



Technological Approaches for Adaptation and Personalization in Educational Video Games

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Abstract. Nowadays, educational video games are a modern means of implementing various pedagogical practices and learners of different ages and educational levels are trained daily through them. There are various genres of educational video games that combine educational content with engaging gameplay, and this paper presents a brief overview of the most popular of them. The most often applied approaches for game personalization and adaptation are also described. The authors conducted both quantitative and qualitative research on the studied area. A systematic quantitative review was performed according to the PRISMA (Preferred Reporting Items for Approaches for Reviews and Meta-Analyses) methodology, providing a comprehensive overview of publications related to the adaptation and personalization approaches applicable to educational video games. The qualitative research is conducted using a software tool, which enables content analysis of the results obtained through the quantitative research methodology. The final dataset included 246 scientific publications related to approaches for tailoring educational video games, published in the last 10 years in the Web of Science and Scopus databases. The authors derived information on the most popular approaches for describing and managing adaptation and personalization in educational video games across various learning domains and current trends of their evolution.

Keywords: Educational Video Games · Adaptation · Personalization

1 Introduction

As part of serious video games, educational video games are a modern means of implementing various pedagogical practices in 21st-century education. Through educational video games, learners of different ages and levels of education are trained every day,

from elementary school to secondary and vocational high schools, as well as in universities and specialized educational institutes [1–3]. Learners use games to perceive and learn knowledge by playing educational video games and are engaged in their gameplay [4].

Diverse game genres, such as simulation games, puzzle games, role-playing games, adventure games, strategy games, etc., allow the development of various educational video games with different pedagogical and learning goals [5]. These learning tools, particularly, can be customized according to different target criteria for learners and adapted to their specific and changing needs [6]. These possibilities for personalization and adaptation make educational video games a modern and relevant tool for learning and teaching at different levels and fields of education globally [7–9].

The paper aims to present a literature review in the area of modern models, methods, and tools for the description and management of adaptation and personalization in educational video games dedicated to STEM (Science, Technology, Engineering, and Mathematics) [7]. The motivation behind this study lies in the authors' previous research experience in the field of design and implementation of adaptable video games in various learning domains. Additionally, some of the authors are involved in a study on approaches used in teaching STEM disciplines, where educational games are among the most engaging ones. The researchers search for suitable technical approaches and methods that can be applied in the creation of such video games, namely: (1) What aspects of the game are appropriate for adaptation: learning and gaming content; type of gameplay, rules, challenges, feedback, and hints; look and feel of the NCPs (non-player characters), etc. (2) How can educational video games be adapted through formal descriptions and methods for realization? (3) How can current models for declarative descriptions in serious educational video games be categorized?

The study aims to identify the modern technological approaches for adaptation and personalization in educational video games, together with contemporary trends of their evolution in the era of massive invasion of Generative Artificial Intelligence (GAI) [10]. Researchers also investigate how GAI can enhance the emerging trends and innovations in serious educational video games that may influence adaptability and personalization. The research questions arising from the goal are as follows:

- (RQ1) What are the most popular and effective approaches for describing and managing adaptation and personalization in educational video games (desktop, Web, mobile, or console games) and in any learning domain?
- (RQ2) What are the current trends for describing and managing adaptation and personalization in educational video games in the epoch of GAI?

The paper continues with a research background and a literature review on the most popular genres of educational video games, as well as approaches for their personalization and adaptation. The third section presents the methodology of this quantitative and qualitative research. The paper then continues with the research results, encompassing approaches for tailoring educational video games published in the last 10 years in the Web of Science and Scopus databases. In the next section, the authors discuss the implications of the gathered results on the research area. The paper concludes with a summary of the results, an overview of the study's limitations, and the researchers' plans for future work.

2 Background

2.1 Genres of Educational Video Games

There is a wide variety of educational video game genres, and all of them combine learning content with engaging gameplay. Below, a short description of the most popular ones is presented. Each game is designed for a specific age group, whereupon the starting player's age varies from 8 up to 16 years.

Puzzle games – here, players solve different types of logically structured problems and tasks using reasoning. Learners progress through the game by going through different challenges while improving their memory, logical thinking, and pattern recognition. In this way, critical thinking, as well as cognitive and problem-solving skills, are developed [11]. *Examples:* Quantum Moves¹, GeoGuessr², Sudoku, and escape rooms.

Simulation games – aim to represent real systems or processes and allow users to experiment with the parameters [12]. The environment is controlled, which prevents negative consequences. This fact encourages players to learn more about the studied matter in various subjects, for example, science, engineering, and technology. The experience with these types of games develops creativity, critical thinking, problem-solving, and practical skills. They also promote teamwork and resource management. *Examples:* Flight and medical simulations, and Minecraft: Education Edition³.

Testing games aim to assess the players' knowledge of the studied subjects through quizzes and challenges. Educational games based on trivia are widely used in classrooms and are appropriate for different subjects. During gameplay, the learners answer questions to earn points or progress in the game. Thus, they study facts and knowledge from different fields in an interactive way and reinforce their retention through repetition and competition [13]. The testing games encourage collaborative learning and peer interaction. *Examples:* Kahoot!⁴ and QuizUp⁵.

Strategy games require players to plan and make decisions to achieve the set goals [14]. They often involve resource management and tactical thinking. *Examples:* Turn-based (for instance Habitat⁶) and real-time strategy games (Genius: Biology⁷).

Sandbox video games have open worlds that allow players to explore and interact with the game environment freely. These games encourage creativity, experimentation, and problem-solving. They build players' strategic planning and decision-making skills, making them effective learning tools. These games enhance understanding of complex systems and their consequences. *Example:* The sandbox edu⁸.

Role-playing games (RPGs) – here, the players assume the roles of characters in fictional or realistic scenarios. This type of game often includes quests and story-driven

¹ <https://scistarter.org/quantum-moves-2>.

² <https://www.geoguessr.com/>.

³ <https://education.minecraft.net/en-us>.

⁴ <https://kahoot.com/>.

⁵ <https://quizup.app/>.

⁶ <https://tobiaslarson.itch.io/habitat>.

⁷ <https://www.igdb.com/games/genius-biology>.

⁸ <https://www.thesandboxgame.com/education>.

gameplay. In an educational context, RPGs can motivate learning through developing a character and narrative [15]. Learners improve their skills and subject knowledge imperceptibly by increasing their character's level and progressing in the game. In this way, RPGs encourage creativity, teamwork, and problem-solving skills. *Examples:* DragonBox⁹ and Classcraft¹⁰.

Adventure games include exploring, narrating, and solving various tasks during gameplay. The quests contain educational matters and follow the storytelling context. These games require problem-solving in studied subjects, such as history, geography, or science. The choices which players make often influence the outcome of the game. In this way, the adventure games improve critical thinking and encourage exploration and curiosity about different subjects [16]. *Examples:* The Oregon Trail¹¹ and Zoombinis¹².

Each genre offers distinct benefits that align with the various learning styles and educational objectives. The student's motivation and the improvement of the learning process are facilitated by interactive gameplay. For this reason, the games are effective tools for teaching a variety of subjects.

2.2 Personalization and Adaptation of Educational Video Games

Recently, the terms related to personalization and adaptation have been increasingly used in educational contexts. Personalized, individualized, and adapted learning are student-centered approaches that aim to accommodate the educational process to meet the different needs of learners [17]. One of the popular definitions of personalized learning considers it an instructional approach optimized for the needs of each learner, where the pace of learning, learning objectives, activities, and content (together with their sequencing) may differ regarding learner needs and interests [18]. Thus, personalization and adaptation are considered methods for providing users with customized experiences adapted to suit their profiles, including prior knowledge, needs, and preferences [19]. Usually, it is achieved by a tailored interface and customizable content, suggestions, or feedback based on the learner's performance and behavior. The key difference between personalization and adaptation is that the former is usually prior and proactive, aimed at creating a tailored experience according to the pre-defined learner characteristics. The adaptation is mainly reactive, adjusting the learning process considering the real-time data about the learner's performance and engagement [20].

Similarly, personalization in educational video games refers to creating or selecting game features that align with the learner's characteristics, including specific goals, prior knowledge, age, and learning or playing styles. It may involve recommending learning and gaming content, e.g., based on a learner's preferences or previous interactions. Adaptation of educational video games encompasses dynamically adjusting game elements, such as content, difficulty level, presentation style, or interface, considering the learner's engagement and performance [21]. It focuses on maintaining an optimal challenge level to keep learners involved.

⁹ <https://dragonbox.com/>.

¹⁰ <https://www.studentcenteredworld.com/classcraft/>.

¹¹ <https://oregontrail.ws/games/the-oregon-trail/>.

¹² <https://www.zoombinis.com/>.

Much research suggests diverse ways to enhance learning experiences through personalization and adaptation of educational video games [20–23]. The main approaches are the following: *User-centered approach* – it focuses on the individual player’s features, taking advantage of data from user interactions to adapt the game experience, e.g., adjusting game difficulty and providing hints or challenges based on the player’s performance and skill level. *Teacher-centered approach* – it is based on educators’ views on the learning objectives and the students’ needs. Teachers select or modify game content and challenges or assign specific game levels and learning paths based on the assessment of students’ abilities and progress. *Designer-centered approach* – it reflects research and the game designers’ experiences and best practices in integrating adaptive learning elements into the game, based on theories of engagement and learning, considering the anticipated player types and learning outcomes. *Platform-centered approach* – it takes advantage of specific platform capabilities (e.g., AR, VR, mobile sensors) to provide an enhanced gaming experience using adaptation based on the features enabled by the platform on which the game is played, e.g., location, device type, or connectivity.

Personalization and adaptation of educational games can be achieved through several additional approaches [22]. They are as follows: *contextual tailoring* of game experience based on real-world factors, e.g., current events, particular location, etc. *Performance-based tailoring* of the game experience is based on the player’s performance metrics and achieved learning outcomes. It includes dynamic difficulty adjustment of the provided tasks based on the level of the player’s performance and uses real-time feedback to adjust the learning path accordingly. *Social-collaborative tailoring* is based on the dynamics of players’ collaboration, reflecting peer feedback and group performance. This approach is suitable for multiplayer educational games where challenges are adapted based on the team’s collective performance. Combining elements from several approaches enables the creation of motivational and engaging educational games tailored to individual characteristics and learning contexts [23].

3 Methodology

The survey applies both quantitative and qualitative research approaches to get deep insight into the research area. For quantitative analysis, the Preferred Reporting Items for Approaches for Reviews and Meta-Analyses (PRISMA) methodology, which allows a transparent, systematic quantitative review and gives a complete view of the publications concerning the adaptation and personalization approaches applicable to educational video games, is applied. The qualitative research is performed through the software tool ATLAS.ti.

The relevant search query that embraces appropriate terms, such as education, computer game, video game, learning game, serious video game, adaptation, personalization, tailoring, and customization, is used to reveal the most used approaches to adaptation and personalization of educational video games. The query is:

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SQ = ("education* computer game*" OR "education* video game*" OR "learning game*" OR "serious video game*" OR "serious computer game*" OR "mobile game*") AND (personali* OR adapt* OR customi* OR tailor*)
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The two most common scientific databases (Scopus and Web of Science) are investigated using this search query. It was passed to them on 26 March 2025, and only results within the last ten years, from 2015 until now, are observed. The search takes into consideration publications in English only representing journal articles, conference papers, books, and book chapters. The results obtained from search queries from both scientific databases are merged, and duplicates are excluded. Then, a quantitative analysis following PRISMA guidelines is performed to gain a complete view of the investigated topics [24]. After that, three researchers carefully read the abstracts of the extracted publications to determine if they are eligible and conform to the survey goals. Finally, researchers compared the given evaluations and decided if each publication was qualified for further content analysis. Figure 1 provides stages of the PRISMA methodology for systematic reviews, which were applied as follows:

1. Using the search query addressing the approaches for tailoring educational video games, the authors found 432 scientific English publications in the Web of Science database and 553 in Scopus (journal and conference papers plus books and book chapters), i.e., 985 in total, for the period 2015–2025.
2. The authors removed 362 duplicates, which resulted in a raw dataset of 623 items.
3. The following inclusion criteria are applied to choose relevant studies: (1) focus on video games; (2) detailed descriptions of relevant approaches and methods for personalization and adaptation; (4) journal articles, conference papers, books, and book chapters; (5) English-language articles.
4. The exclusion criteria were: (1) articles unrelated to educational games, (2) papers lacking an extensive description of game personalization and/or adaptation, and (3) articles not related to our research questions. As a result, there were removed by manual reviewing 321 not-relevant publications being out of the context of the research questions. Thus, the cleaned dataset has 302 eligible publications.
5. The sorting-by-citation process resulted in 191 cited publications. To them are added all the publications published since the beginning of 2023 till now because they could be influential but not yet cited. All documents dated before 2023 and without citations were excluded, considering they do not impact the research area. The results included publication title, authors, authors' institutions, abstract, keywords, DOI, Web address, and citation count.

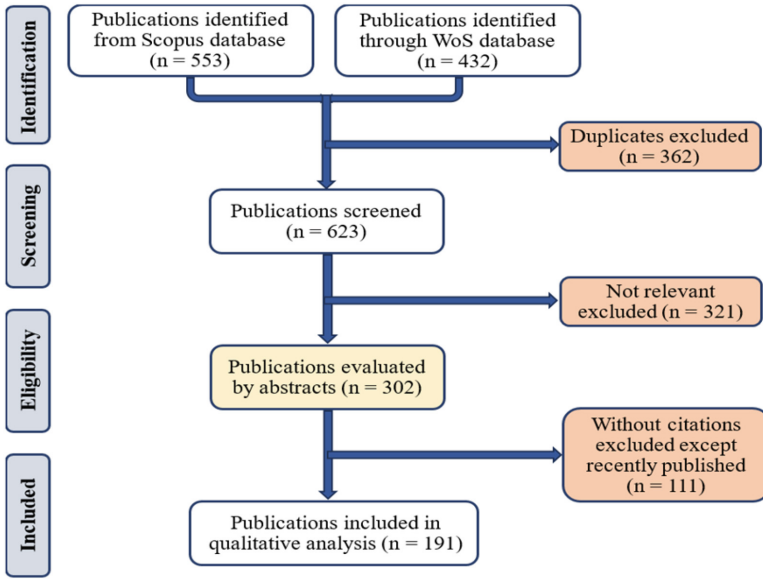


Fig. 1. Stages of PRISMA methodology for systematic reviews.

4 Results

A special coding scheme was developed for turning qualitative data into quantifiable information, where significant themes and concepts were classified into several groups. The most important groups of codes were (1) “Approaches for tailoring educational video games (How?)” and (2) “Objects of tailoring in games (What?)”. Through the analytical query and visualization tools in ATLAS.ti, the authors founded several main research lines across found publications. Concerning group (1), the answers to the question “How?” include approaches for tailoring educational video games based on:

1. Learner outcomes – search query (SQ): (outcome* OR performance*)
2. Emotional state – SQ: (emotion* OR arousal*)
3. Learner model – SQ: (profile* OR model* OR characteristic*)
4. Learning/playing styles – SQ: (learning OR playing) AND style*)
5. Preferences and goals – SQ: (preference* OR goal*)
6. Age – SQ: age
7. Gender – SQ: gender

These search queries about learner-centric tailoring approaches were added as suffixes one by one to the general context of the study represented by a contextual search query CSQ1 = (approach* OR method* OR model* OR framework*) AND (personali* OR adapt* OR tailor* OR customi*) AND (education* OR learn*) AND game* AND (student* OR learner* OR player*). The numbers of publications in English, found for the last 10 years (2015–2024) in Web of Science (WoS) and Scopus databases by the modifications of SQ1 are presented in Fig. 3, including their exponential trends shown in dotted lines.

For the group (2), the answers to the question “What?” determine the objects of learner-centric tailoring, as follows:

1. Learning content – SQ: (learning OR didactic) AND content
2. Learning difficulty – SQ: (learning AND difficulty)
3. Gameplay (or one of its components) – SQ: gameplay AND (mechanic* OR dynamic* OR aesthetic*)
4. NPC (i.e. non-player characters) – SQ: NPC OR “virtual hero*” OR “non-player character*”

They were added stepwise to the general context of the research represented by a contextual search query CSQ2 = (approach* OR method* OR model* OR framework*) AND (personali* OR adapt* OR tailor* OR customi*) AND (education* OR learn*) AND game* AND (student* OR learner* OR player*) AND (outcome* OR performance* OR age OR gender OR preference* OR goal* OR style* OR emotion* OR arousal OR profile*). The numbers of publications in English, found last 10 years (2015–2024) in WoS and Scopus databases by the modifications of SQ1 is presented in Fig. 4, including their exponential trends shown in dotted lines.

AQ2

For outlining the impact of the different tailoring approaches and personalized features of educational video games, the authors have chosen to compare the metrics of mean (M) and standard deviation (SD) for each of the sequences of number of publications represented in Figs. 2 and 3. Table 1 provides M and SD for the publications about the tailoring approaches and Table 2 represents M and SD for the literature about the objects of tailoring in games.



Fig. 2. Numbers of publications by years found in Scopus and WoS according the answers to the question “How?” (bases for approaches for tailoring educations video games).

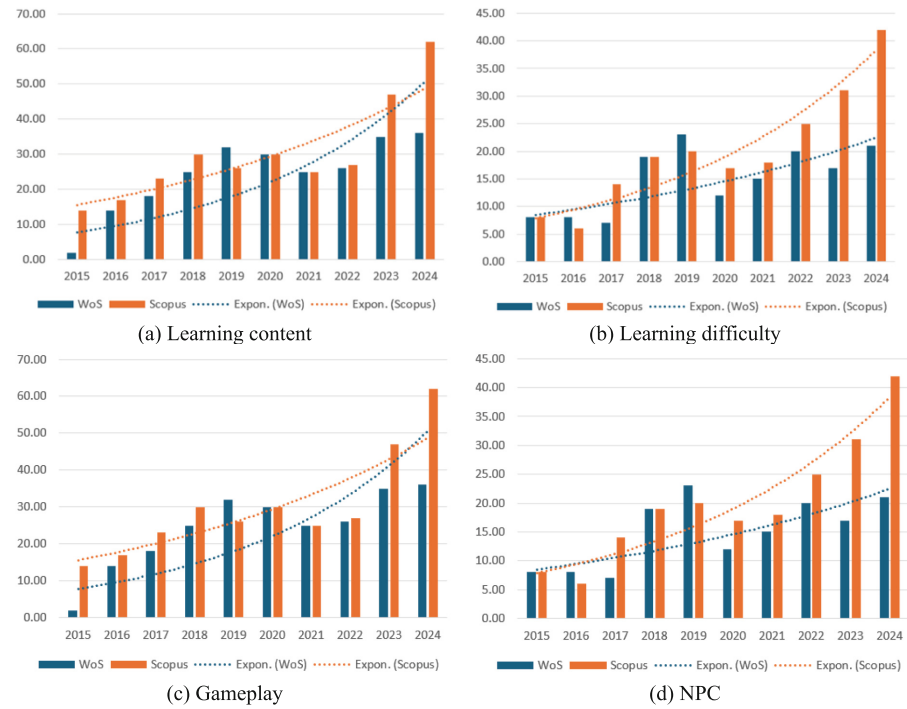


Fig. 3. Numbers of publications by years found in Scopus and WoS about the answers to the question “What?” (objects of tailoring in educations video games).

Table 1. Comparison of mean values and standard deviation for the numbers of publications about the game tailoring approaches (answers to “How?”).

Approach for tailoring	WoS		Scopus	
	M	SD	M	SD
Learner outcomes	97.60	36.85	116.40	58.65
Emotional state	18.00	8.00	23.80	12.51
Learner model	34.00	6.43	37.40	10.55
Learning/playing styles	14.80	5.29	18.40	7.35
Preferences and goals	46.50	10.28	57.40	27.35
Age	23.10	8.41	19.90	10.12
Gender	7.70	3.56	8.10	6.01

Table 2. Comparison of mean values and standard deviation for the numbers of publications about the tailoring game features (answers to “What?”).

Object of tailoring	WoS		Scopus	
	M	SD	M	SD
Learning content	24.30	10.49	30.10	14.29
Learning difficulty	15.00	5.93	20.00	10.65
Gameplay	43.50	13.13	50.70	27.16
NPC	1.50	0.71	2.50	1.96

5 Discussion

This systematic literature review provides valuable insights into the current state and trends of adaptation and personalization approaches in educational video games. The findings reveal distinct patterns in both the methodological approaches employed and the game elements targeted for customization. These patterns provide clear answers to the research questions that guided this investigation.

Addressing the first research question (RQ1), the quantitative analysis demonstrates that learner outcome-based approaches dominate the field, with the highest mean publication counts across both databases (WoS: $M = 97.60$, $SD = 36.85$; Scopus: $M = 116.40$, $SD = 58.65$). This finding suggests that performance-driven adaptation remains the most extensively researched and likely most effective method for personalizing educational video games. The substantial standard deviations indicate significant variability in research interest over the examined period, possibly reflecting the evolving sophistication of assessment technologies and learning analytics.

Preferences and goals-based approaches rank second in popularity (WoS: $M = 46.50$; Scopus: $M = 57.40$), indicating growing recognition of learner agency and self-determination in educational gaming contexts. Interestingly, learner model-based approaches show relatively stable research interest with lower standard deviations, suggesting consistent but moderate attention to formal learner modeling techniques. Gender-based adaptation shows the lowest research interest (WoS: $M = 7.70$; Scopus: $M = 8.10$), which may reflect the limited effectiveness of gender-based personalization.

Regarding the second research question (RQ2), recent publications from 2023 onward signal GAI appears to be an emerging trend. The exponential growth trends shown in the figures suggest increasing research momentum, particularly in learner outcome and emotional state approaches, which align well with GAI capabilities for real-time content generation and emotional recognition. When choosing what game elements to personalize, gameplay adaptation emerges as the most researched area (WoS: $M = 43.50$; Scopus: $M = 50.70$), followed by learning content adaptation. This prioritization

makes pedagogical sense, as gameplay mechanics directly influence engagement and learning effectiveness. The relatively high standard deviations for gameplay adaptation suggest this remains an active research area.

The dominance of learner outcome-based approaches suggests that educational game developers should prioritize performance-based tracking and adaptation mechanisms. The relatively lower attention to emotional state adaptation (despite its moderate research presence) indicates an opportunity for game developers and researchers to stand out their educational games by incorporating affective computing technologies. On the other hand, despite its high potential, the NPC adaptation has received minimal research attention (WoS: $M = 1.50$; Scopus: $M = 2.50$), representing a significant gap in the literature. The capabilities of GAI to generate intelligent, responsive virtual agents represent a promising area for future research and development.

6 Conclusion

The paper presented a literature review of adaptation and personalization approaches in educational video games, providing valuable insights into the current state of the arts and existing trends of their evolution. The results of this study revealed clear patterns in the methods employed and the game elements selected for personalization. The obtained research results answered the research questions posed in the paper.

The study was conducted following several limitation criteria set while planning this research: (1) The period for the search of publications includes only the last 10 years, i.e., 2015–2025. This limitation was purposefully set, taking into account the research questions and the relevance of contemporary trends in scientific developments in the research area. (2) The selection of scientific databases in which to conduct the study was restricted to Scopus and Web of Science since they are world leaders in indexing valuable and globally recognized scientific publications and developments. (3) In terms of relevance to the research questions, the applied criterion was based on the initially obtained data to eliminate publications that are not related to the topic of adaptation and personalization approaches in educational games, nor the research questions posed.

As future work, a more in-depth analysis and study of generative artificial intelligence and its application in combination with NPC adaptation are planned, as these technologies are newly emerging and have yet to gain more popularity and development, along with various opportunities for managing adaptation and personalization in educational video games.

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