Artificial Intelligence in Higher Education Mathematics: A Systematic Reviewof Trends, Benefits, and Challenges.

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Abstract

The integration of Artificial Intelligence (AI) in higher education has evolved significantly, presenting notable opportunities for mathematics education. This systematic literature review aims to answer the question: What are the current trends, benefits, challenges, and future directions in the application of AI within higher education mathematics education? Focusing on peer-reviewed articles from 2010 to 2023, the review applied selection criteria centered on relevance, methodological rigor, and educational impact. Key findings reveal that AI technologies offer potential enhancements in personalized learning, real-time feedback, and data-driven decision-making, promoting a more engaging and efficient learning environment. However, the review also highlights the importance of addressing ethical considerations, ensuring data privacy, and providing sufficient educator training to harness AI's potential fully. By bridging the knowledge gap regarding AI integration and pedagogical efficacy, this analysis aims to inform educators, policymakers, and researchers, ultimately supporting advancements in teaching practices and student achievement in higher education mathematics.

Keywords: Artificial Intelligence, Mathematics Education, Higher Education, Intelligent Tutoring Systems, Adaptive Learning, Machine Learning, Systematic Literature Review, Teaching and Learning.

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1. Introduction

The rapid advancement of Artificial Intelligence (AI) has ushered in a education, particularly in the realm of mathematics, AI technologies are increasingly being utilized to enhance teaching and learning experiences [1].

AI technologies such as intelligent tutoring systems (ITS), machine learning algorithms, adaptive learning platforms, and automated assessment systems are at the forefront of this educational revolution. Intelligent tutoring systems, for instance, have shown promise in delivering personalized instruction and immediate feedback, thereby improving student engagement and performance [2]. These systems leverage machine learning to analyze student performance and adapt instructional strategies in real-time, providing a tailored learning experience that meets individual student needs [3].

Adaptive learning platforms similarly use AI to customize educational content, ensuring that students receive material that is appropriate for their current level of understanding. This approach not only fosters a more efficient learning process but also helps in identifying and addressing knowledge gaps [2]. Moreover, automated assessment systems streamline the evaluation process by providing instant feedback on assignments and exams, which is crucial for timely intervention and sup- port [7]

Through these advanced AI applications, higher education institutions can create more interactive, efficient, and effective learning environments, particularly in mathematics, where conceptual understanding and problem-solving skills are paramount [5]. As AI continues to evolve, its integration into educational practices is likely to become even more sophisticated, further revolutionizing the way we teach and learn.

The integration of AI in mathematics education is particularly significant given the subject's inherent complexity and the varied proficiency levels of students entering higher education. Traditional teaching methods often struggle to meet the diverse needs of students in large classroom settings, leading to gaps in understanding and achievement [6]. By contrast, AI technologies offer scalable solutions that can provide individualized support and enhance overall learning outcomes [7]. Despite the promising potential of AI in education, its implementation is not without challenges. Ethical considerations, such as data privacy and the transparency of AI algorithms, are critical issues that need to be addressed to gain the trust of educators and students alike [8]. Additionally, the effectiveness of AI tools is heavily dependent on the quality of data they are trained on, raising concerns about bias and fairness in educational outcomes [9]. Furthermore, there is a pressing need for adequate training and professional development for educators to effectively integrate AI tools into their teaching practices [10].

This review systematically examines peer-reviewed articles published between 2010 and 2023 to identify key trends, benefits, challenges, and future directions for AI in mathematics education. By doing so, it aims to inform educators, policymakers, and researchers about the current state and potential future developments in this field. As the findings suggest, "AI technologies can significantly enhance personalized learning, provide real-time feedback, and support data-driven decision- making," but a balanced approach addressing ethical, pedagogical, and technical considerations is essential for their successful implementation [7].

This review seeks to contribute to the body of knowledge on AI in higher education, particularly in the context of mathematics, by addressing the following key questions: (1) How is AI currently being used in mathematics teaching? (2) What are the benefits and challenges associated with AI adoption in this context? (3) How can faculty effectively leverage AI to enhance student learning outcomes?

2. Technological Applications in Mathematics Education

Artificial Intelligence (AI) technologies have become integral to modern mathematics education, offering innovative solutions to enhance teaching, and learning experiences. Among the most impactful AI applications in this field are Intelligent Tutoring Systems (ITS), adaptive learning platforms, and automated assessment tools. Each of these technologies plays a crucial role in addressing the diverse needs of students and improving educational outcomes.

Intelligent Tutoring Systems (ITS) are one of the most widely researched and implemented AI technologies in mathematics education. ITS provide personalized instruction by adapting to the individual learning styles and needs of students. These systems use machine learning algorithms to analyse student performance and deliver customized feedback and problem sets. According to [2]. ITS have demonstrated significant improvements in student engagement and performance by offering real-time, tailored support that traditional classroom settings often lack.

Adaptive learning platforms are another key AI application, designed to continuously assess and adjust the difficulty level of educational con tent based on student performance. These platforms use complex algo-

rithms to create personalized learning pathways that keep students chal lenged yet not overwhelmed. [10]. highlight that adaptive learning systems can accommodate a wide range of learning paces and styles, ensur ing that all students receive the appropriate level of difficulty and support. This personalization is particularly beneficial in large classrooms where individual attention from instructors is limited.

Automated assessment tools further enhance mathematics education by providing timely and consistent evaluations of student work. These tools use AI to grade assignments, quizzes, and exams, offering immediate feedback to students. [4] notes that automated assessments not only save educators time but also ensure fairness and consistency in grading. This allows educators to focus more on interactive and personalized teaching methods rather than administrative tasks.

In the South African context, the implementation of these AI technol ogies has shown promising results. [11] report that universities piloting ITS and adaptive learning platforms have observed improved student performance and engagement, particularly in foundational mathematics courses. These technologies provide real-time feedback and personalized support, which are crucial for addressing the challenges posed by large, diverse student populations.

Despite the benefits, the integration of AI technologies in mathematics education also presents challenges, including ethical concerns, data privacy issues, and the need for adequate infrastructure and training. As [12] point out, the success of AI applications heavily depends on the quality of data and the transparency of AI algorithms. Therefore, ad-

dressing these challenges is essential for the effective and ethical implementation of AI in education.

3. Impact of Adaptive Learning on Student Engagement and Performance in Higher Education

Adaptive learning (AL) has emerged as a transformative educational technology, significantly impacting student engagement, learning outcomes, and academic performance in higher education. By leveraging sophisticated algorithms and data analytics, AL platforms customize educational content to meet individual student needs, thereby fostering a more personalized and effective learning environment. Adaptive learning platforms continuously analyse students' performance and adjust task difficulty levels accordingly [13]. This approach ensures that students remain challenged and motivated, catering to the varied learning paces observed in South African classrooms [14]. Such platforms are particularly useful in addressing the learning gaps exacerbated by socio- economic disparities and varied educational backgrounds. [15] highlighted that "adaptive learning technologies can provide a customized learning path for each student, ensuring that no learner is left behind."

Several studies highlight the positive impact of AL on student engagement. For instance, according to [10]. AL systems enhance student engagement by providing tailored instructional content that aligns with each learner's pace and understanding. This personalized approach keeps students motivated and involved, reducing the likelihood of disengagement and dropout. The influence of AL on learning outcomes is also

well-documented. [2] demonstrated that intelligent tutoring systems, a form of AL, significantly improve learning outcomes by delivering immediate, personalized feedback and adjusting problem difficulty based on student performance. This ensures that students are neither bored with overly simple tasks nor overwhelmed by excessively challenging ones, promoting a steady and effective learning progression. Further- more, AL has been shown to positively affect academic performance. A study by [7] found that students using AL platforms performed better in assessments compared to those who did not use such technologies. The adaptive nature of these platforms ensures that students receive the right level of challenge and support, which is critical for mastering complex subjects.

In the South African context, [11], reported that AL tools have been instrumental in addressing the diverse educational needs of students in higher education. By providing real-time feedback and personalized learning paths, AL systems help bridge the educational gaps in large, heterogeneous classrooms, ultimately leading to improved academic performance.

4. Pedagogical Approaches to Integrating Adaptive Learning Technologies into Teaching Practices and Curricula

The integration of adaptive learning (AL) technologies into teaching practices and curricula represents a significant shift in pedagogical approaches within higher education. AL technologies, which personalize educational content based on individual student needs, have been in-

creasingly adopted to enhance the effectiveness of teaching and learning.

One of the primary ways AL technologies are integrated into teaching practices is through intelligent tutoring systems (ITS). These systems offer personalized instruction and real-time feedback, adjusting to the learning pace and style of each student. [2] highlights that ITS can transform traditional teaching methods by providing a more tailored educational experience, thereby increasing student engagement, and understanding.

Moreover, adaptive learning platforms are being embedded within curricula to facilitate differentiated instruction. These platforms continuously analyse student performance data to adjust the difficulty and type of content delivered. [10] discusses how such platforms enable educators to create dynamic and flexible curricula that cater to the diverse learning needs of students, ensuring that each student remains adequately challenged and motivated.

The integration of AL technologies also supports formative assessment practices. Automated assessment systems, a component of many AL platforms, provide consistent and timely feedback on student performance. This allows educators to monitor progress and adjust instruction as needed, fostering a more responsive and effective teaching environment. [4] notes that these systems can significantly reduce the grading workload for instructors, allowing them to focus more on interactive and personalized teaching strategies.

In the context of curriculum design, AL technologies facilitate the development of competency-based learning models. These models empha-

size mastery of specific skills and knowledge, with AL systems providing the scaffolding necessary for students to achieve competency at their own pace. [7] highlight that such an approach not only improves learning outcomes but also aligns with contemporary educational goals of personalized and student-centred learning.

In South Africa, the integration of AL technologies into higher education curricula has shown promising results. [11] report that universities are incorporating these technologies to address the diverse educational needs of their student populations. By providing personalized learning experiences and real-time feedback, AL technologies help to bridge the gaps in traditional teaching methods, particularly in large and varied classrooms.

5. Challenges and Barriers in Implementing AI in Higher Education

Implementing artificial intelligence (AI) in higher education presents a myriad of challenges and barriers, encompassing ethical concerns, data privacy issues, and technical limitations. These factors collectively influence the effectiveness and acceptance of AI technologies in academic settings.

One of the primary challenges in implementing AI in higher education is ethical concerns. The deployment of AI systems often involves making decisions that can significantly impact students' educational trajectories. [8] argues that the lack of transparency in AI decision-making processes can lead to ethical dilemmas, where the rationale behind certain

educational recommendations or assessments may be opaque to both educators and students. This lack of clarity can undermine trust and raise questions about the fairness and accountability of AI systems.

Data privacy is another critical issue that poses a significant barrier to the adoption of AI in education. AI systems rely heavily on vast amounts of personal data to function effectively, raising concerns about the protection and security of this information. [12] highlight that the collection, storage, and analysis of student data must comply with stringent privacy regulations to prevent misuse and breaches. The potential for data breaches or unauthorized access can deter institutions from fully embracing AI technologies.

Technical limitations also hinder the widespread implementation of AI in higher education. The effectiveness of AI tools depends largely on the quality and quantity of data they are trained on. In many educational settings, especially in developing regions, there is a scarcity of high-quality, comprehensive datasets necessary for training robust AI models. [7] point out that this data inadequacy can lead to biased or inaccurate outcomes, further exacerbating existing educational inequalities.

Additionally, the integration of AI into educational practices requires substantial infrastructure and technological support. Many institutions face challenges related to the availability of adequate technological resources and expertise. [16] emphasize the necessity for ongoing professional development and training for educators to effectively utilize AI tools. Without proper training, educators may struggle to incorporate AI

technologies into their teaching practices, limiting their potential benefits.

In the South African context, these challenges are particularly pronounced. [11] note that issues such as uneven access to technology, lack of infrastructure, and varying levels of digital literacy among educators and students further complicate the implementation of AI in education. Addressing these barriers requires a concerted effort to improve technological infrastructure, provide comprehensive training programs, and develop clear ethical guidelines for AI use in education.

6. Theoretical Framework and Model Informing AI Integration in Mathematics Education

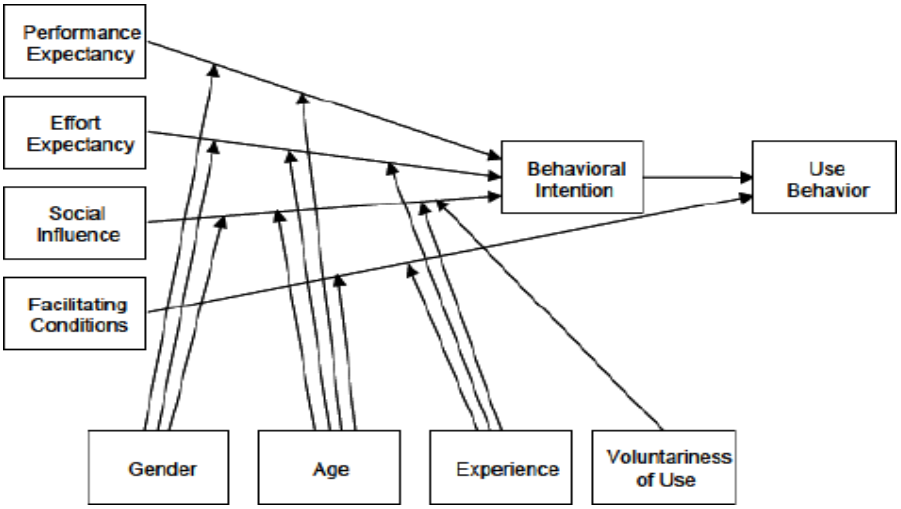

Figure 1: UTAUT theory (Venkatesh et al. 2003)

The current study is informed by Unified Theory of Acceptance and Use of Technology (UTAUT) framework, developed by [17]. The UTAUT is particularly suitable for guiding this study on AI integration in mathematics education within higher education. UTAUT aims to ex- plain user intentions to use an information system and subsequent usage behaviour, providing a robust model for understanding the factors that influence the acceptance and effective use of technology in educational settings. The key components of UTAU, namely: performance expectancy, effort expectancy, social influence, and facilitating conditions, are integral to this investigation. Performance expectancy relates to the belief that using AI tools will enhance learning outcomes, improve student engagement, and facilitate personalized instruction. Effort expectancy involves evaluating the user-friendliness of AI systems and the ease with which educators and students can integrate these tools into their teaching and learning processes. Social influence examines the impact of peer opinions, institutional support, and societal norms on the acceptance and use of AI in mathematics education. Facilitating conditions assess the availability of resources, institutional policies, professional development opportunities, and technical support necessary for the successful implementation of AI tools.

Applying UTAUT to the South African context can help identify specific factors influencing the acceptance and use of AI in mathematics education, addressing challenges such as the digital divide, resource constraints, and the need for culturally relevant educational content. By focusing on performance expectancy, effort expectancy, social influence, and facilitating conditions, UTAUT provides a comprehensive

model to understand the factors influencing technology acceptance and use. This framework enables a thorough analysis of the opportunities and challenges associated with AI in education, contributing valuable insights and recommendations for educators, policymakers, and re- searchers in the South African context. Tailoring AI tools to local needs, promoting equity and access, and supporting professional development are essential aspects that can be explored using UTAUT. The framework ensures that AI technologies are inclusive, address socio-economic dis- parities, and equip educators with the necessary skills and knowledge for effective integration. UTAUT's focus on these critical areas makes it highly suitable for guiding this study, providing a structured approach to understanding and enhancing the use of AI in mathematics education.

7. Research Method

The search strategy for this systematic literature review was meticulously designed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [18]. guidelines to ensure a comprehensive and transparent collection of relevant studies on the application of AI in mathematics education within higher education institutions in Figure 2. PRISMA provides a structured approach for reporting systematic reviews and meta-analyses, enhancing the clarity and reproducibility of the review process. By adhering to the PRISMA guidelines, this systematic literature review ensures a rigorous and transparent approach to identifying, selecting, and synthesizing relevant studies on the application of AI in mathematics education within higher education. As [18] state, PRISMA aims to "help authors improve the reporting of systemat-

ic reviews and meta-analyses," contributing to the reliability and validity of the review's findings and recommendations.

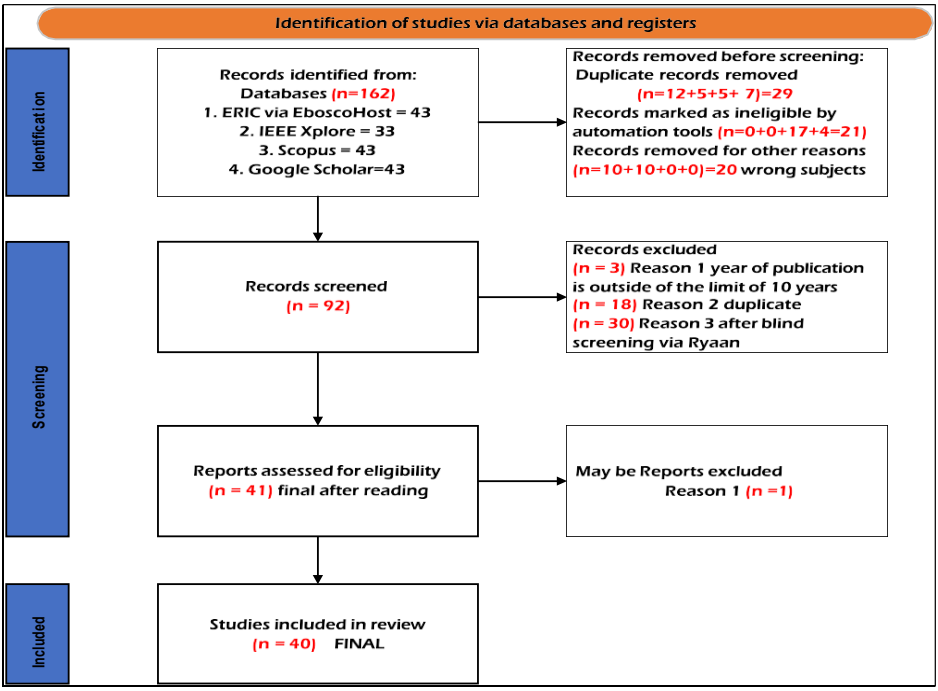

Figure 2: PRISMA flow diagram (Moher et al., 2009)

The search was conducted across several electronic databases, including IEEE Xplore, Google Scholar, ERIC, and Scopus, focusing on peer-reviewed articles published between January 2010 and March 2023. Keywords and phrases such as "Artificial Intelligence," "AI," "Mathematics Education," "Higher Education," "Intelligent Tutoring Systems," "Adaptive Learning," "Machine Learning," "Automated Assessment," and "Personalized Learning" were used, with Boolean operators (AND,

OR) employed to refine the search queries. For instance, searches like: ("Artificial Intelligence" OR "AI") AND ("Mathematics Education" OR "Math Education") AND ("Higher Education" OR "University" OR "College") exemplify the search strategy.

To ensure the relevance and quality of the included studies, specific inclusion and exclusion criteria were established. Studies were included if they focused on the application of AI technologies in mathematics education within higher education institutions, written in English, peer-reviewed, and addressed mathematics education at the higher education level (undergraduate or graduate). Conversely, studies were excluded if they did not focus on AI in mathematics education or did not pertain to higher education, were not peer-reviewed (including editorials, opinion pieces, book chapters, etc.), lacked empirical data or clear methodological details, or were duplicate studies or multiple publications of the same study, with only the most comprehensive version retained.

The data extraction process was systematically carried out following the PRISMA guidelines to ensure consistency and accuracy. Initially, the titles and abstracts of all retrieved articles were screened to deter- mine their relevance based on the inclusion and exclusion criteria. This screening was conducted independently by two reviewers to minimize bias using Rayyan AI-assisted literature review platform. Articles that passed the initial screening underwent a full-text review, where each article was examined in detail to confirm its relevance and extract pertinent information. Discrepancies between reviewers were resolved through discussion. A standardized data extraction form was developed to systematically collect and organize data from each included study.

The form captured details such as study title, authors, publication year, journal/conference, specific AI technology or application, target population (e.g., undergraduate students), research design, sample size, data collection methods, analytical techniques, key results, benefits of AI applications, challenges identified, and recommendations for future research. Additionally, the methodological rigor and relevance of each study were evaluated as part of the quality assessment.

The extracted data were synthesized to identify common themes, trends, and gaps in the literature, informing the overall findings and conclusions of the systematic review. This synthesis provided a nuanced understanding of the current state and potential future developments in the use of AI in mathematics education within higher education institutions.

8. Results

How is AI currently being used in mathematics teaching?

AI is being employed in various innovative ways to enhance mathematics education within higher education institutions, as understood through the lens of the Unified Theory of Acceptance and Use of Technology (UTAUT). This framework helps elucidate the factors influencing the acceptance and usage of AI technologies in educational settings.

Intelligent Tutoring Systems (ITS) have become a staple in mathematics education, offering personalized instruction and immediate feedback to students. These systems utilize machine learning algorithms to adapt to individual learning styles and needs, significantly improving student engagement and performance [2]. According to UTAUT, the perfor-

mance expectancy of ITS is high, as these systems dynamically adjust the difficulty of mathematics problems based on a student's progress, ensuring that students remain challenged yet not overwhelmed. This adaptability directly addresses users' expectations for improved academic performance, a key driver in technology acceptance.

Adaptive learning platforms represent another significant AI application in mathematics education. These platforms continuously analyse students' performance and adjust the difficulty level of tasks accordingly. This personalization addresses the diverse learning paces of students and helps ensure that all students are adequately challenged and motivated 10]. From the UTAUT perspective, the effort expectancy associated with adaptive learning platforms is favourable. These platforms simplify the learning process for students by providing tailored support, thus making the learning experience more efficient and effective.

Additionally, automated assessment systems have been implemented to provide timely and consistent evaluations of student work, freeing educators to focus more on interactive and personalized teaching methods [4] This aligns with the UTAUT's facilitating conditions construct, which considers the availability of organizational and technical infrastructure to support technology use. Automated assessment systems provide the necessary infrastructure to enhance teaching efficiency, thus encouraging adoption among educators.

In South Africa, AI tools like adaptive learning platforms and ITS have been piloted in several universities to tackle the challenges of large, diverse classrooms. For instance, the University of Johannesburg has experimented with AI-driven tutoring systems to assist students who

are struggling with foundational mathematics courses. These systems provide "real-time feedback and personalized support," which have been shown to significantly improve student outcomes [11]. In the context of UTAUT, social influence plays a crucial role here, as the successful implementation and positive outcomes of these AI tools can influence other institutions and educators to adopt similar technologies. The demonstrated effectiveness in enhancing student performance acts as a persuasive factor for broader acceptance and integration of AI in mathematics education.

What are the benefits and challenges associated with AI adoption in this context?

The benefits of integrating AI in mathematics education are substantial, as examined through the lens of the Unified Theory of Acceptance and Use of Technology (UTAUT). AI technologies provide scalable solutions that offer individualized support, enhancing overall learning outcomes. These technologies facilitate personalized learning, which can lead to better student engagement and improved performance. Adaptive learning platforms, for example, ensure that students are neither bored with material that is too easy nor frustrated by material that is too difficult 10]. This aligns with the UTAUT's performance expectancy construct, as students and educators expect AI tools to improve academic performance and learning efficiency.

Automated assessment systems provide consistent and timely feedback, crucial for student development [4] This feedback mechanism aligns with the facilitating conditions construct of UTAUT, highlighting

the importance of a supportive infrastructure that enables educators to focus more on interactive and personalized teaching methods. The ease of use and efficiency provided by these systems also contribute to the effort expectancy construct, making them more likely to be adopted by educators.

However, the adoption of AI in mathematics education is not without its challenges. Ethical considerations, such as data privacy and the transparency of AI algorithms, are critical issues that need to be addressed to gain the trust of educators and students alike. [8] highlights that "AI systems must be transparent and their decision-making process- es clear" to ensure they are used ethically and responsibly. This transparency is essential to address concerns within the social influence construct of UTAUT, as stakeholders must trust and understand AI systems for their widespread acceptance.

The effectiveness of AI tools is heavily dependent on the quality of data they are trained on, raising concerns about bias and fairness in educational outcomes. This issue underscores the need for high-quality data and fair training practices, which are integral to the performance expectancy and facilitating conditions constructs. Furthermore, there is a pressing need for adequate training and professional development for educators to effectively integrate AI tools into their teaching practices [19]. This need for training aligns with the facilitating conditions construct, as the successful implementation of AI technologies relies on educators being well-prepared to use these tools effectively.

In South Africa, these challenges are particularly pronounced given the country's diverse student population and the varying levels of access

to technology. Studies have shown that while AI tools can significantly improve learning outcomes, there is a need for "robust infrastructure and training programs" to ensure that these technologies are effectively utilized [11]. The social influence construct of UTAUT is particularly relevant here, as the adoption of AI in education must consider the influence of cultural and societal factors on technology acceptance. Addressing these challenges requires a concerted effort to build the necessary infrastructure, provide adequate training, and ensure ethical practices in AI implementation.

How can faculty effectively leverage AI to enhance student learning outcomes?

Faculty can effectively leverage AI to enhance student learning outcomes by adopting a balanced approach that combines AI tools with traditional teaching methods. This hybrid approach allows educators to use AI for tasks such as personalized instruction, adaptive learning, and automated assessment while providing the human interaction and mentorship crucial for holistic student development [7]. Through the lens of the Unified Theory of Acceptance and Use of Technology (UTAUT), this strategy addresses key constructs like performance expectancy, effort expectancy, social influence, and facilitating conditions.

Professional development and training programs are essential to equip educators with the skills needed to integrate AI tools into their teaching practices. These programs should focus on helping educators understand how AI technologies work, how to interpret the data generated by these tools, and how to use this data to inform their teaching strategies. Addi-

tionally, educators need training on the ethical considerations of using AI in education to ensure they can address issues related to data privacy and algorithmic transparency [16]. This aligns with the facilitating conditions construct of UTAUT, highlighting the necessity of support structures that enable educators to effectively use AI technologies.

In the South African context, faculty development programs have been initiated to help educators integrate AI tools into their teaching. For instance, the University of Pretoria has implemented workshops and training sessions to help faculty understand and use AI-driven educational technologies. These efforts are aimed at "bridging the gap be- tween technology and pedagogy," ensuring that AI tools are used effectively to enhance student learning outcomes [11]. This initiative exempli- fies the social influence and facilitating conditions constructs of UTAUT, where institutional support and peer influence play significant roles in the adoption and effective use of AI technologies.

Moreover, the performance expectancy construct is addressed as educators see tangible improvements in student engagement and performance using AI. Adaptive learning platforms and intelligent tutoring systems provide real-time feedback and personalized learning experiences, which are directly linked to improved academic outcomes. The effort expectancy construct is also considered as these AI tools are designed to be user-friendly, reducing the perceived complexity and effort required by educators to integrate them into their teaching practices.

By leveraging AI in a balanced approach, educators can provide personalized learning experiences that cater to the diverse needs of students, thereby enhancing overall learning outcomes. The UTAUT

framework underscores the importance of understanding and addressing the various factors that influence the acceptance and use of AI technologies in education. Ensuring that educators are well-prepared and supported in their use of AI tools is crucial for realizing the full potential of these technologies in enhancing student learning outcomes.

9. Discussion

The findings of this systematic literature review underscore the transformative potential of AI technologies in enhancing mathematics education within higher education institutions. AI-driven tools such as Intelligent Tutoring Systems (ITS), adaptive learning platforms, and automated assessment systems have demonstrated significant benefits in providing personalized instruction, immediate feedback, and consistent evaluation of student work. These technologies address some of the inherent challenges in mathematics education, particularly the difficulty of catering to diverse student proficiency levels in large classroom settings. For instance, ITS systems have been shown to adapt to individual learning styles, thereby improving student engagement and performance [2]. This adaptability makes education more accessible and effective, especially for students who may struggle with traditional teaching methods [19].

Moreover, adaptive learning platforms continuously analyze student performance and adjust the difficulty level of tasks accordingly. This ensures that students remain adequately challenged and motivated, which is crucial for maintaining their interest in mathematics [20]. Automated assessment systems, on the other hand, facilitate timely and

consistent evaluations of student work, allowing educators to focus more on interactive and personalized teaching methods [4] These benefits collectively contribute to improved student outcomes, as they provide individualised support and address learning gaps that traditional methods often fail to bridge [7].

However, the integration of AI in mathematics education is not without challenges. Ethical considerations such as data privacy and the transparency of AI algorithms are critical issues that need to be addressed to gain the trust of educators and students alike. As [8] points out, "AI systems must be transparent and their decision-making processes clear" to ensure they are used ethically and responsibly. Additionally, the effectiveness of AI tools is heavily dependent on the quality of data they are trained on, raising concerns about bias and fairness in educational outcomes [21]. These challenges highlight the need for a balanced approach that considers ethical, pedagogical, and technical aspects to ensure the successful implementation of AI in education.

The South African context presents unique opportunities and challenges for the integration of AI in mathematics education. While AI tools offer promising solutions to the educational challenges faced by South African institutions, their effectiveness depends on robust infra- structure and adequate training for educators. Studies have shown that AI-driven tutoring systems can significantly improve learning outcomes, but there is a need for "robust infrastructure and training programs" to ensure these technologies are effectively utilized [11]. Faculty development programs are essential to equip educators with the skills needed to integrate AI tools into their teaching practices. These programs should

focus on helping educators understand how AI technologies work, how to interpret the data generated by these tools, and how to use this data to inform their teaching strategies [16].

In South Africa, future research should focus on developing AI tools that are tailored to the unique educational landscape of the country. This includes considering the diverse socio-economic backgrounds of students, the varying levels of access to technology, and the need for culturally relevant educational content [22]. Additionally, there is a pressing need to address the digital divide and ensure that all students have equitable access to AI-enhanced learning tools. [23] states that "bridging the digital divide is essential to ensure that all students can benefit from the advancements in AI technology, regardless of their socio-economic status."

The findings of this systematic literature review underscore the transformative potential of AI technologies in enhancing mathematics education within higher education institutions, examined through the lens of the Unified Theory of Acceptance and Use of Technology (UTAUT). The UTAUT framework suggests that performance expectancy, effort expectancy, social influence, and facilitating conditions play critical roles in determining technology adoption. In this context, AI-driven tools such as Intelligent Tutoring Systems (ITS), adaptive learning platforms, and automated assessment systems have demonstrated significant benefits that align with performance expectancy, particularly through their ability to provide personalized instruction, immediate feedback, and consistent evaluation of student work. These technologies address some of the inherent challenges in mathematics education, particularly the difficulty of catering to diverse student proficiency levels in large classroom settings. For instance, ITS systems adapt to individual learning styles, thereby enhancing performance expectancy by improving student engagement and outcomes [2]. This adaptability increases the likelihood of acceptance among both students and educators, making education more accessible and effective, especially for students who may struggle with

traditional methods [19].

Moreover, adaptive learning platforms embody effort expectancy by simplifying the learning process through continuous analysis of student performance and dynamic adjustment of task difficulty. This ensures that students remain challenged and motivated, which is crucial for maintaining their interest in mathematics [20]. Automated assessment systems also address effort expectancy by facilitating timely and consistent evaluations of student work, allowing educators to focus on more interactive and personalized teaching methods [4]. These benefits collectively enhance the performance expectancy of AI tools by providing individualized support and addressing learning gaps that traditional methods often struggle to bridge [7].

However, according to UTAUT's social influence and facilitating conditions constructs, the integration of AI in mathematics education is not without challenges. Ethical considerations, such as data privacy and the transparency of AI algorithms, are critical for gaining trust among educators and students. Social influence is particularly relevant here, as AI acceptance is affected by how its ethical use is perceived by stakeholders. As [8] points out, "AI systems must be transparent and their decision-making processes clear" to ensure they are used ethically and responsibly. Additionally, facilitating conditions play a role in determining the effectiveness of AI tools, as their impact relies on the quality of data they are trained on, which raises concerns about bias and fairness in educational outcomes [21]. These challenges highlight the importance of a balanced approach that integrates ethical, pedagogical, and technical considerations to promote successful AI implementation.

The South African context presents unique facilitating conditions and social influences for AI integration in mathematics education. While AI tools offer promising solutions to educational challenges, their effectiveness depends on robust infrastructure and adequate training for educators. Studies have shown that AI-driven tutoring systems can significantly improve learning outcomes, yet there remains a need for "robust infrastructure and training programs" to facilitate effective use [11]. Faculty development programs are essential to provide educators

with the skills needed to integrate AI tools, aligning with UTAUT's facilitating conditions construct. Such programs should focus on helping educators understand AI functionality, interpret AI-generated data, and use this data to guide instructional strategies [16].

In South Africa, future research should focus on developing AI tools tailored to the unique educational landscape of the country. This requires considering the diverse socio-economic backgrounds of students, varying levels of access to technology, and the need for culturally relevant educational content [22]. Addressing the digital divide is crucial, as equitable access to AI-enhanced learning tools aligns with social influence, ensuring all students benefit from advancements in AI technology regardless of socio-economic status. As [23] states, "bridging the digital divide is essential to ensure that all students can benefit from the advancements in AI technology, regardless of their socio-economic status."

10. Conclusion

This systematic literature review highlights the transformative potential of AI technologies in enhancing mathematics education in higher education. Key findings emphasize the benefits and challenges of AI tools such as Intelligent Tutoring Systems (ITS), adaptive learning platforms, and automated assessment systems. These technologies can provide personalized instruction, real-time feedback, and consistent evaluation, addressing challenges related to diverse student proficiency levels.

AI tools like ITS can adapt to individual learning styles, improving engagement and performance. Adaptive learning platforms offer tailored experiences by adjusting task difficulty based on student performance, keeping students challenged and motivated. Automated assessment sys-

tems provide timely and consistent evaluations, allowing educators to focus more on interactive teaching.

However, integrating AI in education comes with challenges, including ethical concerns about data privacy and algorithm transparency, and the need for quality data to avoid bias. Effective AI integration also requires adequate training for educators.

In South Africa, AI tools offer promising solutions to educational challenges but require robust infrastructure and educator training. Disparities in resources and technology access impact AI's effectiveness. Faculty development programs are essential to equip educators with the skills to use AI tools effectively.

This review underscores the need for continued research and informed decision-making to maximize AI's potential in education. Addressing ethical, pedagogical, and technical considerations, along with infrastructural challenges and educator training in South Africa, is crucial for leveraging AI to improve educational outcomes. Continued investment in AI technologies and educator training is essential for enhancing teaching practices and student success in higher education.

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