Development of the Adaptive Learning Concept at CARNET*

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Abstract

The adaptive learning systems aim to provide a customized educational experience that improves students' academic performance and engagement by identifying areas of proficiency and deficiency and allowing them to acquire new knowledge autonomously. Due to the lack of research in this particular area, both in Croatia and other countries, the Croatian Academic and Research Network (CARNET) has collaborated with a team of experts from the educational and research community. Together, they have developed a model of adaptive learning. This study integrates the results of a narrative synthesis of published papers on adaptive learning models, along with a description of the adaptive model under development based on the gathered recommendations.

The primary focus of literature search was on systematic reviews and meta-analyses that organized and synthesized existing knowledge about adaptive learning systems. Multiple facets of adaptive learning models have been investigated, encompassing learner characteristics, pedagogical strategies of technology integration, the utilization of artificial intelligence, and the expected outcomes of personalized educational content. In collaboration with external experts, CARNET will conduct experimental trials of the developed concept to ensure its educational and psychological soundness and investigate the potential of using artificial intelligence tools to create adaptive digital educational content. The model will be modified as necessary after the piloting.

Keywords

adaptive learning system, development of adaptive learning model, narrative synthesis

1. Introduction

CARNET's vision emphasizes human-centered technology, and its mission focuses on innovation, advanced infrastructure, and services that empower and connect the educational and research community. In line with this, CARNET initiated the development of a concept for adaptive learning in October 2023. The goal of developing an adaptive learning concept is not only to facilitate learning but also to empower students to take an active role in their education. Adaptive systems allow students to recognize their strengths and weaknesses, explore and acquire new knowledge

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independently, and develop critical thinking and self-regulation skills. Ultimately, adaptive learning contributes to creating an inclusive and equitable educational environment where every student has the opportunity to reach their full potential.

Adaptive learning is a well-known educational approach, but its combination with artificial intelligence and learning analytics in order to create novel approaches to e-learning is somewhat unexplored both in Croatia and in other countries. Having that in mind, CARNET has collaborated with a team of experts from the educational and research community and has designed a concept for adaptive learning in partnership with them. Although this paper focuses on presenting the final concept of such an adaptive system, in order to ensure its pedagogical and psychological validity and explore the possibilities of applying artificial intelligence tools in the creation of adaptive digital educational content, CARNET will experimentally pilot the educational content in collaboration with experts outside of CARNET. Such educational content will closely follow the concept presented in this paper and, upon completion, will be tested in four 7^{th} grade classes at the elementary school Mladost in Osijek. Based on the outcome results, the concept will be revised if necessary, as explained in more detail in the final section of this paper.

2. Materials and Methods

This paper reports findings from a narrative synthesis of previously published information on the development of adaptive learning concepts. By evaluating and synthesizing multiple individual studies, a broader consistency can be discovered [1]. In this way, with this paper we wanted to provide a global vision that serves as a starting point for understanding which aspects have been studied and which need further investigation. A literature search was performed between February 2024 and July 2024 to identify relevant publications in this field. No time restrictions were imposed as a search criterion. The literature search utilized various databases (e.g., PsycInfo and WOS) using a combination of broad search terms, including variants of adaptive learning (e.g., adaptive learning OR adaptive learning concept OR personalized learning OR adaptive educational systems) AND students' characteristics in adaptive learning models (e.g., cognitive traits OR affective traits), OR pedagogical strategies (e.g., instructional design OR gamification OR feedback mechanisms), OR technological tools (e.g., artificial intelligence OR machine learning OR educational technology), OR outcomes (e.g., academic achievement OR student engagement OR learning efficiency), OR applications (e.g., adaptive content OR digital learning platforms OR virtual reality OR augmented reality)). Inclusion criteria were papers focused on the development, implementation, and assessment of adaptive learning systems. Particular emphasis was given to: a) systematic reviews and meta-analyses that systematize the state-of-the-art knowledge concerning adaptive learning systems; and b) empirical studies focusing on the integration of AI in educational content and its impact on learning outcomes. At least two authors screened the literature on each of the key topics and extracted the data. Any doubts or disagreements were resolved through discussion between the authors according to the selection criteria. Different aspects of the adaptive learning concept were explored, including student characteristics, pedagogical aspects of technological integration, and expected outcomes of personalizing educational content. In this paper, we do not list all reviewed papers, however the complete list of reviewed papers can be obtained upon request.

In our narrative synthesis of adaptive learning models, specific exclusion criteria were established to maintain the relevance and quality of the reviewed literature. Firstly, studies not published in English or Croatian were excluded to ensure that all researchers could fully understand and assess the content. Additionally, publications such as editorials, letters to the editor, opinion pieces, and conference abstracts were excluded as they do not provide sufficient empirical data or comprehensive reviews necessary for a narrative synthesis. Furthermore, studies that did not contribute to the understanding of learning processes relevant to adaptive learning, including cognitive styles, student characteristics, or pedagogical strategies, were excluded. Finally, duplicate studies or multiple publications of the same study results were excluded to prevent redundancy and to ensure that each study contributed uniquely to the synthesis.

3. Results

In the following subsections, we describe features of adaptive learning models recommended in the reviewed papers.

3.1. Students' characteristics

The combination of empirical research on the effectiveness of adaptive systems with theoretical proposals for the development or optimization of new or existing systems has led to the classification of three groups of characteristics [2]. Student characteristics have been categorized based on the three main learning domains according to Bloom's taxonomy: cognition, affect, and behavior or psychomotor skills. An additional category, blended learning, was created to categorize the combination of two or more traits from the three different domains [2]. The cognitive domain, the first category, involves a method of processing information that relies on logical thinking to generate and acquire knowledge throughout the learning process. Second, the affective learning domain refers to the changes a learner undergoes during the learning process in terms of their interests, emotions, feelings, and attitudes. The third learning domain category, pertains to the learner's actions in utilizing motor skills, physical movements, and coordination, commonly referred to as psychomotor skills.

Our review revealed that some previous studies utilized two or more personal traits to enhance the reliability and effectiveness of adaptive learning environments in supporting learners. These traits were often combined in various ways, either integrated within a single domain or separated but used in conjunction with traits from other domain categories.

The most commonly included characteristics in adaptive models are from the group of cognitive traits, such as learning styles, cognitive styles, working memory capacity, and prior knowledge [2]. However, including more thoughtfully considered characteristics enables the system to provide a more individualized educational experience, which should lead to better academic performance and higher student engagement. Both researchers and practitioners recognize this, as evidenced by the review work of Normadhi et al. [2], which states that characteristics from a mixed group of students are the second most frequently used in adaptive models. Therefore, in addition to the aforementioned cognitive characteristics (prior knowledge, learning style, working memory capacity, and cognitive style), some of the adaptive learning models also include affective and behavioral characteristics of students. Most frequently mentioned affective characteristic in research of the adaptive learning models is motivation, while frequently highlighted behavioral characteristic is self-regulated learning (Table 1).

Table 1
Characteristics of Students in the Proposal for Adaptive Digital Educational Content

Characteristics	Description	Relevance for Learning Adaptation
Prior Knowledge	Information, skills, experiences, and concepts that a student has already mastered before starting to learn new content. It includes formal education, informal learning, as well as everyday experiences. Prior knowledge can be specific to a particular subject or general, encompassing a broad range of topics and skills.	Understanding prior knowledge allows for the adaptation of the curriculum and learning methods to meet the specific needs and knowledge level of each student. This can increase learning efficiency as the material can be presented in a way that is most suitable for the student's existing abilities and knowledge.
Learning Style	Learning style can be defined as the preferred way of thinking, processing, and understanding information [3]. One of the most used categorizations of learning styles is into visual, aural, reading/writing and kinesthetic, developed by Fleming [4].	The dominant style is the most effective way for a student to acquire new information, although this style may not be the same for every subject. Learning styles are an important variable affecting the choice of teaching methods, the development of instructional materials, teaching strategies, classroom activities, and student success [5]. Teachers who consider students' learning styles make the teaching process more meaningful and purposeful [6] and it increases motivation and reduces disciplinary problems [7].
Cognitive Style	Cognitive style is an individual's characteristic way of thinking, feeling, remembering, solving problems, and making decisions. Armstrong et al. [8] claim that cognitive style refers to differences in preferred ways of processing information (e.g., perceiving, organizing, and analyzing).	Cognitive style plays a key role in problem-solving or metacognitive skills [9]. Cognitive style is recognized as a significant factor affecting students' search for and processing of information [10]. It is identified as an important factor influencing the effectiveness of learning system navigation strategies [11]. Several studies have shown the effectiveness of considering cognitive styles in designing user interfaces for information retrieval [10] and in developing adaptive learning systems to provide personalized learning guidance [12]
Working Memory	Working memory refers to the system that serves for the temporary storage and manipulation of information necessary for complex cognitive tasks such as understanding language, learning, and reasoning and plays a central role in all forms of complex thinking [13].	It facilitates planning, understanding, and problem-solving. A positive relationship has been observed between working memory and academic success. There is a connection between verbal working memory and achievements in English, mathematics, and natural sciences [14]. Low working memory capacity is associated with poorer calculation skills [15], failure in simple tasks like remembering instructions for more complex activities involving information storage and processing, and tracking progress in challenging tasks [14].
Motivation	Motivation can be seen as an internal state that initiates, directs, and sustains goal-directed behavior	Motivation is a significant factor in learning and teaching situations. It is considered one of the most important components that have a significant impact on learning

Characteristics	Description	Relevance for Learning Adaptation
	[16] or as a set of processes responsible for the intensity, direction, and persistence of efforts to achieve a goal [17]. Motivation can used to describe the reasons behind someone's behavior.	outcomes. When motivation is viewed as the driving force behind and arising from all human activities, it can be said that a student must have sufficient activation, clear goals, and energy throughout the learning process to achieve learning goals. Besides being associated with academic success, motivation also affects students' positive attitudes towards school and learning. Motivated students use more cognitive processes and acquire more instructional content than less motivated students [18]. Therefore, motivating students to learn is a central element of good and quality teaching. Thus, motivation is likely the most important individual element of learning.
Self-Regulated Learning	Self-regulated learning involves students setting their own learning goals, planning, executing, regulating, and evaluating the learning process to achieve these goals. Monitoring and evaluating progress in learning are crucial for self-regulated learning [19]. For students to reflect on their own learning, they should have control over their learning process. Self-control can be achieved by offering choices [20].	Self-regulated learning, with its proactive principles, allows students to achieve success somewhat independently of other factors such as mental abilities, supportive environments, and quality of teaching. Students who use self-regulated learning strategies have better objective academic success, as expressed by grades [21]. With the onset of puberty, social and emotional self-efficacy becomes more important to students than academic achievement. Motivation for school and learning decreases, and self-regulation of learning, which should develop from previous teacher- and parent-directed regulation and the development of abstract-logical thinking, does not occur in all young individuals during this period. The absence of self-regulation during puberty, when young people transition from concrete to abstract thinking, is explained by underdeveloped self-regulatory skills [22]. In research and study of self-regulated learning, good feedback plays a very important role as it can strengthen students' ability to regulate their own performance [23].

3.2. Pedagogical strategies

3.2.1. Gamification and VR

The model of adaptive digital educational content should integrate a gamification element (learning through games) with the aim of increasing motivation, active student engagement, and learning effectiveness, while tailoring game elements to each individual student [26]. Algorithmic systems that personalize learning through games use data on student behavior and responses to adjust the learning content. Different types of challenges are generated based on real-time student progress, and strategies for problem-solving and decision-making used by the student are analyzed to provide appropriate support.

Artificial intelligence algorithms analyze student responses and interactions in real time, adjusting the sequence and difficulty of questions based on individual needs and progress. The analytics of collected data, which includes time spent on each question, time spent in the model, number of attempts, attempt status, number of hints requested, answer accuracy, points earned, and overall score, provides the teacher with insights into student engagement as well as tasks that present difficulties. This way, the teacher can gain visibility into student performance and respond promptly if necessary [26]. The use of Virtual Reality (VR) and Augmented Reality (AR) adds an extra dimension to gamification by fostering an immersive learning experience [27]. These technologies enable the creation of fully immersive environments where students can explore and learn in simulated situations that replicate real-world scenarios [28]. This encourages students' motivation, interest, and desire to learn, as well as making content more accessible, leading to better understanding and deeper retention of knowledge.

3.2.2. Feedback

Feedback on performance is undeniably a cornerstone of informal and formal learning [29]. Feedback is defined as any message generated in response to a student's action [30] and it generally indicates the success of student performance compared to what was expected. In this way, feedback helps students identify mistakes and become aware of misconceptions. Feedback also provides hints about the best approaches to correcting mistakes [30] all the while fostering intrinsic motivation. It is recommended to use words of encouragement that foster self-belief and influence the development of perseverance and determination, rather than simple praise such as “good job” or “excellent” [31].

In the adaptive models, emphasis is usually on local feedback, by providing customized instructions with the possibility of modifying its content according to the individual characteristics and performance of each student. This type of feedback is also referred to as adaptive feedback and is an integral part of adaptive e-learning [32].

3.3. Expected outcomes

Several advantages of the adaptive models are highlighted. Firstly, such models emphasize personalized content and tasks that make learning more engaging and relevant, which increases student motivation and involvement. An adaptive learning model adjusts educational content to individual student needs to achieve greater learning efficiency and better academic outcomes. [33]. Teachers receive detailed and timely feedback on student progress, which enable more effective lesson planning and interventions. Automatically generated reports and analysis save teachers time, allowing them to focus on student interaction and individualized approaches [33, 34].

4. Adaptive Learning Model at CARNET

Following recommendations from expert and scientific literature, a proposal for adaptive digital educational content has been developed, based on personalization, differentiation, automatization, and feedback. Content adaptation combines the aptitude-treatment interaction (ATI) approach and

micro-adaptive teaching. Initial teaching conditions are based on student characteristics collected before the learning process through questionnaires. The intelligent system then continuously adjusts the teaching conditions based on students' behavioral patterns on the digital platform. The system uses an analysis of student results, activities, and behavior to continually adapt the instructional content, ensuring that students' needs are met and their progress is encouraged.

A significant emphasis in the model is placed on fostering motivation throughout the learning process. Intrinsic motivation is enhanced by adapting materials based on students' interests. A student's interest in a particular topic drives their desire to learn about that topic (or engage with it) for its own sake. Interests are defined through Howard Gardner's theory of multiple intelligences. Since people excel in different areas, Gardner's theory of multiple intelligences can provide students with a better understanding of how they learn. It has been shown that incorporating this theory into teaching practice leads to an improved learning environment by encouraging students' strengths while simultaneously broadening their thinking [24]. Based on the type of multiple intelligences, information and tasks are adapted for the student [25]. In this way, students not only have a clearer understanding of information but are also able to comprehend material even when taught in an alternative manner [25]. Moreover, children are more excited about learning as they have the opportunity to showcase what they understand and their strengths. This process introduces creativity into learning and provides opportunities for more effective methods of assessing student achievements, enabling a true measure of students' understanding of the subject

Feedback plays a crucial role in our adaptive model by providing students with immediate and targeted information about their progress and performance. Feedback is designed to encourage students to correct errors, improve understanding of the material, and motivate further learning. Feedback guides each student step by step towards successful task completion. This encourages self-reflection, allowing students to acquire learning skills and set realistic learning goals. Such support empowers students to take responsibility for their own learning. Additionally, feedback fosters intrinsic motivation. In our adaptive concept, we use feedback shaped as encouraging messages. Encouragement focuses on internal evaluation and the contribution that the student makes, specifically on the student's effort. By providing encouraging feedback messages, we teach students to accept their shortcomings, become aware of learning from their mistakes, and foster self-belief and a sense of usefulness. The feedback generated uses positive and supportive language that fosters self-assurance and encourages the development of resilience and tenacity. Teachers receive detailed reports for timely interventions, and students receive feedback on their progress.

Furthermore, the adaptive learning model integrates various student characteristics to provide a personalized educational experience. In this adaptive model, a mixed group of characteristics is included, specifically highlighting cognitive, affective, and psychomotor characteristics as key factors for adapting instructional materials. Cognitive characteristics include prior knowledge, learning styles, while affective characteristics focus on motivation. Integration of virtual or digital assistants (chatbots) is possible within the adaptive model, allowing for the design of authentic scenarios and situations related to the real world and students' lives, which helps students relate to the tasks. This encourages student motivation and fosters creativity. Following literature recommendations, adaptive learning model allows for content adaptation for students with diverse needs, including those with learning difficulties, gifted students, and those requiring additional support in specific areas, thus ensuring compliance with the requirements set forth in the Education Act [35], regarding providing conditions for each student's success in learning.

4.1. Application of Artificial Intelligence in Creating Adaptive Content

In this section we describe details of adaptive learning model developed for the mathematics unit on rational numbers. In this unit, adaptive learning model combines thematic storytelling, interactive tools, and adaptive logic (assessments) to create a personalized and engaging learning experience. By using Moodle's Lesson module, H5P interactive tools, and adaptive quizzes, the teaching activities are tailored to the unique traits, needs and preferences of each student. This provides a customized educational path that enhances understanding of mathematical concepts, motivates students, and makes the learning process more enjoyable and stimulating.

Adaptive learning begins with selecting an appropriate thematic pattern that guides students through their learning adventure. Every culture has its own stories shared as a means of entertainment, education, cultural preservation, or instilling moral values. Stories are often used as a narrative backdrop for educational content, making the learning experience more immersive and engaging. The adaptive teaching activities within the rational numbers unit are structured around several themes, which are tailored based on Gardner's theory of multiple intelligences (Figure 1 shows the theme of Science and Imagination). Students can choose their preferred type of adventure at the beginning, which determines the thematic context in which they encounter mathematical problems. In this case, the themes are not merely decorative; they help students contextualize the mathematical concept, making it more accessible and easier to understand.

Figure 1: Designing Themes for Adaptive Learning Activities and Greta the Virtual Assistant

The basic structure of the learning activities in this case represents a combination of linear and hierarchical organization, as shown in Figure 2.

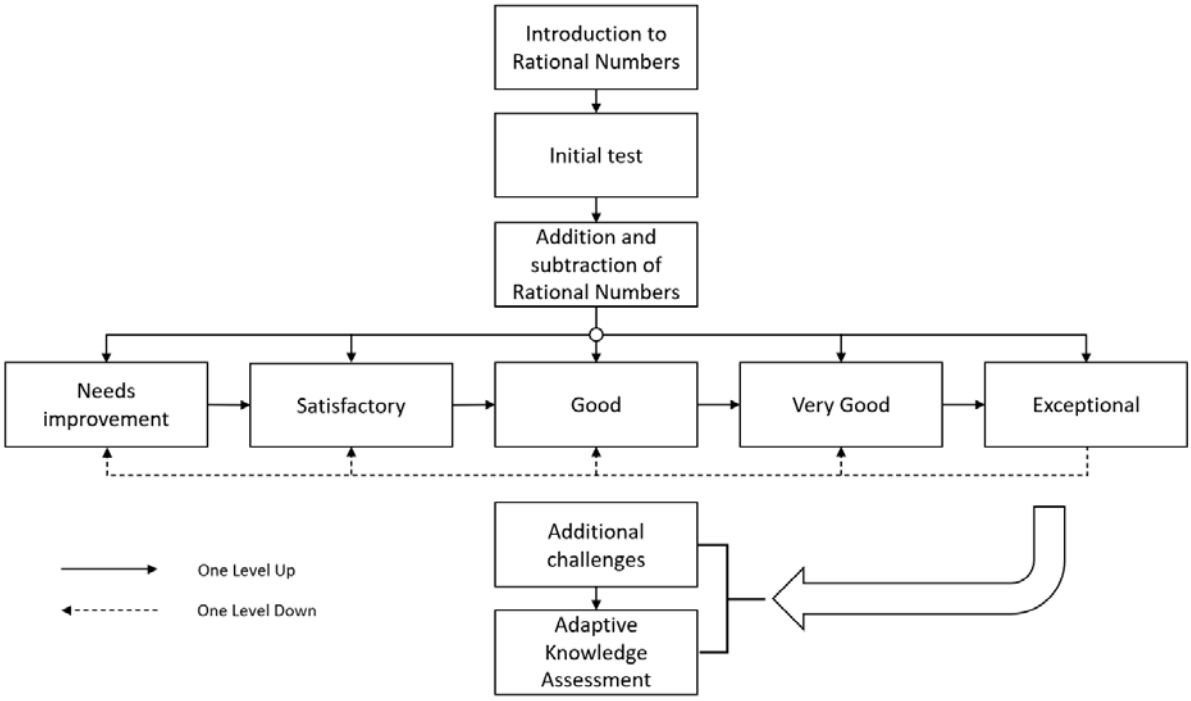

Figure 2: Basic Structure of Designed Learning Activities

The linear structure allows students to progress through the content in a predetermined way, while the hierarchical structure enables a layered approach where students can delve into specific topics or revisit foundational concepts as needed. Within the main activities (e.g., H5P interactive lectures), parallel activities in the form of interactive tasks and branches are added. Branches allow students to advance through the content based on their results and personal choices. For instance, after completing an interactive presentation, students can choose different learning paths depending on

their achieved results and interests. They can build their own story, solve various tasks, and develop the necessary competencies (e.g., using H5P branching scenarios). Gamification helps create personalized learning experiences, enabling students to explore areas that interest them the most or where they need extra practice.

At the beginning of the learning activities and after selecting the main theme, students go through an introductory presentation on rational numbers where they familiarize themselves with the tools, rules, and methods of attending the learning activities. This activity is crucial for helping students quickly overcome initial difficulties and get acquainted with the possibilities of customizing their learning activities using assistive technologies. Additionally, students have the opportunity to adapt to different learning styles: visual, auditory, textual, and kinesthetic. New technologies enable content adaptation in ways that suit students' styles and preferences, making learning more inclusive and accessible.

The visual learning style is supported through the use of subtitles on all video presentations, allowing students to follow the written text while listening to explanations. Additionally, interactive images and illustrations are used to clarify more complex concepts. The auditory learning style is integrated through the use of audio speech and explanations. The virtual assistant Greta, whose animation is synchronized with text and content using speech recognition technology, allows students to listen to explanations and advice in real-time (Figure 1). Subtitles are included for those with hearing impairments or those who prefer visual support. The kinesthetic learning style is addressed through interactive tasks and games, such as crosswords and interactive simulations. These tasks enable students to actively participate in the learning process, manage information, and experiment with different problem-solving solutions.

After the introductory presentation, students take an initial diagnostic test designed to assess their current level of mathematical knowledge (shown in Figure 2 as "Initial Test"). This test categorizes students into one of five levels: exceptional, very good, good, satisfactory, or needs improvement. This classification helps tailor subsequent content to the students' knowledge and skill levels, ensuring that each student receives material that is appropriately challenging. The initial assessment lays the foundation for the student's adaptive learning journey, guiding decisions about subsequent branching paths. Levels are initially set as hidden, with one becoming available after the student completes the initial quiz and meets the conditions for revealing that level. Advanced branching options of the Lesson module are used to create conditional paths through the materials. Using Moodle's "Restrict Access" and "Activity Completion" settings, adaptive teaching activities ensure that students complete certain activities before moving on to more advanced content. Additionally, routing is based on points accumulated during progress through the teaching content. For example, a student who scores 85% or higher on a quiz is directed to the "Exceptional" or "Very Good" branches, which offer more complex problems and advanced concepts, while a student with a lower score is directed to a lower branch for additional support and review.

Adaptive teaching activities include elements of gamification to increase student engagement. For example, Moodle's crossword tool is used as both a learning tool and a game element, encouraging students to engage with the content in a fun and interactive way.

Considering all the previously mentioned parameters necessary for quality learning adaptation, CARNET will conduct a pilot test of the developed adaptive learning concept. Based on the results of the pilot test, the adaptive learning concept will be revised and then promoted and offered to the educational community. For the purpose of piloting the concept, CARNET, in collaboration with the entire expert team, will create digital educational content that will closely follow the pathways outlined in the concept. The digital pilot content will focus on a topic *Addition and Subtraction of Rational Numbers*. After the content is developed, the pilot test will be conducted in four 7th-grade classes at Primary school Mladost in Osijek, with the possibility of expanding the pool of participants.

5. Conclusion and Further Steps

The adaptive learning concept developed by CARNET will represent a forward-thinking approach to education in Croatia, designed to cater to the unique needs of each student. We believe this model will enhance student engagement, motivation, and learning outcomes by integrating various student characteristics, innovative pedagogical strategies, and advanced technological tools such as artificial

intelligence. By providing tailored feedback based on individual student performance, we expect that model will encourage students' self-reflection and continuous improvement to point out their strengths and weaknesses, but also to promote growth of their mindset and resilience.

However, we recognize limitations of described piloting and model being developed. Therefore, further steps should be considered in the future, which we describe. To effectively expand the adaptive learning model, a multifaceted approach involving pilot studies, AI integration, professional development, research, and community engagement is essential. First, pilot studies should be expanded to include additional studies across various educational settings and different grade levels. This will provide comprehensive data on the model's effectiveness. Ensuring a diverse sample of students will validate the model's applicability and scalability. Second, enhancing AI integration is crucial. Continued development and integration of advanced AI algorithms will improve content personalization and adaptability. AI-driven analytics can provide real-time insights into student progress, enabling timely and effective interventions. Third, professional development for educators is necessary. Implementing training programs will enable teachers to effectively use adaptive learning technologies and interpret data insights. Collaboration between educators and technologists should be fostered to refine and improve the model based on practical classroom experiences. Fourth, ongoing research and development must be pursued. Partnering with academic institutions and research organizations will allow for longitudinal studies on the impact of adaptive learning on student outcomes. Finally, community and stakeholder engagement is vital. Engaging with parents, students, and the broader educational community will gather valuable feedback and insights on adaptive learning initiatives. Encouraging a collaborative approach ensures the model meets the needs and expectations of the community it serves.

By following these recommendations, CARNET can continue to lead in innovative educational practices, ensuring adaptive learning becomes a fundamental part of modern education. This will provide all students with the opportunity to reach their full potential, making learning more personalized, effective, and inclusive.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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