of Science and Scopus indexing.

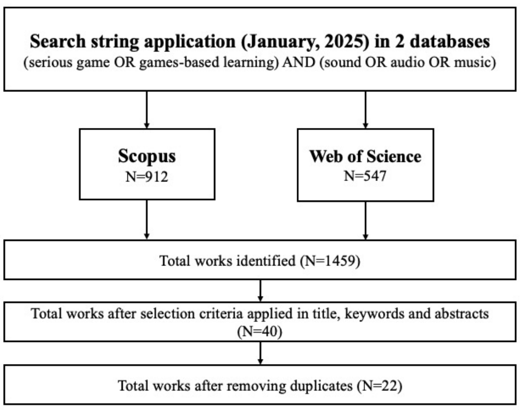

Figure 1: Flowchart depicting the systematic literature review procedure.

2.1.2 Search Terms

The search string included keywords from the two key domains of the study: 1) sound, music, and audio, and 2) serious games and game-based learning. The query `((serious game OR games-based learning) AND (sound OR audio OR music))` was applied to titles, abstracts, and keywords in both databases. Web of Science searched within title, abstract, and keywords (including keyword plus and author keywords), while Scopus searched title, abstract, and keywords. This approach ensured consistent coverage of literature at the intersection of sound design and serious games.

2.1.3 Paper Selection Criteria

The initial search retrieved 912 papers in Scopus, covering the period from 1969 to 2025, and 547 papers in Web of Science, from 1992 to 2025. The results were refined to include only articles presenting empirical evidence through user studies on sound design's impact on user experience and learning outcomes. Following a manual selection process, 22 papers were deemed relevant and included in the review, with 18 appearing in both Web of Science and Scopus. The final set comprised 11 conference papers (50%) and 11 journal articles (50%) published between 2008 and 2024.

2.2 Taxonomic Mapping and Categorization

We used a structured data extraction scheme to categorize game mechanics, context, and sound design strategies. Tables 1, 2, 3 present the resulting classifications based on three taxonomies: serious games, sound design, and their impact on user experience and learning outcomes.

2.2.1 Categorization of Serious Games

We adopted the classification framework proposed by Laamarti et al. (2014) to characterize serious games based on five main dimensions.

- **Application Area:** encompasses the different application domains relevant to serious games, such as education, well-being, training, advertisement, interpersonal communication, healthcare, etc.

- **Activity:** refers to the function carried out by the player in response to and/or as input to the game—for example, physical exertion, physiological, and mental.
- **Modality:** the channel by which information is communicated from the computer to the human(s) participating in the game-for example, visual, auditory, haptic, or others.
- **Interaction Style:** Describes input methods ranging from traditional interfaces (keyboard, mouse, joystick) to advanced interaction systems (movement tracking, tangible interfaces, brain-computer interfaces, eye tracking).
- **Environment**: Defines the game's digital space characteristics, including dimensionality (2D/3D), reality type (virtual/mixed), location awareness, mobility features, and online capabilities.

2.2.2 Categorization of Sound Design

Our sound design categorization follows game sound classifications established by Brandon (2004) and Collins (2008):

- **Sound Effects.** These are audio cues triggered by players' interactions with game elements, serving multiple purposes such as providing feedback, issuing alerts, or reinforcing the narrative.
- **Ambient Sound.** Background audio that represents the surrounding environment, enhancing the sense of place and immersion through environmental cues such as rainfall, distant traffic, or urban sounds.
- **Dialogue.** Voice-based interactions between characters, including narrative exchanges and interactive conversations.
- **Music.** Music refers to the structured arrangement of sounds, combining elements like form, harmony, melody, and rhythm—for example, background music or a theme song that hints at the game's style.

2.2.3 Categorization of Impact of Games

The impact categories follow Connolly et al. (2012) framework for serious games, encompassing both behavioral and learning outcomes.

- **Knowledge Acquisition and Content Understanding** Acquisition and comprehension of domain-specific information and concepts within serious games.
- **Perceptual and Cognitive Skills.** Development of sensory processing and cognitive abilities through gaming interactions, including attention, memory, and problem-solving capabilities.
- **Motor Skills**: Fine and gross motor coordination development through serious game interactions.
- **Physiological Outcomes.** Measurable changes in physiological responses during gameplay, including heart rate, stress levels, and neurological activity.
- **Affective and Motivational Outcomes.** Changes in emotional engagement and motivational factors during serious game interactions, including participation, enjoyment, and persistence.
- **Behavior Change.** Observable modifications in user behaviors and habits resulting from serious game engagement.
- **Soft Skills.** Enhance interpersonal and intrapersonal competencies through game-based learning, including communication, leadership, and adaptability.
- **Social Outcomes.** Development of collaborative abilities and community engagement within and beyond the serious game environment.

We also examined the evaluation methods used in the reviewed studies, categorizing them as quantitative or qualitative based on data collection and analysis techniques. User experience refers to participants' perceptions, emotions, and overall satisfaction when interacting with the game, typically measured through questionnaires, engagement metrics, or observational methods. Learning outcomes denote measurable gains in knowledge, skills, or behavioral changes resulting from gameplay, assessed through tests, task performance metrics, or skill evaluations. This distinction informed our analysis of how sound design affects both dimensions in serious games.

3 RESULTS

This section presents the results of our review, categorizing 22 serious games based on the taxonomy of Laamarti et al. (2014). Subsequently, we examine the role of sound design in serious games, analyzing how different sound elements impact user experience and learning outcomes.

3.1 Serious Games

3.1.1 Game Application Area

Tables 1 and 2 present the classification of 22 serious games according to the taxonomy proposed by Laamarti et al. (2014).

These games span multiple disciplines, including education (9), healthcare (6), training (5), and well-being (2). Games in educational target diverse subjects, such as mathematics (Ke, 2008; Radecki et al., 2020; Ku et al., 2016; Yang et al., 2019), cybersecurity (Cao et al., 2023), language learning (Verwimp et al., 2023), programming (Kao et al., 2021), and software engineering (Alseid and Rigas, 2011). Games in healthcare are designed for various applications, including tinnitus treatment (Schickler et al., 2016), auditory attention diagnosis and training (Barbosa and Nunes, 2015), anxiety reduction and tolerance improvement (Johnston et al., 2022), short-term auditory and visual memory examination (Wersényi and Csapó, 2024), and reducing auditory hypersensitivity in individuals with ASD (Zakari et al., 2017; Johnston et al., 2020). Games in training are utilized in contexts such as medical training (Rojas et al., 2015), Levee Patroller training (Schuurink et al., 2008), and environmental positioning (Byun and Loh, 2015; Boukhris and Menelas, 2017; Connors et al., 2014). Games in well-being emphasize motor rehabilitation (Wongutai et al., 2021) and facilitating navigation for visually impaired individuals (Marshall et al., 2015).

Figure 2 illustrates the distribution of publications across four disciplines: education, healthcare, training, and well-being. Most papers (77.3%) were published in the past decade. The game with educational goals has attracted the most attention except for 2015 to 2019 from researchers during different periods. Research on serious games for training increased from 2005 to 2019 but saw no publications in the past five years. People started to invest in healthcare in 2015, and an increasing trend occurred. Only two publications investigated the game for well-being during the last 20 years.

3.1.2 Environment

Tables 1 and 2 show that among the 22 serious games reviewed, the majority (90.9%) were implemented for PC or laptop, making it the most popular platform. In comparison, only 2 games (9.1%) were designed for mobile devices. Most games focused on mental activity, with only 1 game (4.5%) requiring physical exertion. Interaction styles varied across the games: 10 games (45.5%) used a keyboard and mouse, 4

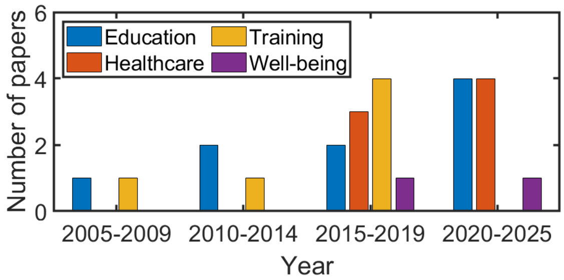

Figure 2: Distribution of publications focusing on four application area categories: Education, Training, Healthcare, and Well-being.

(18.2%) employed touchscreen interaction, 3 (13.6%) relied solely on a mouse, 2 (9.1%) combined movement tracking with touchscreen interaction, and one game each (4.5%) used movement tracking, simple keyboard keystrokes, or a keyboard exclusively.

In terms of game environments, all the games were virtual (100%), with 12 games (54.5%) designed as 3D and 10 games (45.5%) as 2D. Six games (27.3%) incorporated location awareness. Regarding sensory modalities, 20 games (90.9%) involved both auditory and visual elements, while 2 games (9.1%) focused exclusively on auditory input. Additionally, only 2 games (9.1%) were designed for online play.

3.2 Sound Design in Games

Table 3 presents serious games with sound design addressing different learning and behavioral outcomes and impacts. The most frequently reported outcomes were affective and motivational (11) and perceptual and cognitive skills (7), followed by knowledge acquisition and content understanding (4).

The following sound types influence emotion and motivation: sound effects, music, dialogue, and ambient sounds. Sound effects enhance participant engagement by providing auditory feedback (Ke, 2008; Barbosa and Nunes, 2015; Ku et al., 2016), while the dialogue, in the form of voiceover and self-similar sounds, contributes to this engagement as well (Byun and Loh, 2015; Kao et al., 2021). In addition, spatialized sound has a positive effect on improving auditory attention (Barbosa and Nunes, 2015; Johnston et al., 2022). Ambient sounds have been shown to improve navigation efficiency (Schuurink et al., 2008) and reduce anxiety (Johnston et al., 2020, 2022). Music has been shown to improve learning motivation, engagement, immersion, and task performance in the context of a VR shooting exergame (Schuurink et al., 2008). Yang et al. (2019) and Ku et al. (2016) investigated the influence of background music on gamified

Table 1: Categories of Serious Games - Application and Interaction.

Author and year	Application Area	Activity	Modality	Interaction Style
Wersényi and Csapó (2024)	Healthcare	Mental	Auditory, Visual	Mouse
Verwimp et al. (2023)	Education	Mental	Auditory, Visual	Touchscreen
Cao et al. (2023)	Education	Mental	Auditory, Visual	Keyboard, Mouse
Johnston et al. (2020, 2022)	Healthcare	Mental	Auditory, Visual	Motion tracking, Touchscreen
Kao et al. (2021)	Education	Mental	Auditory, Visual	Keyboard and Mouse
Wongutai et al. (2021)	Well-being	PE	Auditory, Visual	Motion tracking
Radecki et al. (2020)	Education	Mental	Auditory	Touchscreen
Yang et al. (2019)	Education	Mental	Auditory, Visual	Keyboard and Mouse
Boukhris and Menelas (2017)	Training	Mental	Auditory, Visual	Mouse
Zakari et al. (2017)	Healthcare	Mental	Auditory, Visual	Touchscreen
Schickler et al. (2016)	Healthcare	Mental	Auditory, Visual	Touchscreen
Ku et al. (2016)	Education	Mental	Auditory, Visual	Keyboard and Mouse
Byun and Loh (2015)	Training	Mental	Auditory, Visual	Keyboard and Mouse
Rojas et al. (2015)	Training	Mental	Auditory, Visual	Keyboard and Mouse
Barbosa and Nunes (2015)	Healthcare	Mental	Auditory, Visual	Keyboard and Mouse
Marshall et al. (2015)	Well-being	Mental	Auditory, Visual	Keyboard
Ferreira and Cavaco (2014)	Education	Mental	Auditory, Visual	Keyboard and Mouse
Connors et al. (2014)	Training	Mental	Auditory	Keyboard
Alseid and Rigas (2011)	Education	Mental	Auditory, Visual	Keyboard and Mouse
Schuurink et al. (2008)	Training	Mental	Auditory, Visual	Keyboard and Mouse
Ke (2008)	Education	Mental	Auditory, Visual	Mouse

Activity: PE = Physical exertion.

Table 2: Categories of Serious Games - Environment.

Author and year	Environment					
	Mobile	Participant	2D/3D	LA	Online	R/V/M
Wersényi and Csapó (2024)	No	University Students	2D	No	No	Virtual
Verwimp et al. (2023)	No	Kindergarten Children	2D	No	No	Virtual
Cao et al. (2023)	No	Adults	2D	No	No	Virtual
Johnston et al. (2020, 2022)	No	ASD adolescents	3D	Yes	No	Virtual
Kao et al. (2021)	No	Adults	2D	No	Yes	Virtual
Wongutai et al. (2021)	No	Adults	3D	No	No	Virtual
Radecki et al. (2020)	No	Blind Children	2D	Yes	No	Virtual
Yang et al. (2019)	No	Uni/highschool students	2D	No	No	Virtual
Boukhris and Menelas (2017)	No	University Students	3D	Yes	No	Virtual
Zakari et al. (2017)	Yes	ASD children	2D	No	No	Virtual
Schickler et al. (2016)	Yes	Tinnitus/healthy	3D	Yes	No	Virtual
Ku et al. (2016)	No	University Students	2D	No	No	Virtual
Byun and Loh (2015)	No	University Students	3D	No	No	Virtual
Rojas et al. (2015)	No	University Students	3D	No	No	Virtual
Barbosa and Nunes (2015)	No	Adults	3D	No	No	Virtual
Marshall et al. (2015)	No	University Students	3D	No	No	Virtual
Ferreira and Cavaco (2014)	No	Visually impaired students	3D	Yes	No	Virtual
Connors et al. (2014)	No	Blind Adolescents	3D	Yes	No	Virtual
Alseid and Rigas (2011)	No	University Students	2D	No	No	Virtual
Schuurink et al. (2008)	No	Adults	3D	No	No	Virtual
Ke (2008)	No	Elementary Students	2D	No	Yes	Virtual

Participant: ASD = Autism spectrum disorder.

learning, indicating that Serialists[2] are generally unaffected by background music, whereas Holists[3] may benefit from mismatched background music in certain contexts. Ku et al. (2016) further suggested that Holists might not consistently prefer listening to music, as they frequently toggled it on and off during tasks.

Sound categories that affect perceptual and cognitive skills include sound effects, music, and ambient sounds. Sound effects have a positive effect on participants‘ cognitive performance. For example, familiar, recognizable sounds can enhance memory retention and accuracy (Wersényi and Csapó, 2024), and sound notification can improve attention (Cao et al., 2023). Spatialized sound effects have a positive effect on perceived location, for example, training tinnitus patients to focus on target sounds and thereby suppress irrelevant background sounds (Schickler et al., 2016), participants identifying the correct direction of sounds (Boukhris and Menelas, 2017), and training blind teenagers in navigation and spatial perception skills (Connors et al., 2014). Ambient sounds such as white noise have had some negative effects, reducing the perception of visual reality by participants (Rojas et al., 2015) and increasing the time taken to complete tasks and reducing the precision of positioning (Schickler et al., 2016).

Sound categories that affect knowledge acquisition and understanding include sound effects, dialogue, and ambient sounds. The dialogue sounds in KlankKr8 have been shown to positively impact learning by reinforcing the association between letters and speech sounds, thereby improving engagement and enhancing performance in letter-speech sound tasks (Verwimp et al., 2023). In the study by Ferreira and Cavaco (2014), conversations were utilized as content in the voice recording game function, encompassing math problems, answers, and feedback. These recordings help students comprehend the content without relying on visual elements. Additionally, in the study by Radecki et al. (2020), sound effects include synthetic sounds across various dimensions, such as frequency (pitch), tone (timbre), and volume dynamics. These sound effects mimic features like color, distance, and geometric edges, enabling visually impaired children to understand images and shapes through auditory perception.

Figure 3 shows the distribution of the number of publications investigated in the four sound design categories mentioned above. It appears that most papers (80%) have been published during the past ten years. The sound effect has always attracted the most attention from researchers during different periods. Research on ambient sound in games has shown an increasing trend from 2005 to 2025. Fewer studies investigate the role of dialogue and music in serious games, likely because their implementation and evaluation are more complex than other sound elements.

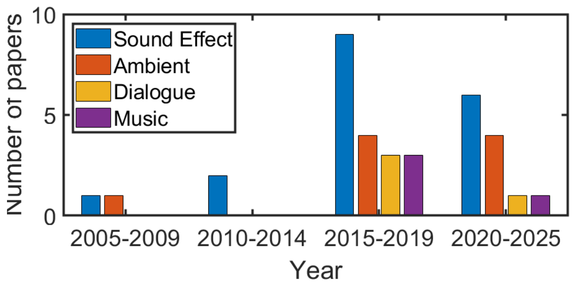

Figure 3: Distribution of publications focusing on four sound categories: Sound effect, Ambient sound, Dialogue, and Music.

3.3 Evaluation Method

Table 3 presents the methods used in the reviewed studies. Of the 22 papers, 10 focused on learning outcomes, 11 focused on user experience, and 1 addressed both. The majority, 17 studies (77%), reported quantitative data, while 5 studies (23%) incorporated both quantitative and qualitative data.

In assessing user experience, most studies employed quantitative methods: 7 (32%) used questionnaires (including 1 qualitative questionnaire), 3 (14%) utilized task performance metrics, 2 (9%) included subjective ratings or rankings, 2 (9%) measured in-game interaction times, and 1 (5%) employed electromyography (EMG).

For learning outcomes, 5 (23%) studies conducted pre-/post-tests, 5 (23%) used task performance metrics, 3 (14%) employed questionnaires, and 2 (9%) measured in-game interaction times. Regarding qualitative research, 2 (9%) studies collected user feedback, while 1 (5%) used interviews and behavioral observations.

The one study that assessed both user experience and learning outcomes incorporated task performance metrics, in-game interaction times, and qualitative user feedback.

[2]Serialists are learners who process information in a structured, step-by-step manner, focusing on details first and building knowledge sequentially.

[3]Holists prefer to process information by understanding the big picture first, making connections between concepts before focusing on individual details.

Table 3: Classification of Sound Design and Evaluation Method.

Author and year	Sound Type	Behavioral and Learning Outcomes	Method	Impact
Wersényi and Csapó (2024)	SE	Perceptual, cognitive skills	Quantitative	Learning outcomes
Cao et al. (2023)	SE, Am	Perceptual, cognitive skills	Quantitative	User experience
Boukhris and Menelas (2017)	SE	Perceptual, cognitive skills	Quantitative	Learning outcomes
Schickler et al. (2016)	SE, Am	Perceptual, cognitive skills	Quantitative	User experience
Marshall et al. (2015)	SE, Am	Perceptual, cognitive skills	Quantitative	User experience
Rojas et al. (2015)	SE, Am, Mu	Perceptual, cognitive skills	Quantitative	User experience
Connors et al. (2014)	SE	Perceptual, cognitive skills	Quantitative	Learning outcomes
Verwimp et al. (2023)	SE, Di	Knowledge acquisition, understanding	Quantitative	Learning outcomes
Radecki et al. (2020)	SE, Am	Knowledge acquisition, understanding	Both	Learning outcomes
Ferreira and Cavaco (2014)	SE	Knowledge acquisition, understanding	Both	Learning outcomes
Alseid and Rigas (2011)	SE	Knowledge acquisition, understanding	Quantitative	User experience
Johnston et al. (2020, 2022)	SE, Am	Affective, motivational outcomes	Quantitative	User experience
Wongutai et al. (2021)	SE, Mu	Affective, motivational outcomes	Quantitative	User experience
Kao et al. (2021)	Di	Affective, motivational outcomes	Quantitative	Learning outcomes
Yang et al. (2019)	Mu	Affective, motivational outcomes	Quantitative	Learning outcomes
Zakari et al. (2017)	SE	Affective, motivational outcomes	Quantitative	User experience
Ku et al. (2016)	Mu	Affective, motivational outcomes	Quantitative	Learning outcomes
Barbosa and Nunes (2015)	SE, Am	Affective, motivational outcomes	Both	Both
Byun and Loh (2015)	SE, Di, Mu	Affective, motivational outcomes	Quantitative	User experience
Schuurink et al. (2008)	Am	Affective, motivational outcomes	Both	User Experience
Ke (2008)	SE	Affective, motivational outcomes	Both	Learning outcomes

Sound Type: SE = Sound Effect, Am = Ambient Sound, Mu = Music, Di = Dialogue. **Method:** Both = Qualitative and Quantitative. **Impact:** Both = Learning Outcomes and User Experience.

4 DISCUSSION, LIMITATIONS, AND FUTURE RESEARCH

Our findings indicate a growing interest in sound design within the context of serious games, particularly concerning its usability and impact, with a notable increase in research since 2015. However, research on sound design has lagged behind the significant advancements in the field of serious games. Given the limited evidence, we discuss our results and highlight key research gaps in the following subsections to provide guidance for future research in this domain.

4.1 Discussion

In addressing RQ1 (What types of serious games and their application domains have been proposed to explore the impact of sound design?), the study confirms that sound design is primarily adopted in education, healthcare, and training. However, other potential domains, such as advertising and interpersonal communication, remain underexplored. Despite the potential benefits of mobile gaming, PC-based implementations dominate serious game development (90.9%), suggesting that accessibility and portability remain underutilized. With their touch controls and sensor-based feedback, mobile platforms offer opportunities for adaptive sound design. Although some applications exist for rehabilitation and language learning, a broader exploration of sound-driven mobile games is needed. Most serious games emphasize cognitive engagement, with minimal focus on physical exertion. However, movement-based learning could benefit significantly from rhythmic cues, spatialized audio, and real-time sonification to enhance motor coordination and immersion.

Addressing RQ2 (What sound design strategies have been implemented in serious games targeting impact on user experience and learning outcomes?), our findings indicate that sound effects, dialogue, music, and ambient sounds contribute to engagement, cognitive performance, and emotional responses, but their implementation varies significantly. While studies highlight the benefits of feedback sounds, voiceovers, and spatialized audio, further research is needed to understand their interaction with learning processes and user characteristics.

While background music can influence user engagement, findings regarding its effects on different cognitive styles remain inconsistent. Few studies examine how auditory elements contribute to cognitive load or how personalized sound environments could optimize learning. Rather than serving as passive background accompaniment, music can enhance motivation, emotional regulation, and cognitive processing by reinforcing narrative elements and guiding user interactions. Future research should explore context-aware adaptive music that dynamically adjusts based on player actions or learning progress. Additionally, synchronized sound cues and rhythm-based feedback may improve attention, retention, and immersion.

Most research focuses on short-term effects, such as engagement and immediate cognitive improvements, with little investigation into long-term impacts, such as learning retention, behavioral change, and sustained motivation. One barrier to longitudinal studies is maintaining participant engagement over extended periods due to resource constraints and scheduling conflicts. Standardized evaluation frameworks could mitigate inconsistencies and facilitate robust comparisons across studies.

4.2 Limitations and Future Research

The scope of our review was restricted to literature available in scientific repositories, which may not fully capture the ongoing development of serious games within the industry. Many serious game platforms have been created and explored without corresponding scientific publications, such as *Scratch* [4], *Alice* [5], and *Kahoot!*. [6] Additionally, commercial companies have made significant contributions to serious gaming, with tools like *Minecraft* [7], *Kodu Game Lab* [8], and platforms like *Celestory* [9] and *Serious Factory* [10]. Given the importance of sound design in these developments, unpublished industry advancements may offer valuable insights.

Future research should investigate a wider range of serious games, covering academic and commercial implementations, to improve understanding of sound design's role in learning. Longitudinal studies are particularly needed to investigate the sustained impact of auditory elements on motivation, knowledge retention, and cognitive skill development over extended periods. Additionally, standardized evaluation frameworks could help mitigate inconsistencies across studies, facilitating more robust comparisons and deeper insights into how different sound design strategies influence user engagement and learning effectiveness.

[4]Scratch: https://scratch.mit.edu/, developed by the Massachusetts Institute of Technology (MIT).

[5]Alice: https://https://www.alice.org/, Carnegie Mellon University (CMU).

[6]Kahoot!: https://www.kahoot.com, developed by Morten Versvik with the Norwegian University of Science and Technology (NTNU).

[7]Minecraft: https://education.minecraft.net/, developed by Microsoft.

[8]Kodu: https://www.kodugamelab.com/, developed by Microsoft.

[9]Celestory: https://www.celestory.io/learning.

[10]Serious Factory: https://seriousfactory.com/en/elearning-solutions/serious-games

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REFERENCES

Alseid, M. and Rigas, D. (2011). The role of earcons and auditory icons in the usability of avatar-based e-learning interfaces. In *2011 Developments in E-systems Engineering*, pages 276–281. IEEE.

Barbosa, L. F. and Nunes, F. L. (2015). Whisperluck: A game using virtual reality to evaluate and train the auditory attention in adults. In *2015 XVII Symposium on Virtual and Augmented Reality*, pages 112–120. IEEE.

Boukhris, S. and Menelas, B.-A. J. (2017). Towards the use of a serious game to learn to identify the location of a 3d sound in the virtual environment. In *Human-Computer Interaction. Interaction Contexts: 19th International Conference, HCI International 2017, Vancouver, BC, Canada, July 9-14, 2017, Proceedings, Part II 19*, pages 35–44. Springer.

Brandon, A. (2004). *Audio for Games: Planning, Process, and Production (New Riders Games)*. New Riders Games.

Byun, J. and Loh, C. S. (2015). Audial engagement: Effects of game sound on learner engagement in digital game-based learning environments. *Computers in Human Behavior*, 46:129–138.

Cao, Z., Magalhães, E., and Bernardes, G. (2023). Sound design impacts user experience and attention in serious game. In *Joint International Conference on Serious Games*, pages 95–110. Springer.

Collins, K. (2008). *Game sound: an introduction to the history, theory, and practice of video game music and sound design*. Mit Press.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., and Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & education*, 59(2):661–686.

Connors, E. C., Chrastil, E. R., Sánchez, J., and Merabet, L. B. (2014). Action video game play and transfer

[11]https: //www.csc.edu.cn.

of navigation and spatial cognition skills in adolescents who are blind. *Frontiers in human neuroscience*, 8:133.

Ferreira, F. and Cavaco, S. (2014). Mathematics for all: a game-based learning environment for visually impaired students. In *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, pages 1–8. IEEE.

Johnston, D., Egermann, H., and Kearney, G. (2020). Soundfields: A virtual reality game designed to address auditory hypersensitivity in individuals with autism spectrum disorder. *Applied Sciences*, 10(9):2996.

Johnston, D., Egermann, H., and Kearney, G. (2022). The use of binaural based spatial audio in the reduction of auditory hypersensitivity in autistic young people. *International journal of environmental research and public health*, 19(19):12474.

Kaczmarczyk, J., Davidson, R., Bryden, D., Haselden, S., and Vivekananda-Schmidt, P. (2016). Learning decision making through serious games. *The clinical teacher*, 13(4):277–282.

Kao, D., Ratan, R., Mousas, C., and Magana, A. J. (2021). The effects of a self-similar avatar voice in educational games. *Proceedings of the ACM on Human-Computer Interaction*, 5(CHI PLAY):1–28.

Ke, F. (2008). A case study of computer gaming for math: Engaged learning from gameplay? *Computers & education*, 51(4):1609–1620.

Ku, O., Hou, C.-C., and Chen, S. Y. (2016). Incorporating customization and personalization into game-based learning: A cognitive style perspective. *Computers in Human Behavior*, 65:359–368.

Laamarti, F., Eid, M., and El Saddik, A. (2014). An overview of serious games. *International Journal of Computer Games Technology*, 2014(1):358152.

Marshall, J. B., Tyson, G., Llanos, J., Sanchez, R. M., and Marshall, F. B. (2015). Serious 3d gaming research for the vision impaired. In *2015 17th International Conference on E-health Networking, Application & Services (HealthCom)*, pages 468–471. IEEE.

Mystakidis, S., Besharat, J., Papantzikos, G., Christopoulos, A., Stylios, C., Agorgianitis, S., and Tselentis, D. (2022). Design, development, and evaluation of a virtual reality serious game for school fire preparedness training. *Education Sciences*, 12(4):281.

Radecki, A., Bujacz, M., Skulimowski, P., and Strumiłło, P. (2020). Interactive sonification of images in serious games as an education aid for visually impaired children. *British Journal of Educational Technology*, 51(2):473–497.

Rojas, D., Cowan, B., Kapralos, B., Colllins, K., and Dubrowski, A. (2015). The effect of sound on visual realism perception and task completion time in a cel-shaded serious gaming virtual environment. In *2015 Seventh International Workshop on Quality of Multimedia Experience (QoMEX)*, pages 1–6. IEEE.

Schickler, M., Pryss, R., Reichert, M., Schobel, J., Langguth, B., and Schlee, W. (2016). Using mobile serious games in the context of chronic disorders: a mobile game concept for the treatment of tinnitus. In *2016 IEEE 29th international symposium on computer-based medical systems (CBMS)*, pages 343–348. IEEE.

Schuurink, E. L., Houtkamp, J., and Toet, A. (2008). Engagement and emg in serious gaming: Experimenting with sound and dynamics in the levee patroller training game. In *Fun and Games: Second International Conference, Eindhoven, The Netherlands, October 20-21, 2008. Proceedings*, pages 139–149. Springer.

Susi, T., Johannesson, M., and Backlund, P. (2007). Serious games: An overview.

Verwimp, C., Snellings, P., Wiers, R. W., and Tijms, J. (2023). A randomised proof-of-concept trial on the effectiveness of a game-based training of phoneme-grapheme correspondences in pre-readers. *Journal of Computer Assisted Learning*, 39(5):1607–1619.

Wersényi, G. and Csapó, Á. B. (2024). Comparison of auditory and visual short-term memory capabilities using a serious game application. *Infocommunications Journal*, 16(2):51–60.

Wongutai, K., Palee, P., and Choosri, N. (2021). The effect of sound in vr exergame to adult player: a primary investigation. In *2021 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering*, pages 1–4. IEEE.

Yang, T.-C., Chen, M. C., and Chen, S. Y. (2019). The effects of background music on game-based learning: A cognitive style approach. *The Asia-Pacific Education Researcher*, 28:495–508.

Zakari, H. M., Poyade, M., and Simmons, D. (2017). Sinbad and the magic cure: A serious game for children with asd and auditory hypersensitivity. In *Games and Learning Alliance: 6th International Conference, GALA 2017, Lisbon, Portugal, December 5–7, 2017, Proceedings 6*, pages 54–63. Springer.