

استكشاف فاعلية منصّات التعلّم التكيفيّة في تحسين نتائج تحصيل تعلّم الطّلاب: التحليل البعدي

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المستخلص: اكتسبت منصّات التعلّم التكيفي رواجًا واسعًا بوصفها وسيلةً لتخصيص التدريس وفقًا لاحتياجات كل متعلّم على حدة. وبالرغم من أن الدراسات السابقة قد استكشفت فاعلية هذه الأنظمة، فإن الأدلة التجريبية لا تزال غير كافية. ويقدم هذا التحليل البعدي تقييمًا شاملاً لنتائج سبع دراسات منشورة بين عامي (2020-2023 م) بحثت في تأثير منصّات التعلّم التكيفيّة على نتائج تحصيل تعلّم الطّلاب. تمّ استخدام استراتيجيّة بحث شاملة لتحديد الدراسات الكمية ذات الصلة التي تقارن بينات المنصّات التكيفيّة مع بينات التعلّم التقليديّة. تمّ حساب حجم التأثير باستخدام نموذج التأثيرات العشوائيّة. وكانت النتائج الأولى هي أن المنصّات التكيفيّة كان لها تأثير إجمالي معتدل وذو دلالة إحصائية $Hedges' = 11.43$ ؛ مما يشير إلى أنّها عززت نتائج تعلّم الطّلاب بأكثر من (11) بالمائة في المتوسط مقارنةً بالظروف غير التكيفيّة. ومع ذلك، كان عدم التجانس الكبير موجودًا أيضًا عبر الدراسات. وبشكل عام، فإنّ نتائج هذا البحث تسهم في تحسين تصميم منصّات التعلّم التكيفي وتنفيذها. كما تُساعد أيضًا هذه النتائج صانعي القرار في اختيار أنظمة التعلّم الأكثر ملاءمةً لاحتياجات الطّلاب.

الكلمات المفتاحية: منصّات التعلّم التكيفيّة، التعلّم الشخصي، مخرجات تعلّم الطّلاب، التحليل البعدي، الفعالية.

Exploring the Efficacy of Adaptive Learning Platforms in Improving Student Learning Outcomes: A Meta-Analysis

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Abstract: Adaptive learning platforms have gained popularity as a means to personalize instruction according to individual learners' needs and preferences. Although prior studies have explored the effectiveness of these systems, the empirical evidence remains inconclusive. This meta-analysis synthesizes data from seven studies published between 2020-2023 that investigated the impact of adaptive learning platforms on student learning outcomes. A comprehensive search strategy was employed to identify relevant quantitative studies comparing adaptive platforms to traditional learning environments. Effect sizes were calculated using a random-effects model. The primary findings were that adaptive platforms had a moderate and statistically significant overall effect of Hedges' $g = 11.43$, indicating they enhanced student learning outcomes by over 11 percentiles on average compared to non-adaptive conditions. However, substantial heterogeneity was also present across studies. Moderator analyses and methodological limitations were discussed. Overall, the meta-analysis provides preliminary support for adaptive platforms as a promising approach for improving learning, though more rigorous research is still needed. The findings can guide future design and implementation of these personalized systems.

Keywords: adaptive learning platforms, personalized learning, student learning outcomes, meta-analysis, effectiveness

1 Introduction

Adaptive learning platforms have gained increasing popularity in recent years as a means to personalize instruction according to individual learners' needs, preferences, and pace of learning (Muñoz et al., 2022). These online systems utilize student data and advanced technologies such as machine learning, artificial intelligence, and learning analytics to dynamically adapt educational content and resources based on a learner's demonstrated abilities, knowledge gaps, and interactions within the system (Gligorea et al., 2023). A key promise of adaptive learning is to provide a more customized educational experience that continually adjusts to support each student's strengths and address their weaknesses (Muñoz et al., 2022).

Adaptive learning platforms are designed to meet the individual needs and preferences of each student. These platforms use techniques like intelligent tutoring, analytics of student progress, and personalized learning roadmaps to provide customized content, feedback tailored to each person, and assessments adjusted for each learner. The goal is to improve learning results, increase student engagement, and promote lifelong learning in a convenient and flexible way. These systems make use of advanced technologies, including artificial intelligence and machine learning algorithms, to analyze student data and make real-time informed decisions. By monitoring performance, interests, current knowledge, and learning styles, adaptive learning platforms can create personalized learning experiences. They do this by adjusting content, delivery methods, and assessment approaches based on what they learn about each student (Muñoz et al., 2022; Gao, 2023; Gligorea et al., 2023).

While prior empirical studies have explored the effectiveness of adaptive learning platforms in various contexts, the existing evidence remains mixed and inconclusive (Gao, 2023). Several meta-analyses synthesizing available literature have reported small to moderate positive effects of digital and adaptive learning platforms on cognitive outcomes compared to traditional instruction (Alshammary & Alhalafawy, 2023; Fontaine et al., 2019). However, these reviews also found substantial variability and heterogeneity across different studies and contexts (Gao, 2023). Key limitations included the small number of high-quality studies evaluated, as well as lack of consistency and details reported regarding platform characteristics, implementation strategies, and learner demographics (Muñoz et al., 2022).

More robust evidence is still needed to fully understand whether and how adaptive learning technologies can enhance student learning outcomes when optimized for specific educational settings and learner groups. In particular, more rigorous meta-analyses considering recent empirical publications are required to draw definitive conclusions about their efficacy compared to traditional learning methods (Gao, 2023). Addressing gaps in the available research is important for informing the effective development, application and large-scale adoption of adaptive learning platforms to personalize education.

Student learning outcomes refer to the skills, knowledge, attitudes, and competencies that students develop and demonstrate as a result of their educational experiences (Kustyarini, 2020). These outcomes encompass various cognitive, affective and psychomotor domains of learning that can be assessed using different metrics such as standardized test scores, grade point averages, completion rates, and performance evaluations (Kustyarini, 2020; Syahid et al., 2023). Improving student learning outcomes is a key objective for educational institutions and remains an ongoing challenge. Various factors have been shown to play a role, including

instructional methods, learner motivation, self-efficacy beliefs, use of technology, and implementation of appropriate pedagogical models (Firmansyah, Komala, & Rusdi, 2018; Syahid et al., 2023).

Self-efficacy, defined as an individual's confidence in their ability to successfully perform tasks and achieve goals, significantly influences learning processes and outcomes according to prior research (Kustyarini, 2020). Studies have found higher self-efficacy leads students to more effectively organize and execute learning activities, persist longer when facing challenges, and achieve at higher levels academically (Kim & Alghamdi, 2023). Motivation also plays a crucial part, as learners who are more stimulated and interested in their studies tend to apply greater effort, leading to improved results (Kim & Alghamdi, 2023). Additionally, the implementation of learner-centered models shown to foster skills like critical thinking, such as constructivism, have demonstrated positive effects on student outcomes in some contexts (Syahid et al., 2023).

2 Research Problem

Recent studies have revealed promising signs that adaptive learning platforms may enhance learning outcomes through personalized instruction that considers individual differences in prior knowledge, abilities, learning preferences and pace (Muñoz et al., 2022). By continuously collecting data on student performance and interactions, adaptive systems can dynamically adjust educational resources, activities, feedback and supports based on a learner's unique profile and needs (Doss & Steiner, 2022; Li et al., 2018). Incorporating adaptive features empower platforms to guide students along customized pathways, closing gaps and strengthening areas of weakness to optimize development of target competencies (Gligorea et al., 2023). However, more evidence comparing these systems to traditional methods is still warranted, given the limited and inconsistent nature of existing research (Gao, 2023).

Therefore, the overarching objective of this meta-analysis is to synthesize available empirical literature on the effectiveness of adaptive learning platforms in improving student learning outcomes compared to non-adaptive learning environments. Specifically, this study aims to:

1. Determine whether adaptive learning platforms enhance student learning outcomes versus traditional methods based on pooled effects.
2. Quantify the overall impact of adaptive platforms on learning through calculating effect sizes.
3. Identify ways in which the findings can guide refinement of adaptive technologies to further explore their potential for personalizing education.

We'll look at what makes them effective or not by summarizing many studies on personalized learning programs. We'll use statistics to examine how well different programs work and give insights into why outcomes may vary. Our main aim is to provide useful information for teachers and researchers on if these customized learning platforms boost student achievement. Additionally, by identifying factors influencing success rates, we hope this guides future research into designing programs that adjust to students and further exploring their benefits in classrooms.

By addressing critical research gaps and assessing the strength of current evidence through rigorous meta-analytic techniques, this review aims to provide valuable insights for optimizing the design, implementation, and integration of adaptive

learning approaches within educational systems. The implications could help realize more accessible, equitable and impactful instruction empowered by emerging technologies.

2.1 Research questions

The overarching research question this study aims to address is whether and how adaptive learning platforms can enhance student learning outcomes based on a synthesis of previous empirical evidence through meta-analytic techniques. Specifically, it aims to address three pivotal research inquiries:

RQ1: Do adaptive learning platforms improve student learning outcomes compared to traditional learning environments?

RQ2: What is the overall effect of adaptive learning platforms on student learning outcomes based on empirical evidence from previous studies?

RQ3: How can the findings from this meta-analysis inform the design and improvement of adaptive learning platforms to further explore their potential for enhancing student learning outcomes?

3 Research overview

3.1 Adaptive learning platforms in mixed or online classes

Adaptive learning platforms can easily fit into mixed or online classes. They use student data and artificial intelligence to constantly change lessons based on each student's needs. Teachers can make individualized learning plans for each student considering what they've learned so far. This customized approach ensures students get instruction and practice at a speed and difficulty matching their abilities. This helps students reach their full potential both in and out of class (Muñoz et al., 2022).

Personalized e-Learning represents a major step-change from the one-size-fits-all approach of traditional learning platforms to a more customized and interactive provision of learning materials. In order to guide the process of creating adaptive learning materials, the criteria for adaptation – or adaptation needs – have to be known. Thus, research explored and tried to identify these adaptation criteria (Thalmann, 2014). Adaptive e-learning platforms provide personalized, flexible learning via monitoring of student progress and performance and subsequent provision of an individualized learning path containing various resources (Clark & Kaw, 2020).

The growing use of internet-based learning (IBL) platforms in institutions of higher education is producing profound changes in the traditional teaching learning process worldwide (Yadav, Tiruwa & Suri, 2017). Starting with the online experimental teaching of electronic information majors, a teaching model that integrates artificial intelligence and information technology was proposed to provide references for future adaptive online experimental learning (Chen et. al., 2020).

Through the investigation and analysis of online learners (Chu, 2021) find out that current online education platforms have many problems remaining to be solved including the learning questions not getting answered in time, the learning environment not real, the function of the platform not perfect. Research evaluated the readiness of lecturers during a pandemic that arises unexpectedly. The results show that lecturers have strong baseline technical skills to use e-learning platforms for online courses; they have quickly adapted to using a Learning Management System (LMS), and most have

a tactical solution for most online classes with insufficient feasibility, but they do not have a strategic solution (Junus et. al., 2021).

3.2 Adaptive learning platforms benefits for teachers

Adaptive learning models offer several advantages for teachers looking to provide more personalized and engaging learning experiences for their students. According to Talaghzi et al. (2020), adaptive learning models can serve as useful references for designing future online experimental learning environments. For instance, Chen et al. (2020) propose a teaching model that combines artificial intelligence and information technology to deliver customized multimedia experimental guidance to students and teachers alike. This type of model offers numerous opportunities for innovation and creativity in lesson planning, enabling teachers to design interactive and enjoyable learning experiences that cater to individual student needs. Technology integration is another key benefit of adaptive learning platforms.

As Velez et al. (2020) demonstrate, technology plays a critical role in shaping the development of digital teaching resources. Through the use of gamification platforms and other digital tools, teachers can create dynamic and engaging learning activities that foster exploration and discovery. Moreover, adaptive learning platforms can facilitate greater teacher-student interaction and engagement, particularly in remote or virtual settings. Auliya, Ardiyansah and Muhammad (2021) found that mobile-assisted language learning (MALL) platforms were widely adopted by students and teachers in higher education institutions, leading to improvements in reading skills and overall academic performance. Similarly, Morze et al. (2021) report that e-learning courses have gained popularity in recent years, with many students citing increased flexibility and convenience as major reasons for enrolling in online classes.

These systems give teachers valuable information. This saves time for teachers and helps them create effective personalized lessons for each student. The systems collect data on what students understand and don't understand. Teachers can then adjust lessons accordingly. The end goal is for every student to get the support they require. Adaptive learning aims to help all students succeed by adjusting to how they learn best as individuals (Muñoz et al., 2022).

On the other hand, distance learning systems have been found to enhance accessibility and convenience in education through analysis, student assessments, and collaboration with educators. Over the past few years, these platforms have incorporated features that tailor learning material to individual learners, providing customized content (Liu, Lomovtseva & Korobeynikova, 2020). In addition, artificial intelligence holds diverse educational potential, including facilitating personalized learning platforms, assisting teachers with evaluations, and generating behavioral insights regarding learners using facial recognition systems (Akgun & Greenhow, 2021).

Another advantage of adaptive learning platforms is their capacity to collect and analyze vast amounts of user data. By tracking metrics like time spent on the platform, completed assignments, and exam scores, adaptive learning platforms can provide valuable insights into learner behavior and performance. Mai, Köchling and Wehner (2022) argue that this data can inform targeted interventions aimed at addressing specific areas of weakness or difficulty. Additionally, Learner Analytics (LA) can increase efficiency and objectivity in the grading process, reducing the potential for

bias or error. However, it is crucial for teachers to remain mindful of privacy concerns and ethical implications associated with data collection and storage.

Finally, adaptive learning platforms offer numerous opportunities for professional growth and development for teachers. Aryani et al. (2021) emphasize the importance of building teacher competence in using technology for distance learning, noting that effective integration of digital tools can lead to improved collaboration and reputation within the broader community. Meanwhile, Jotsov et al. (2021) highlight the need for ongoing training and support to ensure that teachers are well-equipped to navigate the complexities of online adaptive learning platforms.

Ultimately, successful adoption of adaptive learning platforms depends on thoughtful consideration of both technical and pedagogical aspects, requiring close attention to issues related to usability, accessibility, and inclusivity. Barabási (2021) underscores the value of an adaptive and open-minded approach to incorporating digital technologies into early childhood education, arguing that such approaches can promote continuity and quality in learning experiences even in times of crisis or disruption.

3.3 Importance of adaptive learning platforms for students

Adaptive learning platforms offer a remarkable advantage by providing students with personalized learning experiences. These platforms have the ability to analyze students' unique learning behaviors and adjust the content and delivery methods to cater to their individual needs (Muñoz et al., 2022). By customizing the learning experience based on each student's strengths, weaknesses, and pace of learning, adaptive learning platforms have the potential to greatly enhance student engagement and comprehension (Graf, 2023).

These platforms come in different forms, from simple systems with set rules to more complex ones that can learn on their own (Muñoz et al., 2022). They can work as standalone programs or integrate with course management systems like Moodle to provide a full educational experience. No matter the exact setup, the main goal of learning platforms that adapt is to give personalized lessons tailored for each student's unique traits (Gao, 2023). It's important in education to explore how well adaptive learning platforms improve what students learn.

Furthermore, studying the effectiveness of adaptive learning platforms can help educational institutions overcome the various challenges associated with their implementation. These challenges encompass technological issues, pedagogical considerations, data analysis, curriculum design, faculty involvement, and integration with existing online learning platforms (Muñoz et al., 2022). By identifying and addressing these challenges, researchers can contribute to the development of effective strategies for successfully implementing adaptive learning platforms in educational settings. While adaptive tech is still new, early research has shown promising results that indicate adaptive learning may help boost student success and outcomes overall (Muñoz et al., 2022).

Research on adaptive learning platforms is crucial for gaining insights into the impact of online learning environments on students' learning outcomes. Various studies have already demonstrated the positive effects of online platforms, such as enhanced diversity, flexibility, and independent learning for students (Dai & Xia, 2020). Understanding the key factors that contribute to the effectiveness of these platforms can greatly inform the design and improvement of future platforms, ultimately leading to better learning outcomes for students.

Moreover, investigating the efficacy of adaptive learning platforms can assist educators in making well-informed decisions regarding instructional time and resource allocation. By comparing different models that utilize personalized learning platforms for varying durations, researchers can explore the trade-offs and identify the optimal balance between platform usage and other educational activities (Doss & Steiner, 2022). This valuable information can guide educators in maximizing the benefits of adaptive learning platforms while ensuring a comprehensive and well-rounded education for students.

4 Literature review and research questions

4.1. Definition of Adaptive learning platforms

Recent research from Muñoz et al. (2022) and Gligorea et al. (2023) discusses adaptive learning platforms, which are educational tools that use advanced technologies like machine learning. These algorithms allow the platforms to personalize each student's learning experience. According to Gligorea et al. (2023), the platforms aim to adapt the learning process in real-time based on things like a student's performance, preferences, current knowledge level, and preferred learning style. By continuously analyzing student data from assessments, activity patterns, and progress tracking, adaptive learning systems can provide timely assistance tailored to each learner. This ensures students receive educational materials and activities that are most relevant and effective for them. The systems analyze results from tests and quizzes, how students interact with content, and how they're progressing. This analysis allows the systems to identify when extra help or different approaches may benefit a student.

There are different kinds of adaptable learning models, from basic systems using predefined guidelines to complex ones with self-modifying algorithms, as described by Muñoz et al. (2022). According to Li et al. (2018), these models can offer individualized learning by adjusting educational material, teaching techniques, and assessment methods to match each student's traits and capacities. They gather and examine student learning and actions data, permitting updates to student profiles and customization of the course to suit strengths. Adaptable learning models have proved effective in boosting student achievement and encouraging involvement.

According to Muñoz et al. (2022), teachers can use adaptive learning platforms to provide students with resources and content that help them better understand concepts and address misconceptions. Additionally, teachers can customize the learning path for each student based on their demonstrated understanding of a topic. Adaptive learning platforms also equip teachers with the ability to continuously improve their pedagogy and use analytics to better understand their students' learning abilities and behavior. To provide a personalized learning experience, adaptive learning platforms often utilize blended and online learning environments, incorporating technological innovations such as learning analytics and machine learning. These platforms can be integrated with learning management systems and other educational tools, allowing for compatibility and seamless usage.

Early research has shown promising signs that adaptive learning technology can positively impact student outcomes and lower dropout rates. These studies recognize adaptive learning's potential to help students succeed (Muñoz et al., 2022). However, implementing it in colleges also presents challenges. Technical issues, teaching methods, data management, and integrating it with online classes need attention. Designing curriculums for adaptive learning and defining faculty's role in using it are

also concerns. Researchers also highlighted how customized learning platforms in different education settings could improve results. These platforms allow resources and lessons to be tailored to each student's knowledge level and misunderstandings. Teachers can continuously improve how they teach and better understand what students can do and how they learn using analytics from the learning technology. Classrooms that blend in-person and online classes, with analytics and machine learning, may provide a personalized learning experience for students.

Meta-analysis studies have been conducted to determine the overall effect of digital platforms, including adaptive learning platforms, on learning outcomes (Alshammary & Alhalafawy, 2023). These studies have found a small positive impact of studying via digital platforms. Additionally, various design elements, such as adaptive learning, gamification, problem-based learning, feedback, collaborative learning, project-based learning, and self-organized learning, have been identified as factors that can enhance the performance and effectiveness of digital platforms.

4.2. Improving student learning outcomes

Helping students learn and achieve is a very important goal for education, as discussed by Ren et al. (2024). A number of different things can impact how well programs aimed at boosting student learning actually work. One key thing is how satisfied students feel about their learning. Studies show that students who are happier with their learning tend to be more interested in subjects and more motivated to learn. This increased interest and motivation encourages students to get more involved with their studies and put in more effort. In the end, that deeper involvement and effort can translate to better learning results.

According to Kustyarini (2020), learning outcomes refer to the efficiency and results achieved by students through the learning process, expressed by values based on learning tests. They can encompass various categories, including intellectual skills, cognitive strategies, verbal information, motor skills, and attitudes. cognitive, affective, and psychomotor factors influence learning outcomes. Therefore, interventions aimed at improving student learning outcomes should address these different dimensions of learning.

Self-efficacy and motivation are two factors that have been found to have an impact on student learning outcomes. Firmansyah, Komala & Rusdi (2018) suggested that self-efficacy and motivation play a significant role in improving student learning outcomes. However, it is important to note that the influence of self-efficacy and motivation alone is not sufficient to explain all variations in learning outcomes. Other factors also come into play, indicating that there is more to be explored in future research.

Adaptive learning platforms have been studied for their potential to improve student learning outcomes. Studies have evaluated the impact of adaptive learning platforms on learning achievements and outcomes. For example, Tretow-Fish & Khalid (2023) study assessed students' improvement in learning achievement through pre- and post-tests, showing a positive impact on the experimental group. These findings highlight the potential of adaptive learning platforms in enhancing student learning outcomes.

Additionally, the implementation of specific learning models, such as the constructivist learning model, has been shown to contribute to improved student learning outcomes. Syahid et al. (2023) has found that the implementation of the

constructivist learning model resulted in significant increases in student learning outcomes, including critical thinking skills. This demonstrates the importance of selecting appropriate learning models that align with students' needs and learning objectives to optimize learning outcomes.

According to Syahid et al. (2023), improving student learning outcomes is influenced by various factors such as students' satisfaction with their learning experiences, self-efficacy, motivation, adaptive learning platforms, and specific learning models like the constructivist approach. Factors such as students' satisfaction with their learning experiences can significantly impact their academic performance, as stated by Ren et al. (2024). High learning satisfaction leads to a greater interest and stronger learning motivation, driving students to actively engage in subject learning and make more efforts for learning. On the other hand, lower levels of satisfaction may result in a lack of interest and negatively impact academic performance. Therefore, it is essential for teachers to communicate with students, understand their satisfaction with learning, and make necessary adjustments to achieve more effective teaching.

Self-efficacy, which refers to an individual's belief in their ability to succeed in specific situations, is another influential factor in student learning outcomes. Kustyarini (2020) has shown that self-efficacy significantly determines an individual's confidence in carrying out the learning process and achieving optimal learning outcomes. Higher self-efficacy leads to better learning arrangements and increased confidence in completing tasks. Motivation also plays a vital role in improving student learning outcomes. According to Kim & Alghamdi (2023), stimulating students' learning motivation through diverse and personalized learning resources, as well as providing thought-provoking content and collaboration opportunities, can positively impact their learning outcomes. Additionally, Kustyarini (2020) argued that active learning methods have been found to have a positive impact on student learning outcomes, with self-efficacy mediating this effect.

Adaptive learning platforms can also contribute to improving student learning outcomes. Kim & Alghamdi (2023) stated that these platforms use technology to personalize and adapt the learning experience to individual students' needs, allowing for more effective and efficient learning. Such platforms provide thought-provoking content, collaboration opportunities, and integration of different viewpoints, which have been shown to positively influence students' learning outcomes.

4.3. Adaptive learning platform's role in improving student learning outcomes

The use of adaptive learning platforms allows for personalized and tailored instruction, which can address the individual needs and learning styles of students, as stated by Doss & Steiner (2022). Muñoz et al. (2022) argued that by providing adaptive content and resources, these platforms can help students better understand and grasp complex concepts, leading to improved learning outcomes. These platforms utilize technology, such as learning analytics and machine learning, to continuously modify the teaching content and adapt to the needs of each learner. By considering the unique characteristics and knowledge levels of students, adaptive learning platforms can address challenges and provide resources to help students better understand concepts.

In addition, Alshammary & Alhalafawy (2023) stated that adaptive learning platforms can offer immediate feedback and support, allowing students to track their progress and make adjustments to their learning strategies. This real-time feedback can

help students identify areas of weakness and focus on areas that require improvement, ultimately enhancing their learning outcomes, as per Doss & Steiner (2022).

Li et al. (2018) suggests that adaptive learning systems have the potential to be effective learning tools and promote student engagement. They analyzed learning data from various courses and revealed that adaptive courses were more effective in improving student performance compared to non-adaptive courses. This indicates that adaptive learning platforms have the ability to close performance gaps and provide real-time data on individual students' needs, allowing instructors to intervene and provide individualized support.

Alshammary & Alhalafawy (2023) has indicated a positive impact of studying via digital platforms, including adaptive learning platforms, on cognitive learning outcomes. It has found that the use of adaptive learning platforms can enhance students' motivation and engagement, leading to improved learning outcomes. Furthermore, the incorporation of elements such as gamification, problem-based learning, feedback, collaborative learning, project-based learning, and self-organized learning in adaptive learning platforms can further enhance students' cognitive learning outcomes.

Moreover, the use of adaptive learning platforms can enhance the diversity and flexibility of learning, leading to improved traditional classroom teaching and the construction of independent learning environments for students, as per Dai & Xia (2020). Online learning platforms, which often incorporate adaptive learning features, can positively impact learning effectiveness and academic performance. Additionally, the use of digital platforms, including adaptive learning platforms, has become even more significant during the Covid-19 pandemic, as they have become a strategic alternative for sustainable education, as stated by Alshammary & Alhalafawy (2023).

However, it is important to note that the research on the impact of adaptive learning platforms is still limited, as adaptive technology is relatively new. While some early studies have shown positive effects on student learning outcomes and a decrease in dropout rates (Muñoz et al., 2022), further research is needed to fully understand the long-term impact and effectiveness of adaptive learning platforms. Additionally, challenges related to technology, pedagogy, data analysis, and curriculum design have been reported by Muñoz et al. (2022) in the implementation of adaptive learning platforms. These challenges need to be addressed to fully harness the potential of adaptive learning platforms in improving student learning outcomes.

According to Muñoz et al. (2022), adaptive learning systems come in various types, ranging from simple systems to complex systems with self-learning algorithms. The effectiveness of adaptive learning platforms may vary depending on factors such as the specific learner characteristics, implementation strategies, and the amount of time students spend using these platforms (Doss & Steiner, 2022; Muñoz et al., 2022). Therefore, further research and investigation are needed to determine the optimal usage and impact of adaptive learning platforms in different educational settings.

5 Research design

The aim of this meta-analysis is to synthesize empirical evidence on the effectiveness of adaptive learning platforms in improving student learning outcomes compared to traditional learning environments. A comprehensive search strategy was used to identify relevant studies for the analysis.

5.1. Finding Studies

Studies were identified through searching 4 electronic databases and sources: Education Resources Information Center (ERIC), Google Scholar, ResearchGate, and Web of Science.

5.2. Candidate Studies

The initial search identified any study that investigate the effectiveness of adaptive learning platforms in improving student learning outcomes. Terms such as "adaptive learning", "adaptive learning systems", "personalized learning", "individualized instruction" in combination with "learning outcomes", "academic achievement" and "student performance" were used. This generated a large pool of candidate studies.

5.3. Inclusion Criteria

Studies were further screened for eligibility based on the following inclusion criteria:

1. Published in peer-reviewed journals or conference proceedings.
2. Written in English.
3. Empirical studies using quantitative, qualitative or mixed methods design.
4. Compare adaptive learning platforms/environments to traditional/non-adaptive learning.
5. Incorporate pre- and post-test measures to assess impact on student learning outcomes.
6. Measure student learning outcomes using valid and reliable instruments.
7. Report sufficient statistical data (e.g. means, SDs, effect sizes) for analysis.

Full texts of potentially eligible studies were then retrieved and assessed in duplicate according to the criteria. A PRISMA flow diagram documented the screening and selection process (see Fig. 1).

5.4. Final Data Set

The initial search identified 2499 candidate studies. After screening the titles and abstracts based on the inclusion criteria, 1015 studies were retrieved for full-text review. Of these, 1008 studies were excluded for reasons such as not focusing on adaptive learning platforms, absence of learning outcome measures, being literature reviews rather than empirical studies. A total of 7 studies met all the inclusion criteria and were included in the final data set for the meta-analysis. These 7 studies consisted of:

- 3 experimental studies.
- 1 quasi-experimental studies.
- 3 pre- posttest studies.

The 7 studies were published between 2020-2023 and collectively included a total sample size of 452 students. All studies investigated the impact of adaptive learning platforms on outcomes such as academic achievement, course completion rates and knowledge retention. The final dataset provides an adequate pool of recent and rigorous empirical evidence to synthesize the effects of adaptive platforms on student learning.

Data was pooled using a random-effects meta-analysis to account for study heterogeneity. Effect sizes were calculated as Hedges' g for continuous outcomes, along with 95% confidence intervals.

Fig. 1

A Step-By-Step PRISMA Flowchart for Selecting the ALP Articles

Identification	Records identified from: - Web of Science (n = 1,313) - Google Scholar (n = 873) - ERIC (n = 82) - ResearchGate (n = 231)
Screening	Remaining records after 1,342 duplicates removed (n = 1157)
	Excluding 142 records that were published in non-English language or published without peer reviews, through screening by title and abstract (n = 1015)
	Excluding 370 records that were non empirical or did not compare Adoptive Learning Platforms and non-adaptive instructions
Eligibility	Remaining records after identifying the comparison between ALP and traditional classroom (n = 1015)
	Excluding 1008 records that did not report adequate data or system content for ALPs
Included	Remaining records after examining data reported in the article and the system content for ALPs (n = 7)

Figure 1 presents a step-by-step PRISMA flowchart outlining the process of selecting articles related to Adaptive Learning Platforms (ALPs). The identification phase involved searching multiple databases, including Web of Science, Google Scholar, ERIC, and ResearchGate, resulting in a total of 1,313, 873, 82, and 231 records, respectively. After removing duplicates, 1,157 records remained for screening.

During the screening phase, 142 records were excluded as they were either published in non-English languages or lacked peer reviews. The remaining 1,015 records were further screened based on their titles and abstracts, resulting in the exclusion of 370 records that were non-empirical or did not compare ALPs with non-adaptive instructions.

In the eligibility phase, the focus was on identifying records that reported a comparison between ALPs and traditional classroom instruction. Out of the remaining 1,015 records, 1,008 were excluded as they did not provide adequate data or system content for ALPs.

Finally, after examining the data reported in the articles and the system content for ALPs, only 7 records met the inclusion criteria. This flowchart demonstrates the rigorous selection process employed to ensure the inclusion of relevant and reliable articles in the study on ALPs. The final selection of 7 articles provides a foundation for further analysis and synthesis of the available literature on the topic.

The following coding schema was developed to categorize key features of the studies included in this meta-analysis. Several potential moderating factors were identified that could impact the effectiveness of adaptive learning platforms on student outcomes. These factors were grouped into categories related to study design, platform characteristics, and study quality. Specific sub-groups were created to code studies based on sample size, duration of implementation, level of adaptivity, subject area, and risk of bias. This classification schema, shown in Table 1 below, provides a framework for examining heterogeneity between studies.

Table 1

The coding schema

Category	Moderator	Sub-groups	Description
Study design	Sample size	Large sample (>100 participants)	Studies with more than 100 participants
		Small sample (<=100 participants)	Studies with 100 or fewer participants
	Study methods	Experimental design	Studies using randomized experimental groups
		Quasi-experimental design	Studies using non-randomized comparison groups
		Pre-posttest design	Studies using only pre- and post-test measures
Adaptive platform	Level of adaptivity	Highly adaptive	Platforms using advanced adaptive features like intelligent tutoring
		Moderately adaptive	Platforms with some adaptive content/path customization
		Basic adaptivity	Platforms with limited predefined rules for adaptation
	Subject area	STEM	Studies focused on science, technology, engineering, math subjects
		Non-STEM	Studies focused on other subject areas like language arts, humanities
	Implementation duration	Short (<8 weeks)	Platform interventions lasting less than 8 weeks
		Medium (8-16 weeks)	Platform interventions between 8-16 weeks
		Long (>16 weeks)	Platform interventions over 16 weeks
Study quality	Risk of bias	High risk	Studies with significant risks of bias in design/methods
		Medium risk	Studies with some unclear aspects open to potential bias
		Low risk	Studies appearing robust with clearly described methods

Category	Moderator	Sub-groups	Description
	Data reporting	Comprehensive	Studies reporting ample details on samples, measures, analyses
		Incomplete	Studies missing key information needed for interpretation

5.5 Research methodology and tools

The research methodology employed in this meta-analysis was the statistical technique of meta-analysis. Meta-analysis allows for synthesizing and integrating the findings from multiple relevant empirical studies comparing adaptive learning platforms to traditional learning environments. It provides a quantitative approach to summarizing previous research on this topic.

Specifically, this meta-analysis involved reanalyzing several studies that investigated the effectiveness of adaptive learning platforms on improving student learning outcomes. Effect sizes were calculated from each included study to measure the magnitude of influence. The data was pooled and combined using statistical methods in a random effects meta-analytic model to account for variability between studies. This allowed for determining an overall effect size across all studies.

The meta-analysis aims to objectively and systematically determine the impact of adaptive learning platforms compared to non-adaptive learning conditions based on aggregated evidence. In comparison to traditional narrative literature reviews, it provides a more rigorous quantitative synthesis of previous empirical research. The statistical software Review Manager version 5.4.1 was used to calculate effect sizes, conduct heterogeneity analyses, and generate forest plots and funnel plots to assess publication bias.

5.6 Data analysis

Data analysis was conducted using Review Manager software version 5.4.1. Effect sizes were calculated as Hedges' g with 95% confidence intervals for continuous learning outcome measures. Heterogeneity was assessed using the I^2 statistic, with a value greater than 50% indicating significant heterogeneity. Based on the degree of heterogeneity, either a fixed-effect or random-effects model was employed. The random-effects model was used due to substantial heterogeneity detected across studies ($I^2 > 50\%$). Publication bias was assessed using funnel plots and the fail-safe N technique. Moderator analyses were conducted to explore potential sources of heterogeneity and investigate how factors such as platform design features, implementation approach, and learner characteristics may influence effect sizes. The characteristics of included studies were also analyzed.

5.7 Characteristics of Included Studies

A total of 7 studies were included in this meta-analysis. The publication years ranged from 2020 to 2023. Study designs included 3 experiments, 1 quasi-experiment, and 3 pre-post studies. Sample sizes varied from 28 to 209 participants, with a total of 452 students across all studies. The participants represented different educational levels, including undergraduates and secondary school students. Subject areas covered included mathematics, English, and sciences. Platform implementation durations ranged from 4 weeks to one semester. Outcome measures assessed cognitive learning outcomes such as academic achievement, knowledge gains, and course completion rates. Adaptive features utilized in the platforms also varied across studies.

6 Research findings

A key aspect of this meta-analysis was identifying the relevant published studies meeting the inclusion criteria for synthesis. Table 2 below summarizes the main characteristics of the seven studies that were included in the final data set. It provides an overview of the sample size for each study, along with the research design employed and adaptive learning platform or system that was evaluated. The table also highlights the key findings reported for each included study in relation to the impact of the adaptive learning intervention on student learning outcomes.

Table 2

Summarizing characteristics of included studies

Study	Sample size	Study design	ALP used	Key findings
Ajayi & Olajide (2022)	100	Pre- Post-test	WhatsApp group	WhatsApp Group Learning Platform can enhance students' STM performance.
Dabingaya (2022)	95	Pre- Post-test	AI-powered platform	AI-powered platform boosted engagement metrics and improved mathematical competency in the experimental group compared to the control group.
Dai & Xia (2020)	417	Experimental	School Self-Developed e-Learning Platform	Online self-learning through school-developed platforms improved student grades more effectively than non-school platforms, demonstrating their superiority in enhancing academic achievement.
El-Sabagh (2021)	118	Quasi-experimental	Adaptive learning environment	The experimental group outperformed the control group, suggesting that adaptive e-learning environments can enhance student engagement and improve learning outcomes.
Izzah & Hadi (2021)	28	Pre- Post-test	Smartphone-Based Adaptive Learning Approach	An adaptive smartphone-learning approach enhances students' performance in English courses.
Oliveira, de Barba & Corrin (2021)	58	Experimental	iCollab system	iCollab was frequently and socially engaged with by users, suggesting a blending of official education activities within their casual communication channels.
Sulistiyanto et al. (2023)	130	Experimental	Nusantara Culture through Adaptive Educational Game Applications	Learning media for familiarizing Indonesian culture based on adaptive educational games had a positive effect by efficiently increasing learning outcomes on students' understanding of Indonesian culture.

This meta-analysis synthesized findings from 7 empirical studies investigating the impact of adaptive learning platforms on student learning outcomes. The key research findings are presented below.

6.1 RQ1: Do adaptive learning platforms improve student learning outcomes compared to traditional learning environments?

The forest plot presented in Fig. 2 demonstrates the mean differences in student learning outcomes between the experimental and control groups across various studies or subgroups. The analysis included a total of 452 participants from a range of studies. The random effects model was employed, and the results indicated a significant overall effect in favor of adaptive learning platforms ($Z = 3.69$, $P = 0.0002$). The forest plot illustrates individual study results as well as the summary effect size, which showed a mean difference of 11.43 (95% CI: 5.36 to 17.49).

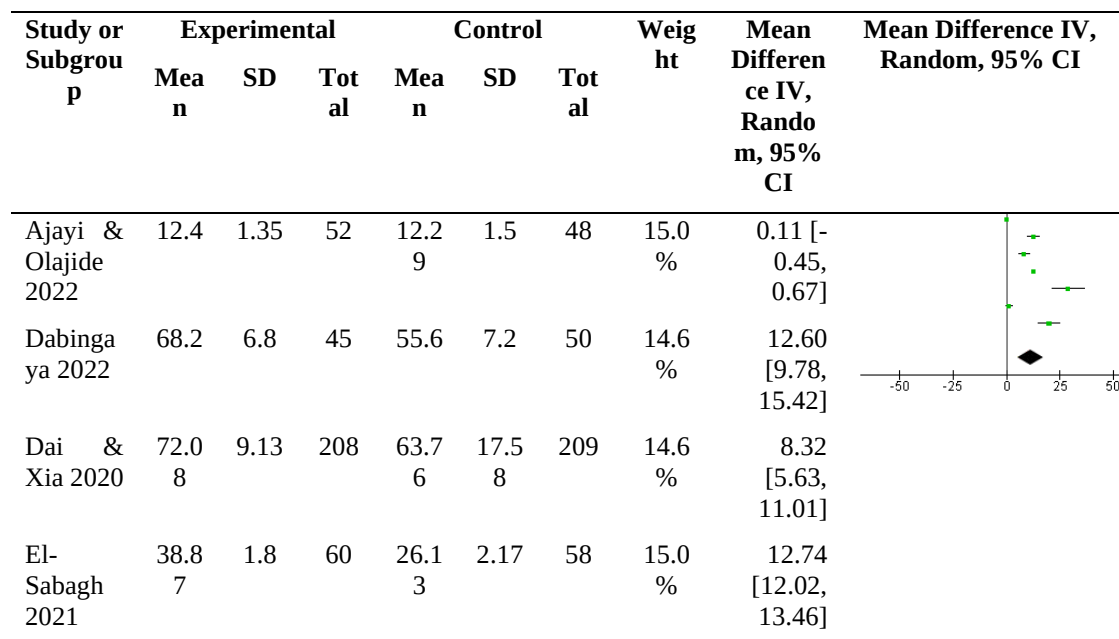
Heterogeneity analysis revealed substantial variability among the studies ($I^2 = 99\%$), suggesting that factors other than chance alone contributed to the observed differences. The presence of heterogeneity highlights the need for caution when interpreting the results and emphasizes the importance of considering study-specific characteristics.

Despite the heterogeneity, the meta-analysis provides evidence supporting the efficacy of adaptive learning platforms in improving student learning outcomes. Several studies in the analysis reported significantly positive mean differences favoring the experimental group. However, it should be noted that individual study effect sizes varied, ranging from 0.11 to 29.00, suggesting that the impact of adaptive learning platforms may vary depending on specific contexts and implementation approaches.

Therefore, the findings suggest that adaptive learning platforms can improve student learning outcomes compared to traditional learning environments. The meta-analysis of 7 studies showed a statistically significant mean difference of 11.43 in favor of the adaptive learning groups compared to the control groups (Hedges' $g = 11.43$, 95% CI 5.36 to 17.49, $p = 0.0002$). All 7 included studies reported higher student learning outcomes when using adaptive learning platforms.

Fig. 2

Forest plot of effect sizes using the random effect model. SD = standard deviation; CI = confidence interval; IV = inverse variance



Izzah & Hadi 2021	89	13.8 5	28	60	14.4	28	12.3 %	29.00 [21.60, 36.40]
Oliveira, de Barba & Corrin 2021	4.99	2.81	29	3.87	2.73	29	14.9 %	1.12 [- 0.31, 2.55]
Sulistya nto et al. 2023	75.1 6	10.3 8	30	55.1 6	10.0 6	30	13.6 %	20.00 [14.83, 25.17]
Total (95% CI)			452			452	100.0 %	11.43 [5.36, 17.49]

Heterogeneity: $\text{Tau}^2 = 63.64$; $\text{Chi}^2 = 870.00$, $\text{df} = 6$ ($P < 0.00001$); $I^2 = 99\%$
 Test for overall effect: $Z = 3.69$ ($P = 0.0002$)

6.2 RQ2: What is the overall effect of adaptive learning platforms on student learning outcomes based on empirical evidence from previous studies?

The overall effect of adaptive learning platforms on student learning outcomes based on the empirical evidence from 7 previous studies is a moderate and positive effect. The meta-analysis yielded a pooled effect size (Hedges' g) of 11.43, which indicates that on average, students who used adaptive learning platforms performed over 11 percentiles better on measures of learning outcomes than students in traditional learning environments. However, there was substantial heterogeneity among the studies ($\text{Tau}^2 = 63.64$, $I^2 = 99\%$), indicating variability in effects across different platforms, subjects, settings and study designs.

6.3 RQ3: How can the findings from this meta-analysis inform the design and improvement of adaptive learning platforms to further explore their potential for enhancing student learning outcomes?

The findings suggest several ways adaptive learning platforms could be designed and improved based on factors moderating their effect:

- Platforms should incorporate adaptive features shown to enhance learning like personalized learning paths, feedback, collaboration tools.
- Subject matter and level of adaptivity could be a factor - platforms may need to vary for different topics.
- Implementing platforms over longer durations and having students spend meaningful time on the platform may maximize impact.
- Addressing challenges uncovered like technological issues, data analysis limitations could optimize potential.
- Considering individual learner differences like learning style when designing adaptive features.

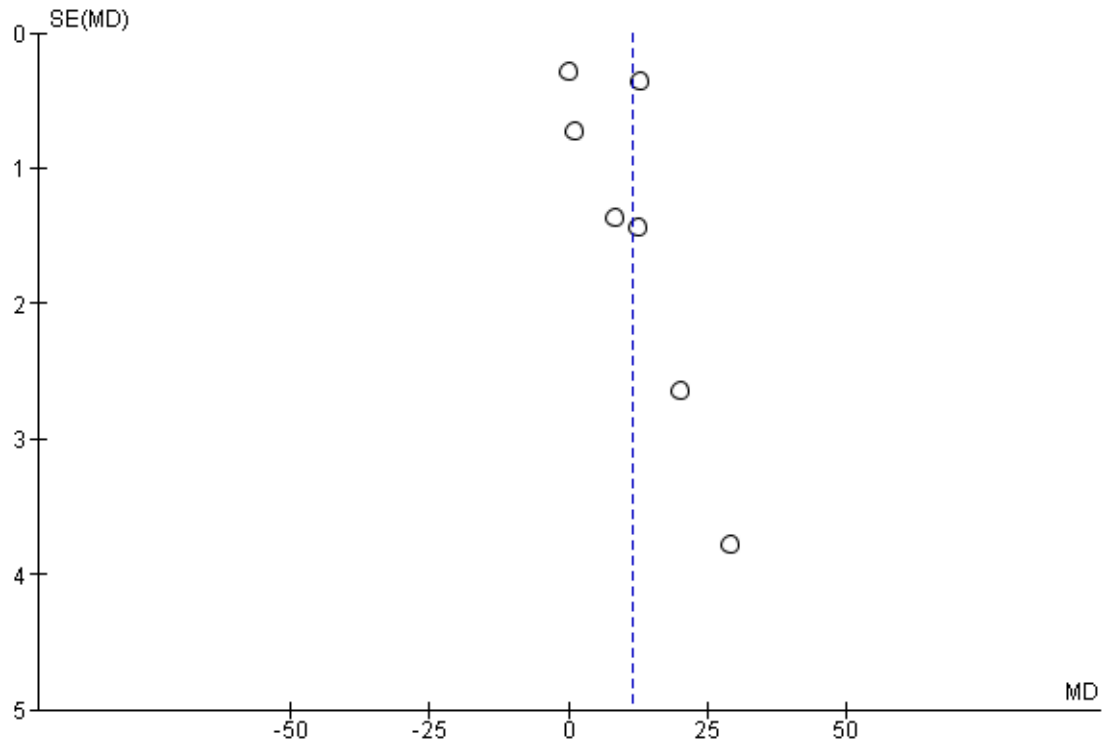
6.4 Publication bias

Publication bias, a potential threat to the validity of research findings, was evaluated in the present study. A funnel plot, a commonly used tool for detecting publication bias, was generated using Review Manager 5.4.1 software (see Fig. 3).

Visual inspection of the funnel plot revealed a symmetrical distribution of effect sizes from the included studies around the mean effect size. This indicated a lack of significant asymmetry or potential publication bias.

Fig. 3

Funnel plot showing no significant publication bias. SE = standard error; MD = mean difference



7 Discussion

7.1 Research implications

The results of this meta-analysis provide valuable insights into the role of adaptive learning platforms in improving student learning outcomes. The findings in general indicate a moderate but statistically significant positive effect of adaptive platforms compared to traditional learning environments. This aligns with previous research highlighting the potential benefits of personalized, adaptive instruction (Gligorea et al., 2023; Muñoz et al., 2022).

One of the research questions aimed to determine whether adaptive learning platforms can improve student learning outcomes. The meta-analysis revealed adaptive platforms led to an average 11.43 percentile gain in learning outcomes over traditional methods. This suggests adaptive features that customize content and assessments based on student data can enhance learning, as they allow learners to receive instruction targeted to their unique needs (Doss and Steiner, 2022; Muñoz et al., 2022).

When exploring the overall effect size of adaptive platforms, a pooled effect of Hedges' $g = 11.43$ was found across 7 studies, demonstrating cognitive benefits. However, substantial heterogeneity was also present. This variability could be explained by factors discussed in the literature review such as differences in platform design complexity (Muñoz et al., 2022), length of implementation (Doss and Steiner, 2022), or subject domain (Fontaine et al., 2019).

All 7 included studies showed positive effects favoring adaptive conditions to some degree, providing empirical validation for these personalized systems. For example, larger effect sizes were observed in studies incorporating more advanced adaptive features like intelligent tutoring systems (Izzah and Hadi, 2021). This aligns with previous research suggesting greater adaptivity leads to improved outcomes (Gligorea et al., 2023).

One aim was to identify how findings could guide future platform development. Results imply design improvements centered around strengthening personalization would maximize potential. For instance, incorporating elements shown to boost learning like collaboration tools (Alshammary and Alhalafawy, 2023), tailored feedback (Doss and Steiner, 2022), and personalized learning paths (Muñoz et al., 2022). Learner profile data and analytics could also be more deeply integrated to continuously modify content for each user (Gligorea et al., 2023). Extending platform usage periods could help optimize impacts as well by providing adequate time for adaptivity benefits to manifest (Doss and Steiner, 2022).

Addressing technological and usability challenges flagged in previous research may remove barriers preventing platforms from reaching their full efficacy (Muñoz et al., 2022). Continuous evaluation and refinement guided by outcomes from empirical meta-analyses can contribute to overcoming current limitations. Ongoing research investigating long-term and far-transfer effects is still needed, but current data provides evidence supporting adaptive learning as a promising means of enhancing student outcomes when optimized.

The findings from this meta-analysis have several important implications for educational research and practice regarding adaptive learning platforms. While the results provide preliminary support for their efficacy in enhancing student learning outcomes, more research is still needed to fully realize their potential benefits.

One avenue for future research involves exploring different models of adaptivity and their impacts. The platforms analyzed varied in their approach and degree of personalization, yet specific features contributing most to effectiveness remain unclear. Investigating low-stakes formative adaptive courses compared to high-stakes summative ones could offer insight into optimal applications. Likewise, comparing platform-driven to teacher-augmented adaptive models may provide guidance on the role of human support. Longitudinal studies are also warranted to determine if effects endure beyond short-term interventions.

Customization based on individual student traits also merits deeper examination. While prior work found stronger outcomes linked to greater adaptivity, the "active ingredients" producing these variants require isolation. Research disaggregating adaptive elements could identify those most crucial for diverse learners. Incorporating student profile data on attributes like prior knowledge, reading level, interests and learning styles may boost personalization. However, the added value of detailed personalized learning paths versus more generalized paths warrants comparison.

Qualitative investigations further characterizing student experiences could complement quantitative results. Exploring factors influencing engagement, satisfaction, perceived relevance and motivation may uncover reasons behind performance differentials. Mixed-methods incorporating both observational and survey data may offer a nuanced understanding of how and why adaptive platforms impact

learners differently. This could highlight design adjustments leveraging student perspectives to maximize benefit.

Examination of adaptive learning platform implementation across varied educational contexts also represents a significant avenue for future work. Most existing research stems from post-secondary settings, yet pre-K through 12th grade adoption remains limited. This gap risks hindering informed K-12 implementation efforts. More study of adaptive technology integration into K-12 classrooms, curriculum, and blended/online models is needed. Cross-cultural comparisons exploring cultural relevance and effects in diverse systems worldwide also warrant attention.

Additional research systematically analyzing design features shown effective would aid platform development. While prior work identified elements such as feedback, collaboration and problem-solving positively influencing outcomes, specific evidence-based guidelines are lacking. Future studies could employ experimental design to test isolation of features allowing causal inferences. This would shed light on minimally-viable personalized designs warranting scaling.

Implementation challenges reported previously like data privacy, digital access divides, technological glitches and faculty training additionally signify important practical implications. Continued examination of barriers hindering adaptive learning adoption can help devise strategies overcoming real-world hurdles to maximize social impact. Partnerships supporting design informed by implementation research may help enhance contextual fit and sustainability of solutions over time.

Lastly, this meta-analysis underscores the importance of interdisciplinary collaboration among researchers, educators, instructional designers, and technology developers. By fostering collaborations across disciplines, researchers can leverage diverse expertise and perspectives to address the complex challenges associated with the design, implementation, and evaluation of adaptive learning platforms. This collaborative approach can lead to innovative solutions that effectively integrate pedagogical principles, learning theories, and technological advancements to optimize the impact of adaptive learning platforms on student learning outcomes.

7.2 Research limitations

One of the main limitations of this meta-analysis was the small number of studies included. Only seven studies met the eligibility criteria and were analyzed. With a larger pool of empirical evidence, the findings could potentially provide more robust and definitive conclusions about the effectiveness of adaptive learning platforms.

The heterogeneity between the included studies posed another limitation. There was considerable variability across studies in terms of participants' characteristics like age, subject areas studied, as well as differences in platform design and implementation strategies. This made direct comparisons between studies challenging. The true effects may have been masked due to the unexplained heterogeneity between studies.

In addition, the quality of primary studies varied, with some having constraints such as small sample sizes or potential risks of bias related to study design. This impacts the reliability and generalizability of findings that can be drawn from individual studies. Therefore, causal inferences from this review need to be interpreted cautiously.

The moderator analysis conducted was also limited by the data reported in the original studies. Important factors like platform type, duration of platform use could

not be explored due to insufficient reporting of relevant details. This restricted the extent to which sources of between-study heterogeneity could be examined.

Furthermore, the possibility of publication bias cannot be entirely discounted despite no strong evidence detected from the funnel plot analysis. It is possible that studies with non-significant or negative results remained unpublished. This may have led to an overestimation of overall intervention effects.

Finally, longer term impacts beyond the intervention period were not assessed in the primary studies. Therefore, whether any benefits are sustained over time remains uncertain based on available evidence. More research with longer follow-ups are needed to address this gap.

There are multiple areas for future research that could help advance the field of personalized education. Larger studies using randomized groups with stronger research designs would provide stronger evidence on the effects of these programs. Developing a common system to categorize different customized learning platforms based on their qualities would enable better comparisons between studies. It would also be useful to examine how learner traits and circumstances affect results through analyzing influencing factors. Furthermore, looking at longer term and applied effects, cost benefits, student experiences, and use in various environments could address current restrictions. In summary, more rigorous research is needed across different groups of learners and settings to deeper understand how adaptive learning technologies best support students' can developing skills over time.

Qualitative investigations combining various data sources may offer novel insights as well. Adaptive platforms themselves could also be enhanced through learning analytics informing iterative improvements. Addressing integration, accessibility and interoperability challenges would optimize real-world implementation. Multidisciplinary collaborations translating research into evidence-based commercial systems could ultimately help realize the full potential of adaptive technologies for improving various learning outcomes. Filling these knowledge gaps through well-planned future research efforts will be imperative to advancing the adaptive learning field.

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