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Adaptive game-based learning in education: a systematic review

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The advent and abundance of mobile devices and network connectivity have provided learners of all ages with access to potentially unlimited sources of educational material, from pre-school activities to conventional and after-school courses and continuing education. One of the challenges that learners face is how to locate and access interesting contents suited to their preferences and, more importantly, to the level of expertise and individual needs. From the point of view of content creators and educators, adapting the content and the experience to each learner usually leads to better user retention and a more meaningful and deeper learning experience. In this study, we utilized the PRISMA review methodology to examine research on content and experience adaptivity in educational contexts and report on the authors' findings. Consisting of well-defined steps (keyword-based retrieval, study scope definition, result filtering, and grouping and analysis), the systematic nature of this methodology ensures its objectivity and replicability at a future stage or replicated by other researchers.

KEYWORDS

adaptation, personalization, content-generation, game-based learning, games, education

1. Introduction

According to the 2021 Mobile Customer Engagement Benchmark Report (Apptentive, 2022), movement and schooling restrictions during the COVID-19 pandemic not only resulted in a major shift in teaching paradigms but also affected user retention in educational apps, which scored an average of 4% compared with the overall average of 35%. Among the issues stated in the report, application behavior and performance topped the list, but the need for content updates was evident among the phrases used in application reviews and messages to customer support services. While the former may be the result of applications being developed and deployed in a rush so as to answer the towering need during the pandemic, the requests for content updates may reflect the uniformity of teaching and evaluation material supplied by those apps.

Alshammari et al. (2016) discussed adaptivity in the context of e-learning and their results indicated that the adaptive version of their learning system had better results in learning effectiveness and perceived usability level, which (according to their analysis) may lead to learners who are more satisfied, engaged, and motivated. The conceptual advantages of adaptivity in a learning system have to do with identifying or selecting the particular areas of interest for each learner and providing them with teaching material and activities suited to those needs; beyond this approach, Mavrikis et al. (2019) and Tsatiris and Karpouzis (2021) designed an adaptive system which responds not only to the particular aspects of language that need to be taught but also to the competence level of each learner: beginning students are presented with introductory material, which they need to master in order to proceed to more advanced aspects, while better performing or more advanced learners skip this part and focus on more sophisticated gameful exercises, avoiding the inevitable boredom of going through a content that is too easy for someone's level, according to Karpouzis and Yannakakis (2016).

Alshammari et al. discussed the appeal of adaptive behavior to learners, stating that it "may influence learners to believe that the system would support them dynamically in accordance with their knowledge and preferences," while making the e-learning system easier to use and improve their engagement.

In terms of engagement with learning material, research has shown that it can also be positively affected by introducing *digital games* as a complement to conventional teaching. In the study by Vargianniti and Karpouzis (2019), we utilized *Geopoly*, a clone of the popular Monopoly board game, where the street names were replaced with European countries and tested it in the context of a relevant module of a primary school Geography course. The results showed that students in the experimental group not only showed better performance compared with their fellow students who used only the standard material but were also more motivated and showed more interest in the course. This review was conducted to investigate whether the results of game-based learning methods, with the use of personalized games in various contexts, met the educational needs of the 21st century and contributed to the educational process. The *Preferred Reporting Items for Systematic Reviews and Meta-Analyzes* (PRISMA) (Page et al., 2021) methodology was used for the systematic review of implementations of adaptive GBL. Essentially, PRISMA consists of a sequence of well-defined steps, outlined in the next section (cf. Figure 1), which help retrieve research studies from one or more repositories, based on the queries defined by a set of related keywords, defining the scope of the study by eliminating some of these studies following pre-defined rules (usually referring to when a study was conducted or published or to the instruments used) and finally grouping the remaining studies so that they can be analyzed more thoroughly. The systematic nature of this methodology ensures that there is no room for subjective decisions, which would reduce the validity of the selection process, and, hence, the results of the review can be replicated at a later stage or replicated by other researchers.

The following sections describe the necessary information for this method, i.e., the sequence of systematic steps to conduct the review and a flow diagram is presented in Section 2, while Section 3 presents the selection of studies that corresponds to the scope of the review. Finally, Section 4 provides details on the findings of the reviewed studies and draws conclusions across different approaches, and Section 5 concludes our study.

2. Review methodology

A systematic review methodology was used to identify how an adaptive game-based learning (GBL) approach is applied in education. It is important to identify the subjects (number and gender) that used the educational content, the scope of the adaptation that has been done in the game, and whether there are positive or negative results.

In this systematic review, all studies were published after 2010 and up to 2022. The review methodology is presented in Figure 1.

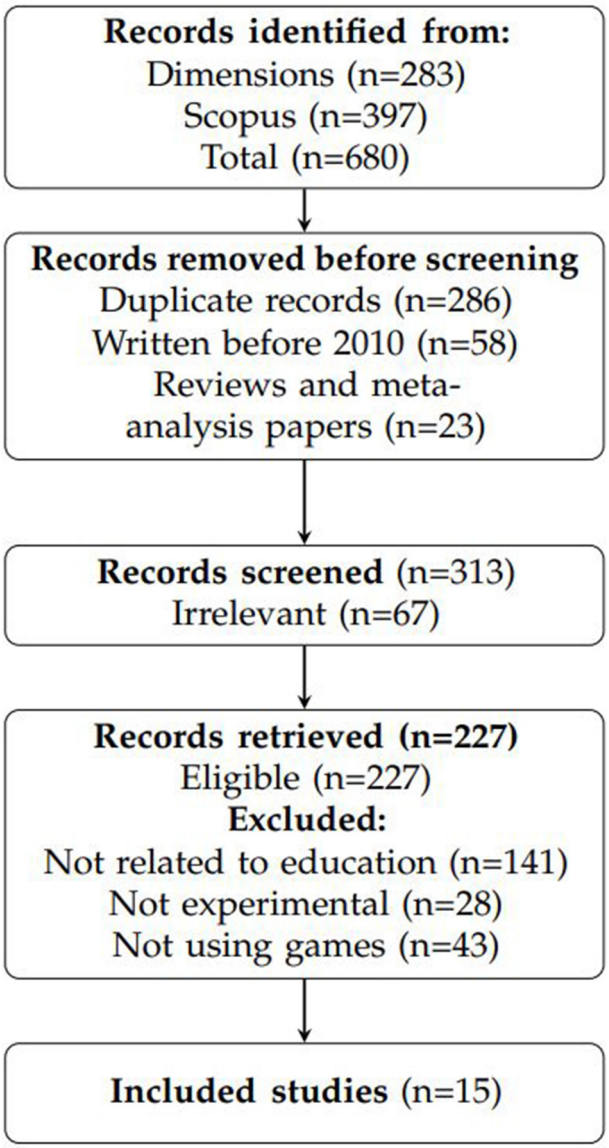

FIGURE 1
Review methodology.

2.1. Search criteria

The following word groups were used for the search: "*personalized GBL*" OR "*adaptive GBL*" OR "*personalized game-based learning*" OR "*adaptive game-based learning*" OR "*adaptation of game based learning*" OR "*customization of game based learning*" OR "*adaptive game*" OR "*adaptive educational game*" OR "*adaptive digital educational game*" OR "*personalized educational game*" OR "*personalized digital educational game*".

Our aim was to identify research efforts based on game-based learning, individualized or adapted on a case-by-case basis in its application to the characteristics of the game or its content. The scope of the educational intervention could be any learning space (formal or informal, in class or after school, and online or in person)

and any level of education, without restrictions on the learning subject.

To be taken into consideration in the review, an article should include research that has been carried out in a school environment and concerns the use of a game that is adaptable and does not have a specific flow or content selection for all students. During the process, we rejected research efforts utilizing GBL concepts but conducted in areas other than education, such as medicine or physiotherapy. Reviews and articles that refer to the subject were also excluded. Moreover, articles written after 2010 were selected.

2.1.1. Information sources

The search engines that were used are Scopus and Dimensions. These search engines were used because they are known for the quality and high impact of the research they contain (Tsai et al., 2012). An additional advantage of them is that they allow researchers to export the results of a query, in order to group and edit them. Surveys were not excluded in this phase of the review, but later, when the results were submitted to EndNote for further processing.

2.1.2. Selection process

Since the results were entered into a single database on EndNote, the results with the words *review* and *meta-analysis* were rejected. In the process, the titles of the results were screened in order to reject those that did not have the application in the educational field as their object, did not concern any research, or were not related to the GBL method.

3. Results

3.1. Study selection

The initial results of the survey included 283 studies from the DIMENSIONS search engine and 397 from the Scopus search engine. Out of these 680 results, the duplicates that were rejected were 286. From the remaining 394 articles, the ones which have been written since 2010 until today were selected, and reviews were separated from the 336 articles. Of the last 313 remaining articles, the rest were carefully examined and 298 were excluded because they did not meet the criteria that had been set from the beginning. This process is presented in Figure 2, while Table 1 shows an overview of the 15 remaining studies, including information on their subjects and number of subjects they were tested with.

4. Discussion

Table 2 presents the scope and objectives of each of the studies corresponding to the review selection process; the next subsections discuss the studies in more detail, focusing on their individual contribution, outcome evaluation processes, and utilized means of adaptivity.

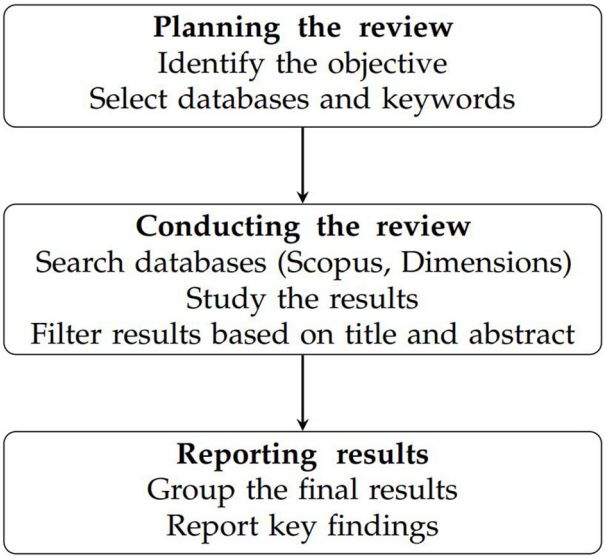

FIGURE 2
Flow diagram for the PRISMA method.

4.1. Evaluating effectiveness

Our review revealed the wide range of applications of adaptive GBL in education. Approximately half of the surveys used a game that could be personalized in the student's profile, aiming to test its usability. The other half compared a personalized game with a one that presented students with predetermined sets of content, to draw conclusions about what is most interesting or useful to students. Almost all surveys used pre-test and post-test to compare performance, as well as questionnaires, mainly to test for usability. In addition, in the research of Leonardou et al. (2019), the trainers were interviewed about the educational role of the game. In addition to this, research projects comparing adaptive games with non-adaptive ones or using adaptive games to test their effectiveness have shown that they have better results in improving student performance, boosting self-confidence, motivation, engagement, and interest (Hwang et al., 2012; Conati et al., 2013; Papadimitriou and Virvou, 2017; Brinkhuis et al., 2020; Vanbecelaere et al., 2021; Hooshyar, 2022), even with older students or more advanced study subjects (Legaki et al., 2019).

Some studies aimed to test not only the effectiveness of a game but also to check if there would be a difference in the criteria they controlled, by modifying the degree of adaptability. Three studies observed no significant difference between the different versions of the game, except from an increase in performance and interest of children, respectively (Peirce and Wade, 2010; Nguyen et al., 2018; Vanbecelaere et al., 2021). More specifically, in terms of game personalization in the research by Brinkhuis et al. (2020), the customizable element of the game changes from the object response theory and is based on the Elo rating system combined with response times. This model calculates the student's ability and the difficulty of the subject.

The personalized AutoThinking game used in Hooshyar's research was adaptable to both the learning process and its rules.

TABLE 1 Overview of results.

Paper	Research field	Objective of the game	Subjects	Age
Vanbecelaere et al. (2021)	Mathematics	Number sense game-early childhood mathematics	84	6-7
Leonardou et al. (2019)	Mathematics	Multiplication's game	41 (23 M + 18 F)	8–9
Papadimitriou and Virvou (2017)	Technology	HTML language	28	13–15
Hooshyar (2022)	Mathematics	AutoThinking-computational thinking	79 (45 M + 36 F)	11–12
Brinkhuis et al. (2020)	Mathematics	Math garden	13,578	5–14
Vanbecelaere et al. (2020)	Language	Reading game (RG)-Reading skill	191 (114 M + 77 F)	4–5
Nguyen et al. (2018)	Mathematics	Decimal point	159 (82 M + 77 F)	10–11
Peirce and Wade (2010)	Foreign languages (German)	Language trap	83 (38 M + 45 F)	14
Hwang et al. (2012)	Physics	Knowing campus plants (role-playing game)	46	10
McCarthy et al. (2020)	Language	iSTART-Reading skill	113 (62 M + 51 F)	16–18
Monterrat et al. (2017)	Foreign languages (French)	Projet voltaire	59 (28M + 31F)	14–15
Tsai et al. (2012)	Language	Whac-a-mole-based language puzzle, trained using learners' recorded emotional states	90	6–7
Kickmeier-Rust et al. (2011)	Geography	80 days	109 (63 M + 46 F)	11–12
Stefanidis et al. (2019)	Prosocial skills	Path of trust	20	7–10
Conati et al. (2013)	Mathematics	Prime climb	13 (7 M + 6 F)	10–12

More specifically, it was tailored to the level of students' skills and provided personalized feedback, help, and guidance (Hooshyar, 2022).

In the research by Hwang et al. (2012), which aimed to examine whether a personalized game contributes more to the learning process, the game was adapted to the learning profile of each student, provided that the students' level of knowledge, their motivations and the level of their self-control had been determined in advance. Based on the results from the measurements of these factors, the game environment was created in the personalized game. Similar research by Tsai et al. (2012) used facial emotion for determining the challenge level of the game or the learning content. Each group has a different adaptation depending on the recorded emotions. In the first group, the difficulty of the game was adapted, while in the second group, it was the learning content of the game which was adapted; in the third group (control group) there was no adaptation.

The game created by Leonardou et al. (2019) employed an algorithm to identify the weaknesses of each student individually and help them to overcome them. For example, at each point where a difficulty was identified, the game repeated the exercise so that the student could improve through repetition.

4.2. Means of adaptivity

Nguyen et al. (2018) offer a different approach to personalized games in their research, which uses two different versions of the same game. The difference lies in the self-action in each game (low-agency, high-agency). In the low-agency version, the order is predetermined, and the player has no jurisdiction over it, while in the high-agency version, the player is in control of learning. For example, learners can choose the order of the themes of the game, they can end the game once they have reached the middle of each theme, and they can even choose if they want to play some of the themes with extra content. These differences and options mean that, while in the low-agency version of the game players play 48 mini-games, in the high-agency version they can play from 24 to 72.

In Papadimitriou and Virvou's research, their game offered personalized help when needed and was individualized based on the student's level determined at the beginning of the game by a test. The main feature of the game was the ability to expand the script based on the weaknesses of each player, which appeared during the game, aiming to mobilize students and engage them in the game by providing them with a new environment or increasing the time available to complete the game (Papadimitriou and Virvou, 2017).

In the game created by Peirce and Wade for learning German as a foreign language, personalization emerged from the ALIGN system. This system provides four forms of personalization which are dialogs of adapted difficulty, performance-based feedback, and motivation and metacognitive reasoning. Great care was taken so that all customizable functions have a non-intervening nature in order to not alter the gaming experience (Peirce and Wade, 2010).

In the research by Vanbecelaere et al. (2020), the duration of the game and the game itself remained fixed. However, what changed were the parameters depending on the students' correct answers. The two versions of the game (adaptive and non-adaptive) displayed all the stages of the game in order so that no letter of the alphabet is omitted in this letter learning game. In the non-adaptable game, the exercises were 20, in contrast to the adaptable where the number changed based on the performance. In particular, the number of exercises increased when the student had difficulty.

In another research from the same authors (Vanbecelaere et al., 2021), the game was adapted based on the Elo-rating algorithm, as in the research by Brinkhuis et al. (2020). The parameters were

TABLE 2 Study objectives, method, and conclusions.

Study	Study objectives	Method	Conclusion
Vanbecelaere et al. (2021)	Investigating the effectiveness of an adaptive game compared to a non-adaptive one in terms of cognitive and non-cognitive outcomes	78 children from the 1st grade of three different schools participated. 39 used the non-adaptive NSG game, while 45 children used the same game adapted with a psychometric model based on the "Elo-rating algorithm"	The results revealed that the adaptive environment performed better for the students. This result came from the students' score (pre-test, post-test) and from the time they spent in the game. The results showed that the children improved their arithmetic ability. In addition, students who played the adapted game learned more efficiently. Finally, low-achieving students initially benefited more from unadapted play, while high-performing students did the opposite
Leonardou et al. (2019)	The aim was to learn the multiplication table through a game that was adapted according to the numbers that the students had difficulty with	Applied on 41 students of 3rd and 4th grade (18 girls and 23 boys)	The results were encouraging as 92.7% of the students considered the game fun and, in respectively high percentage, useful, and helpful in improving their self-confidence. Accordingly, 92.7% of students would like to play the game again outside of school
Papadimitriou and Virvou (2017)	Programming learning (HTML)	The research was conducted on 28 students, between 13–15-year-olds, at the summer school of the University of Piraeus. A different profile was used for each student, and individual help was given. The game had several customizable features	Based on the questionnaire given, it seemed that the students were aided to understand basic HTML processes, while they expressed their desire to continue playing the game
Hooshyar (2022)	Computational thinking development	A total of 79 students participated, between 11–12 years old, divided into 2 groups. The first group used the AutoThinking game, while the other group used a PowerPoint presentation	The game promoted computational thinking as opposed to the traditional way of learning
Brinkhuis et al. (2020)	Governing students during an educational game	With the participation of 13,578 students, the new method of supervision was tested by using the Math Garden game	Positive results in engagement and learning
Vanbecelaere et al. (2020)	Improving reading ability	A total of 191 students used the game (adapted or not) at the same level of difficulty. The difference was that, in the non-adapted game, there were 20 questions, while in the adapted game, the number was different depending on the student's performance	The results showed that, although both teams completed the learning objective set, there was no difference between the two versions of the game
Nguyen et al. (2018)	The aim of the research is to investigate whether taking initiative in the game helps to not only increase interest but also to learn about a subject	The sample consisted of 159 students who were divided equally into 2 groups. One group used the game with minimal modification options, while the other group had the ability to have much more autonomy	Students were shown to respond equally well to both forms of play, and no significant differences were observed
Peirce and Wade (2010)	The aim of the research was to find out the differences between the two different versions of the game not only in terms of learning performance but also in regard to the interest of students	With the creation of two groups (83 students participated in total), the two versions of the game were tested. The first version had a very small adjustment, while the second had many adjustments	Post-tests showed that the performance of the students in both cases was increased, with no significant difference between them. In addition, the students responded to the game and found it very useful
Hwang et al. (2012)	The aim was to investigate the performance of personalized play in the learning process	The sample was separated into two groups. The first group used the personalized game, while the second group used the same game without adapting to each student	Research has shown that the personalized electronic game not only promotes learning but also improves students' learning achievements
McCarthy et al. (2020)	The focus of this research was to find out if the game with the adaptive texts increases motivation and enjoyment or helps the less-skilled readers	Participants completed three 2.5-h sessions of iSTART training. The students received texts in this game randomly or adaptively	Students who took part with the adaptive text selection in the game showed increased sense of learning. Adaptive text selection was also helpful for less-skilled readers
Monterrat et al. (2017)	The objective of this study is to investigate if the adapted gaming features improve the learners' engagement	In total, 59 students aged between 14 and 15 years from three classes of middle school took part in the study. Three different adaptive features were used and five groups were created, with each one given different features	Research has shown that the adaptation of gaming features has an effect on learners' perception
Tsai et al. (2012)	The aim of the study was developing the affective interface of a game-based adaptive learning, to enhance	The sample (90 students) was separated into 3 groups of 30 students each. The participants' facial reactions were recorded and processed	Adapting the game's difficulty to the learner's emotions was found to be more effective compared with adapting the learning content

(Continued)

TABLE 2 (Continued)

Study	Study objectives	Method	Conclusion
	children's learning motivation. The premise was that learners' facial emotion could determine the challenge level of a game or the learning content	using eMotion and the Facial action Coding System (FACS) to derive emotional states. These states were, then, used as input to modify the affective interface for a game-based adaptive learning software. For the first group, the game difficulty was adapted based on recorded emotions. For the second group, learning content was adapted based on recorded emotions. For the third group (control), no adaptation was applied	
Kickmeier-Rust et al. (2011)	The main goal of the study was to measure the increase of knowledge after the game between adaptive and no adaptive interventions	The study samples were divided into three different groups: The first group with motivational interventions and macro adaptation, the second group with macro adaptive interventions only, and the third group without interventions	The results showed that the first group has the highest learning performance. The second group has, unexpectedly, weaker results than the third group
Stefanidis et al. (2019)	This study aims to examine if the performance of students in a prosocial game could be improved by an intelligent AI adaptation mechanism	This case study used offline and online adaptation mechanisms. Offline adaptation with the use of AI chooses game scenarios depending on students' ability	The results showed that the online and simultaneously offline adaptation is able to increase player's performance in order to gain the learning objectives
Conati et al. (2013)	This study investigates how the student's attention is affected by user-adaptive hints during an educational game	In this method, eye-tracking data is used to estimate the user's attention to adaptive hints and how much these hints have an impact on their performance.	The study proved that, when a student is attended to hints can improve its performance with the game

calculated from the correct answers so that, when one level was completed, the student would have been able to proceed to the appropriate level based on their previous performance.

In the study by Kickmeier-Rust et al. (2011), the terms of *macro* and *micro* adaptivity were used to distinguish between traditional approaches, such as adaptive presentations, and non-invasive adaptivity, that do not change the game's characteristics, such as adaptive feedback. The macro-adaptivity with emotional interventions has the best results in this study (Kickmeier-Rust et al., 2011). Stefanidis et al. (2019) suggested the concept of *online* vs. *offline* adaptivity. In this study, the serious game was adapted to the needs of each student in order to maintain students' engagement. The online adaptation during the game refers to corrective feedback and positive reinforcement, while the offline adaptation occurs during the game loading and refers to an AI mechanism that selects the most appropriate conditions of the game for each student that expected to ease the player to express the desired prosocial skills.

Finally, Conati et al. (2013) investigated the effectiveness and usability of an adaptive educational game, based on how students benefit from individual concepts, such as adaptive hints, and how the adaptive features help them maintain focus. The results showed that the lack of hints could lead to lower performance, while an abundance of them may result in the lack of attention and focus.

4.3. Future directions

In future research, it would be interesting to further investigate whether a game can be personalized in terms of provoking student's interest or even based on his/her characteristics. For example, students with low self-esteem who have experienced failure in school may be presented with a different game environment and feedback so as to be aided in this area as well. In addition, several games pre-determined the level of adaptation based on an introductory pre-test; however, the benefit from a constantly individualized game, based on live performance would be interesting to be more thoroughly examined. Finally, there is room to explore the use of a game that utilizes graded personalization based on difficulty level, which guides students in the acquisition of knowledge gradually and in various teaching units (Legaki et al., 2021).

5. Conclusion

The studies we reviewed utilized adaptivity in game-based learning, following different approaches with respect to the values or mechanics, altered during the course of the intervention; in some cases, it was content selection which was changed according to the skills and expertise of the students, while in others, it was the total number of exercises (e.g., levels or mini-games) presented to the players. In most cases, the games were chosen from a finite number of pre-defined sets of content, so adaptivity was potentially limited, and students had to be grouped according to the metric used by the researchers; however, in well-defined subjects, such as mathematics, this did not seem to cause any problems or limit the performance of the students.

What was obvious from the studied papers was the need for learning applications, and more specifically games, to take into account the performance and engagement of the students during the intervention and adjust the learning content of the game and the mechanics offered to students accordingly. This adaptive strategy appears to have a strong positive influence on the students' performance (especially those who perform better than the average) and has been shown to be extremely useful when it comes to

specific parts of the curriculum that students need help with (e.g., specific phenomena in grammar or syntax). In addition, the fact that the gameful application *responds* to the choices, preferences, and performance of the students was shown to create better rapport and enabled learners to trust the applications and invest time and effort in them, leading to improvements in app retention and conformance with their study programs.

In order to improve the learning experience during distance learning, either as part of everyday practice or as a result of special situations, such as the movement restrictions imposed during the pandemic, the ability to personalize the content of each educational intervention and to respond to different levels of engagement (e.g., Legaki et al., 2019) or performance (Mavrikis et al., 2019) points to a new generation of adaptive educational approaches which produce a better experience *in real time*, as a response to how each learner interacts with them and not merely based on a pre-defined set of materials or a rigid narrative. It has to be noted, though, that, besides engagement, adaptive approaches do not tend to take into account other cognitive or affective states (Pantic et al., 2011), such as frustration, burn-out, or confusion, and only respond to the effect of those states on performance, usually confusing them with the lack of knowledge (Douglas-Cowie et al., 2007).

Author contributions

DC and KK: conceptualization and data curation. KK: methodology and revisions. VP: validation. DC: writing—original draft preparation. KK and VP: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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