

Adaptive vs. Traditional Learning: Long-Term Knowledge Retention -A Literature Review

Amal Altahi ^{1,2*}, Chaitali Bonke ³ and Khaled Alblowi ⁴

¹ Center of Information Systems and Technology, Claremont Graduate University, Claremont 91711, USA.

² Department of Management Information Systems, Faculty of Business Administration, University of Tabuk, Tabuk 47512, Saudi Arabia.

³ Department of Information Systems, Robert C. Vackar College of Business and Entrepreneurship, University of Texas Rio Grande Valley, Edinburg, Texas 78539, USA.

⁴ Department of Accounting, Faculty of Business Administration, University of Tabuk, Tabuk 47512, Saudi Arabia.

* **Corresponding author:** amal.altahi@cgu.edu.

ABSTRACT: Adaptive learning, a personalized educational approach, has appeared as a substitute paradigm to conventional teaching methodologies. Opposed to instruction-based learning, adaptive learning prepares learning content in a way that corresponds to individual learner needs, increasing engagement and knowledge retention. The present study has been conducted to review the literature to evaluate the influence of adaptive learning systems on long-term knowledge retention as compared to their traditional counterparts. Real-time feedback, spaced repetition, and scaffolded content can reduce cognitive load and enhance the learning experience, as they are considered highly effective tools. Several studies have shown that retention improves through the use of adaptive systems, as they help fill information gaps and encourage active learning, especially in STEM fields. Despite the benefits of using adaptive systems in relevant areas, some challenges remain, including limited access in low-resource settings, underrepresentation in non-STEM areas, and difficulties integrating with traditional teaching methods. The present research suggests that future studies should concentrate on longitudinal studies, hybrid models, and equitable access to adaptive technologies. Adaptive learning will revolutionize the learning sector in various situations by addressing these challenges.

Keywords: adaptive learning, knowledge retention, traditional learning, personalized learning.

I. INTRODUCTION

Education as a dynamic profession appears to be in a state of continuous development to meet the new demands of its own society as well as the different fields within the society by changing accordingly. In this situation of unceasing change in the educational sector, adaptive learning turns out to be one of the most effective and appropriate options to control the power of education, technology, and data processing algorithms accordingly. Opposed to traditional approaches with standardized pacing and formal direction, adaptive learning gives a beam of hope by adapting content according to learners' requirements, progress, and engagement. This student-centered model represents a significant shift toward tailored educational experiences, offering a promising future for education and learning outcomes [9, 13]. The significance of long-term knowledge retention cannot be exaggerated, as it is supported by deep learning and skill acquisition. Retention, the competency to recall and implement information over time, is occasionally limited by conventional approaches that fail to correspond to diverse learner needs in heterogeneous classrooms. The lack of flexibility in implementation when it comes to curriculum, systems of feedback, and instruction processes makes it difficult to consolidate learning [2, 17]. These issues are resolved in adaptive learning by

incorporating timely feedback, spaced repetition, and algorithmic content, as proposed in the cognitive load theory, to increase the right side of cognitive engagement while decreasing the wrong side [15, 23, 29].

Numerous studies have demonstrated that adaptive learning has the potential to enhance knowledge enrichment and facilitate student retention across various areas. Based on its features and capabilities, the adaptive learning system enhances students' knowledge, particularly in knowledge acquisition areas that are variable and require effective management of content and students' cognitive load [29, 21]. Adaptive learning platforms create a learning experience that helps students adapt according to their ease of grasping information, time availability, and flexibility, which adds to the learning experience and could enhance their productivity [15, 18]. Nonetheless, there is controversy regarding the specific advantages of adaptive learning over conventional teaching practices for enhancing long-term knowledge retention [13, 21].

Nevertheless, the literature available indicates that there are three significant gaps that need to be addressed. To begin with, the available evidence is mainly in the STEM fields, whereas non-STEM is under-researched. Second, a large number of studies concentrate on short-term results and do not provide any longitudinal results regarding long-term retention. Third, combination of adaptive and traditional techniques into the hybrid models is not a systematically studied topic. That is the reason that the present research seeks to ascertain the answer to the following question: How does adaptive learning influence knowledge retention over the long term, unlike traditional methods? By addressing the above gaps, this review contributes to clarifying the potential and limitations of adaptive systems.

II. METHODOLOGY

The comparative effect of adaptive learning systems on long term knowledge retention in comparison to traditional learning systems is done through the literature review carried out in the present study, systematically applying the concept-centric framework developed by Webster and Watson (2002) [27]. It is a framework that places appropriate categories of research articles by determining the themes. The idea is so that a structural analysis beyond the scope of author-based or chronological summaries should be performed. Google Scholar, PubMed, Scopus and Web of Science were used to retrieve the relevant literature. Such keywords as adaptive learning, knowledge retention, and personalized learning were used, and Boolean operators were used to expand the results. The search and selection process followed the PRISMA 2020 guidelines [30] to ensure transparency and reproducibility.

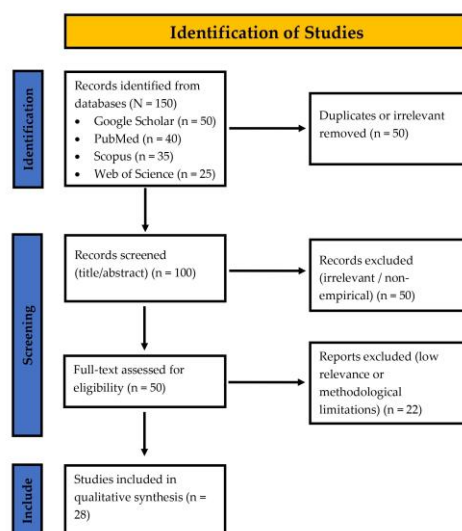


FIGURE 1. PRISMA-style flow diagram of the literature search and selection process.

The studies that were published within 2018-2024 were prioritized to receive the newest results. Relevance was ensured by a strict inclusion and exclusion criterion. Peer-reviewed journal articles that discussed adaptive or traditional learning, and their influence on the knowledge retention process, were considered only. Papers that were not in English, conference papers, and studies that did not address retention outcomes were excluded. The PRISMA-style flow was used in the search process Figure 1. Out of 150 records, there were duplicates and irrelevant records that were eliminated ($n=50$). The other 100 were filtered by title and abstract with 50 full-texts evaluated as eligible. Having eliminated the articles, which were not relevant or had limitations in their methods of study ($n=22$), in the end, 28 articles were included in the final synthesis. A review matrix was then adopted to identify and tabulate major findings in the background of the research, intervention type and outcomes. This framework aided thematic analysis and aided in identifying patterns and new insights.

III. FINDINGS

1. STRATEGIES OF ADAPTIVE LEARNING

1.1 Real-Time Feedback

Instant review provides corrective information to learners to proactively address any misunderstandings throughout the learning process. This feature enhances retention in chemistry education and, helps to minimize extraneous cognitive load and enhance these processes [25, 29]. It has also been highlighted in a few studies how real-time feedback facilitates mastery learning by allowing learners to focus on essential material without cognitive overload [21, 28]. Adaptive learning could help students improve their study cycles [25].

1.2 Spaced Repetition

Spaced repetition enjoys the benefits of spacing and enhances memory by revisiting it at scheduled intervals. This mechanism increases retention, especially in science, technology, engineering, and math (STEM) areas, since students build schemas as a result of the mechanism [5, 13]. A study has gone further with this finding to reveal that spaced repetition and retrieval practice not only improve the capacity of learners to combine and organize knowledge but also to arrange it [29]. This is constructive synergy with Bruner's approach to learning, especially scaffolding and repeating simple concepts several times [5].

1.3 Scaffolded Content

The scaffolded content of a given task or idea enables the learner to be capable enough to do the task with little assistance in order to ensure that tasks are never below the Zone of Proximal Development (ZPD). As far as mastery and retention of knowledge is concerned, it has been established that scaffolded tasks vary in the degree of difficulty [21]. The mechanism underpinning this is founded on the theory and principles of the learning environments proposed by Vygotsky (1978), with the focus on an aspect of structure in learning [5]. Examples of such mechanisms include CogBooks and Cerego, where difficulties are customized according to changes in the learner [6, 18].

1.4 Learner Analytics

Learner analytics improve adaptive systems by collecting and processing engagement details, performance data, and learning progress to offer customized learning processes [14]. Analytics facilitate real-time modification of content gainful for clientele with uniform and heterogeneous needs [4]. Connectivism principles have been identified as the variables that affirm networked learning supported by technology to integrate self-organized learning for individuals [5, 22]. Analytics has also been endorsed by a researcher as a technique for enhancing student participation and knowledge retention in the long term [18]. These strategies and their effects on cognitive processing and retention are summarized in Table 1.

Table 1. Adaptive learning strategies and their effectiveness.

Mechanisms	Description	Intermediate Effects	Final Outcome	Sources
Real-time Feedback	Provides immediate corrective insights to reinforce understanding and address gaps.	Reduces cognitive load.	Enhanced long-term retention.	[25, 21, 29]
Spaced Repetition	Revisits key concepts at scientifically determined intervals to strengthen memory consolidation.	Promotes schema construction and retrieval.	Retention of material over time.	[29, 14, 5, 11]
Scaffolded Content	Gradually increase complexity of material to match learners' progress, aligning with their capabilities.	Facilitates mastery learning.	Improved retention and application.	[22, 6, 26, 18].
Learner Analytics	Uses performance data to adapt content and pathways in real-time.	Supports personalized learning trajectories.	Sustained engagement and retention.	[18, 4, 10]

In relation to retention, adaptive learning systems have been observed generating improved results as compared to traditional methodologies. It has been discovered that the first-year statistics retention rate was higher for students who used adaptive platforms in their chemistry courses [25]. The adaptive system that uses scaffolded content and spaced repetition reveal better results than conventional practices by promoting constructive interactions with contents in the context of STEM syllabi [29].

When implementing adaptive systems focused on mathematics education, it was concluded that the retention rates among the learners were also high regardless of the initial knowledge of the learners implementing it for each learner type [13]. This finding is consistent with another study regarding the effectiveness of personalized learning pathways in addressing knowledge deficits and fostering long-term memory [5]. Furthermore, a few researchers have also highlighted the fairness of using adaptive platforms in dissecting retention inequalities among underrepresented learners and designing instructional materials within the learning platform to enable effective training to address their needs [10]. However, it is important to note that retention findings are not always consistent and often depend on contextual factors. Their constancy depends on context. In conventional classrooms that adopt sound instructional approaches, it has been established those adaptive systems received similar boosts in retention [7]. Adaptive technologies are even more impactful when applied within structured and sound learning models [6, 9]. Subsequently, it has been noted that engagement in active learning during the application of the adaptive learning environments boosted retention compared to passive approaches and conventional practice [20].

Table 2. Comparative studies on learning outcomes.

Study	Focus	Adaptive Learning Outcomes	Traditional Learning Outcomes
[25]	Chemistry education	Significantly better long-term retention on post-assessments.	Moderate improvement; lower retention over time.
[13]	STEM	Higher completion and retention rates, particularly for diverse learners.	Lower retention rates; less effective for variability.
[7]	General retention outcomes	Improved retention but context-dependent benefits.	Comparable retention in high-quality settings.

[29]	Adaptive vs. traditional STEM	Enhanced long-term retention through spaced repetition and scaffolding.	Static delivery hindered diverse learners.
[10]	Equity in adaptive platforms	Bridged knowledge gaps among underrepresented learners.	Inconsistent support for learners with diverse needs.
[20]	Active vs. passive learning	Adaptive methods with active strategies led to higher retention rates.	Passive methods limited long-term retention.

According to the summary in Table 2, comparative research has consistently shown that adaptive systems have better retention results as compared to traditional methods, especially in STEM situations, but with some variation in the intensity of these advantages depending on the study design and learning environment.

2. CONTEXTUAL FACTORS INFLUENCING RETENTION

Adaptive learning systems are highly dependent on contextual variables, including technology, learners' abilities, institutions, and area of study. These factors determine how adaptive systems can help in accomplishing pedagogical missions effectively and increase the learners' information within long-term retention.

2.1 Subject Matter and Disciplinary Relevance

Scaffolding and sequential learning are effective methodologies for STEM disciplines, making adaptive systems famous. It has been observed that adaptive platforms enhanced retention in chemistry as they tackled knowledge prerequisite deficiencies [25]. Adopting adaptive learning increases content retention in mathematics and engineering using spaced repetition and feedback [29]. In addition to STEM, adaptive tools are not often used in other fields like arts and humanities, where learning is solved in more abstract strategies [5]. Other studies also indicate the potential to utilize adaptive learning to integrate such aspects as self-regulation and creative problem-solving into the existing model, keeping in view the needs of non-STEM students.

2.2 Learner Demographics and Equity

Adaptive systems may therefore be seen as an optimistic effect that offers new hope as regards to the possibilities of creating learning environments that are more sensitive and responsive to the needs and features of students who might have been oppressed in the traditional classroom environment. Adaptive platforms bridge the equity divides so that adjustments are made in time and in a personalized manner. However, the digital divide prevents or limits equal levels of digital literacy, which can hinder its application [10]. In future work, the need for technology training to support marginalized learners in effectively accessing and using adaptive technology systems should be addressed [21]. Equity-oriented designs should address the inclusion of multiple languages and localization [7].

2.3 Technological Infrastructure and Access

The availability of accurate technology is still a challenge. Achieving sustainable and adaptive systems for low-resource settings seems to be a crucial assignment [21, 18]. In self-regulated learning, the learners maintain, explore, and examine their learning process through introspection and active engagement. It is associated with better performance, higher academic engagement, and superior material retention [16].

On similar lines, it has been noted that large-scale solutions with offline mode can serve groups with limited internet access [4]. The information grasping and retention rate is higher among individuals who utilize the M-learning platforms. Still, the progress among individuals is higher when they get educated using the traditional method [10]. Additionally, they reflect on the recommendation to develop platforms that operate light and are compatible with mobile devices, as they are compulsory in the case of a remote learning background.

2.4 Institutional or Educator Support

The currency study has recognized the fact that supportive institutions have an essential part in the practice of adaptive systems. A claim has been made those adaptive systems are supportive and do not eliminate educators who analyze information and take corrective actions [22]. The need to incorporate adaptive tools in teaching requires the creation of professional development programs to train educators in using such tools [4]. For instance, a study considers it fit to acknowledge that to ensure the adaptive systems remain in sync with other pedagogic aims, there should be another engagement after every interval [25]. It has been discovered that several contextual variables play an important role in predisposing and identifying the suitability of adaptive learning systems. Cooperation between teachers, S3 policymakers, and technology creators is required for these systems to be seamlessly integrated and evidence-based and increase their usage efficiency [19].

IV. DISCUSSION (CRITICAL ANALYSIS AND INTERPRETATION)

1. INTERPRETATION OF FINDINGS

The literature review shows that adaptive learning systems have shown high effectiveness in enhancing long-term memory of knowledge, especially in the STEM fields. Such preeminence is commonly due to the fact that STEM disciplines are well structured and that learning goals can directly be improved by use of learning tools like spaced repetition, content scaffolding, and real time feedback [24, 28]. Such mechanisms curtail extraneous cognitive load and facilitate schema formation, which allows learners to consolidate knowledge more effectively than when learning in a traditional environment.

However, evidence also indicates that, in some cases, adaptive learning results are also similar to traditional ones. As an illustration, the benefits of adaptive systems are less visible in high-quality classrooms where the instructors use high levels of scaffolding and interactive pedagogies [7]. It indicates that the moderating variables are contextual variables, which include teacher expertise, digital literacy, and quality of current instructional design, in determining whether adaptive platforms will prevail over traditional means [12]. These ambivalent outcomes reinforce the significance of both learning about the strengths of the adaptive systems as well as the circumstances in which they can overlap with or become disconnected from the traditional approaches.

2. THEORETICAL INSIGHTS

Established learning theories can provide additional interpretation of the evidence as to why adaptive strategies increase retention. Cognitive Load Theory offers a solid explanation, where it is hypothesized that feedback and spaced repetition techniques lower the extraneous cognitive load and allow the learner to devote more working memory resources to the required processing. This theoretical perspective explains why the adaptive systems are more effective than standard methods in systematic areas where cognitive overload is prevalent. Equally, the popular concept of scaffolded content in adaptive platforms is based on the zone of proximal development (ZPD) described by Vygotsky. Adaptive systems implement Vygotskian principles by modifying the complexity of tasks in line with the developmental stage of a learner, where the learner is not too easy or too difficult [25]. Such a coincidence between theory and system design demonstrates the way adaptive strategies can facilitate mastery and retention systematically.

Lastly, Connectivism is a more generalized theoretical approach, especially in relation to adaptive tools fueled by analytics. Adaptive systems enable networked knowledge environments by using data about learners and allowing them to follow self-regulated and personalized paths [21]. This theoretical approach underlines the significance of technology-mediated relations in determining retention outcomes and complements cognitive approaches by pointing out the importance of digital networks in building knowledge. Collectively, these theoretical resources help to gain a better understanding that the success of adaptive learning is not a coincidence but rather based on well-known cognitive and socio-constructivist principles. They also report the necessity of combined theoretical perspectives that can be used to describe the interaction of adaptive technology, learner engagement, and retention with time.

All these theoretical backgrounds form the conceptual framework of Figure 2 that integrates the relations between the adaptive approach to learning, mediating variables, and the lasting retention of knowledge. According to the model, retention is indirectly improved by the mechanisms of real-time feedback, spaced repetition, scaffolded content, and learner analytics to decrease cognitive load, foster learner engagement [21], and promote equity and accessibility [4, 10]. The individual mediating factors all lead to better knowledge consolidation over time, thus justifying the differences in adaptive and traditional learning methods.

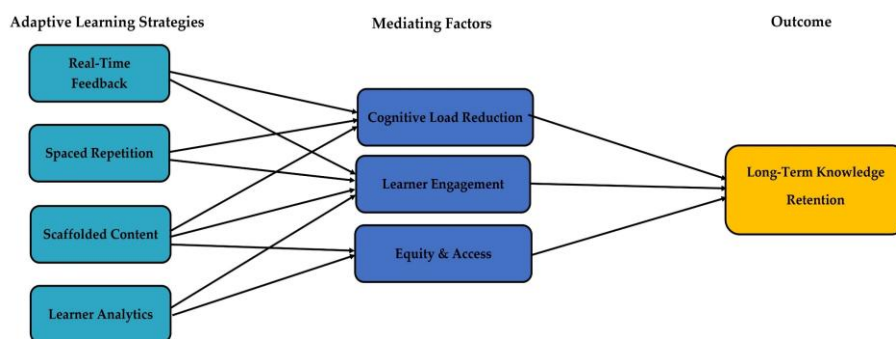


FIGURE 2. Conceptual model: adaptive learning strategies and long-term knowledge retention.

Adaptive learning strategies in a personalized learning environment (real-time feedback, spaced repetition, scaffolded content, and learner analytics) improve long-term knowledge retention as shown by the model through the following key mediating factors: reduced cognitive load, higher learner engagement, and improved equity and access.

3. CRITICAL INSIGHTS AND GAPS

Even though adaptive learning does not lack research from any perspective, a few areas indicate the need for further study.

3.1 Maintenance and Enduring Processes for Data Retention

Several research works have investigated short-term retention rates, which hampers understanding long-term adaptive learning dynamics [29, 13]. However, an improved chemistry knowledge retention across the semester has been observed, pointing out gaps in the longitudinal research and evaluating the knowledge retention that spans years and semesters on the durability of these effects [25]. It has been concluded that personalized review systems could improve long-term retention, but their applicability to adaptive systems needs further examination [12].

3.2 Underrepresentation in Non-STEM Disciplines

The reason for the research occasionally happening in STEM fields is that adaptive learning correlates more with linear acquisition and clear-cut knowledge. For example, it has been discovered that learning with scaffolding and spacing was effective when applied in STEM environments [5, 25]. However, the effectiveness of adaptive learning in the humanities and arts, concentrating mainly on problem-solving, understanding abstract concepts, and creativity, is still quite limited. Future studies are required to explore and interpret the possibility of implementing adaptive learning principles in the fields characterized by open-ended solutions.

3.3 Hybrid Models and Integration

A few researchers have shed light on the robust potential of learning adaptivity tools in conjunction with conventional teaching methodologies for enhancing learning outcomes. Still, challenges remain in making adaptive systems correspond to the traditional teaching methodologies [21, 6]. As persistence and participation can be improved by using blended models, the act of demonstrating how such versatile tools can be adapted to support face-to-face learning is still a matter of debate [24].

3.4 Access and Equity Challenges

Furthermore, a continued disparity persists in having equal access to adaptive learning technologies in developing backgrounds [10, 18]. Considering this existence, affordable and scalable solutions for large populations without meeting the standards of better education and training access are key to obtaining technological equity [4]. Consequently, the opportunities to provide effective and equal learning by using AMs are still untapped in such cases, especially taking into account the need for useful CLM and microlearning adaptation.

3.5 Impact on Student Engagement

Although adaptive systems provide several advantages to their implementors, several studies have shed light on their potential disadvantages, aiming at individualized learning. A study has identified the fact that, as much-heralded Learning Space designs serve to offer highly individualized learning progressions, they put a limit on learning interactions respectively [8]. Another issue of integrating individualized learning models and permitting peer interactions to avoid the feeling of being a stranger and promote development mainly emerged as a result of this finding. These gaps elaborate on the necessity of performing more studies on adaptive learning and its difficulties, research on longitudinal impact, and the significance of moving to non-STEM areas, ensuring that STEM students who could not transfer to fully online sections have equal access to high-quality learning, and identifying the best hybrid modalities to take advantage of live and recorded Instruction. This will be used as a basic strategy that can underpin other areas of research and ensure that effective adaptive learning systems are applied to various education situations.

V. FUTURE DIRECTIONS

The adaptive learning systems still need to be extended more rigorously in order to be used to their fullest potential in fields and situations. Although they have proven effective, there are a number of critical areas that have not been well explored. The majority of the available research focuses on the short-term retention outcomes, and the long-term viability of adaptive learning is unknown over the course of semesters or years. The next step in research should consequently be to longitudinal research studies to monitor knowledge retention in the long-term to establish whether the advantages of adaptive platforms are therefore sustainable after the initial evaluations [29, 13, 25]. One of the key questions here is: To what degree can adaptive learning systems maintain knowledge retention across semesters or academic years in comparison with conventional approaches?

The second priority is the development of adaptive learning in other areas other than STEM. Although adaptive strategies have produced good outcomes in formal knowledge domains (such as science, technology, engineering, and mathematics) there is little use in non-STEM areas. Research in the future should thus pose the question: How can adaptive strategies be successfully developed to facilitate abstract reasoning, creativity and problem-solving in the arts, humanities and social sciences? Concurrently, hybrid and blended models can be considered more closely. Integrating adaptive tools with conventional classroom strategies may have the best results. Studies need to investigate: Which are the best settings of adaptive and instructor-based strategies that will best attract and retain learners? Access and equity problems also need to be approached more clearly. Low-cost platform development based on the needs of low-resource environments, and multilingual and culturally aware design, will not enable adaptive systems to reach their full potential. One of the questions is: How would we make adaptive systems prepared to make learning equitable to learners in low-resource or linguistically diverse environments? The training of teachers is also of paramount importance, as those who teach in a classroom are the key to the implementation of adaptive tools into the educational process [4, 10, 18].

Lastly, adaptive platforms can be discriminating in terms of collaborative opportunities and peer learning, although this is not the goal of these platforms. Future studies should answer: What can adaptive learning models do to strike a balance between personalized learning experiences and collaborative and social learning opportunities to improve overall learning and retention rates? In general, in future work, it is hoped that it can be attempted to create more inclusive, more sustainable, and theoretically based adaptive systems by

filling in these gaps. This will not only enhance evidence base of adaptive learning but also make sure that it is applicable to different learners, disciplines, and learning contexts.

VI. CONCLUSION

The current study, which is a literature review, has contemplated the information on the effects of adaptive learning on retention in the long term as opposed to traditional frameworks. In the framework of the modification of constructivism, cognitive load theory, and connectivism, the present research outlines how the process of adaptive systems enhances retention with the help of feedback, content assistance, and distributed practice. It has been demonstrated that adaptive learning systems can be used to reduce extraneous cognitive load and provide individual interventions toward a quality education. It is argued that these systems are more efficient in retention as compared to conventional methodology since the participants have said that they have more retention in STEM disciplines. Nevertheless, issues such as access limitations, scalability, and compatibility with traditional instructional ways of learning still exist.

The current literature review also adds to the existing body of knowledge by pointing out the crucial problems of hybrid learning platforms and the possibility of adaptive systems to redefine education beyond STEM, humanities, and arts. It also illuminates the importance of a long-term assessment of the retention improvement and the percentage-related implementation of the strategies in the various settings. Therefore, as education is ever evolving, improvements in the behavioral learning systems are the future. Such systems establish an effective, collaborative, dynamic, intuitive, and personal learning environment. Adaptive learning has the potential to transform education among learners in other circumstances by sealing the available gaps and incorporating technology into learning activities.

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Author Contributions

Amal Altalhi was responsible for idea generation, data curation, formal analysis, writing, reviewing, editing, and formatting the manuscript. Chaitali Bonke contributed to the review and editing of the manuscript. Khaled Alblowi was involved in data analysis and in reviewing and editing the final manuscript.

Conflicts of Interest

The authors have no potential conflicts of interest or divergences associated with this research study.

Data Availability Statement

Not applicable. All data used in this study were obtained from previously published research cited in the manuscript

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