Augmented Reality Integration in Mathematics Education: Implications for Enhancing Students' Conceptual Knowledge

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ABSTRACT

Augmented Reality (AR) has been recognized as a powerful tool for facilitating classroom instruction. This concept paper discussed the significance of integrating AR in mathematics teaching and learning to enhance students' conceptual understanding. Conceptual knowledge in mathematics is essential for comprehending the relationships among facts, principles, and procedures that support logical reasoning and problem-solving. However, Malaysian students' performance in mathematics has shown a concerning trend, partly due to traditional teaching approaches and low student interest. AR integration is viewed as an innovative approach that can enhance learning by making it more interactive, visual, and student-centered. This paper outlines the objectives, issues, challenges, and implications of AR used in mathematics education, and proposes strategies for effective implementation. Overall, AR has the potential to transform mathematics education, making it more relevant to the demands of 21st-century learning.

Keywords: Augmented Reality (AR), conceptual understanding, Mathematics, educational technology, 21st-Century Learning.

INTRODUCTION

Mathematics is a branch of knowledge that develops logical and systematic thinking in problem-solving. However, mathematics education is often perceived as a complex subject because it not only requires high cognitive skills but also involves dynamic interactions between students' internal attributes, the physical learning environment, and sociocultural influences that shape students' experiences and understanding of the subject (Hui & Rosli, 2021). Students often face challenges in grasping mathematical conceptual knowledge, which can lead to a decline in interest in learning mathematics. The failure to grasp both conceptual and procedural knowledge contributes to negative attitudes among students, including phobias, anxiety, fear, and low self-confidence in mathematics learning.

Mathematical conceptual knowledge encompasses a comprehensive understanding of the relationships that link facts, procedures, and principles. It enables learners to explain why a method is used rather than merely knowing how to perform calculations with formulas. Mastery of conceptual knowledge plays a significant role in strengthening procedural knowledge and subsequently enhances students' ability to solve mathematical problems flexibly, particularly in algebra (Abdullah, 2020). Other topics that can be challenging for students to understand include fractions, ratios and proportions, geometry, volume and surface area, coordinates, statistics, and probability.

Teaching and learning (T&L) through technology is an important approach in implementing 21st-century learning. The integration of technology in the teaching and learning process fosters students' critical, creative, and innovative thinking, as well as digital literacy. Through this integration, student-centered and collaborative learning can be implemented more effectively in mathematics classrooms. Active student involvement in collaborative learning can build collective knowledge construction and promote students' cognitive and social development. As a result, it can improve students' mathematical conceptual knowledge. AR technology is a branch of technology that is increasingly used in education. AR is a technology that applies virtual information to the physical world in three dimensions, which produces an interactive and comprehensive experience for users. (Bakim & Abdul Hanid, 2024).

Integrating augmented reality (AR) into mathematics education transforms the learning process into an active, student-centered experience. AR facilitates the development of mathematical conceptual knowledge through interactive engagement and peer collaboration. It serves as an effective pedagogical tool that enhances understanding by allowing students to manipulate and explore three-dimensional geometric shapes. This interactive approach aids in comprehending fundamental concepts such as area, perimeter, and volume. Furthermore, the use of AR has been shown to increase students' interest and achievement in spatial reasoning and related mathematical domains. Consequently, the incorporation of AR in mathematics instruction is considered a promising strategy to bridge the gap between abstract mathematical concepts and students' tangible understanding, utilizing visual and experiential learning modalities.

DEFINITION

Mathematics

Al-Farabi translated the original Greek term *ta mathēmata*, which means “something that can be learned” and at the same time "something that can be taught" (Azlan, 2019). Mathematics serves as a universal language to explain real-world phenomena and forms an essential foundation in various fields, including science, technology, engineering, economics, and education. Mathematics is a discipline that trains individuals to think logically through proof processes, using its own unique language to convey concepts within (Ahmad Sabri & Othman, 2014). Mathematics cultivates logical thinking through reasoning, symbolic representation, and the systematic study of structures, patterns, numbers, shapes, space, and change. This is achieved through logical reasoning, abstraction, and symbolic modelling.

Mathematical Conceptual Knowledge

Mathematical conceptual knowledge involves a comprehensive grasp of concepts, principles, and the relationships between mathematical ideas. It enables teachers to deliver effective teaching and to integrate various concepts in a more meaningful way (Abdullah, 2020).

Augmented Reality

Augmented Reality (AR) is a technology that combines real and virtual elements interactively in a learning environment, aiming to enhance focus, conceptual understanding, and student motivation towards a subject. AR overlays virtual information onto the physical world in three-dimensional form, creating immersive and interactive experiences for users (Bakim & Abdul Hanid, 2024). Figure 1 illustrates the physical reality, digital reality, and their integration (phygital) as the foundation for mixed reality technologies, such as AR (Augmented Reality) and VR (Virtual Reality). The physical represents real-world elements, the digital refers to virtual entities, while the phygital integrates both dimensions through technology. This integration gives rise to Mixed Reality (MR), which enables immersive experiences that seamlessly merge real and virtual interactions.

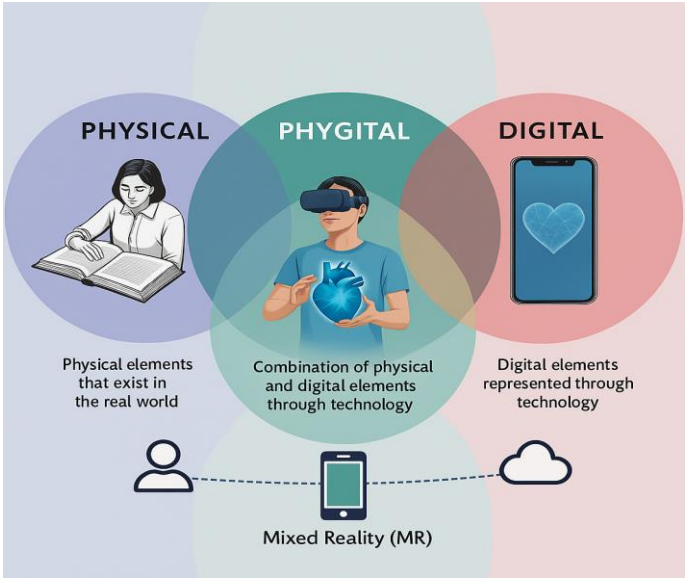

Figure 1 The diagram of Augmented Reality (AR)**.** Source: Wadah ICT UKM, 2025

The Importance of Mathematics Education in Life

Mathematics education is a crucial element in developing the ability to think logically, analyze information, and solve problems systematically. Mathematics is not only symbolic, but is a reality built through rational thinking to understand the structure and phenomena of nature (Azlan, 2019). Mathematics plays a crucial role in human daily life, helping to develop essential skills such as numeracy, statistical understanding, and financial management, among others. Students realize the importance of mastering mathematics in other fields, such as management, and in making decisions based on data. (Ahmad Sabri & Othman, 2014). Therefore, mastering mathematical concepts is crucial for producing competitive individuals in the era of the Fourth Industrial Revolution (IR 4.0).

Conceptual Teaching and Learning of Mathematics

Conceptual teaching and learning focus on a deep understanding of concepts, as well as the relationships between mathematical ideas and their applications in real-world contexts. This approach differed from procedural teaching, which emphasizes steps and formulas alone (Abdullah, 2020). In her study, she noted that teachers need to master conceptual knowledge, enabling them to explain concepts meaningfully and identify student misconceptions. A balance between procedural and conceptual teaching is necessary to ensure that students can maintain a long-term understanding (Leong et al., 2020).

Meanwhile, Christopher Jerry and Jamaludin (2021) found that the critical inquiry learning approach can enhance students' higher-order thinking skills, helping them understand mathematical concepts more deeply. Therefore, the implementation of conceptual teaching systematically is essential in forming students who can think logically, analytically, and creatively when solving mathematical problems.

21st Century Mathematics Education

The needs of 21st-century education demand changes in the teaching and learning approach to mathematics to be more interactive and student-centered. The implementation of critical inquiry-based learning can stimulate students' higher-order thinking, especially in mathematics (Christopher Jerry & Jamaludin, 2021). Meanwhile, Ramli and Mohd Tajudin (2021) found that innovative teaching strategies can increase student engagement and encourage self-exploration in problem-solving. This coincides with the elements of 21st Century Learning, which emphasize collaboration, creativity, communication, and critical thinking skills among students. Therefore, the integration of technology such as AR in mathematics teaching is in line with today's educational aspirations.

Augmented Reality (AR) Technology in Education

Augmented Reality (AR) is a recent innovation that seamlessly blends real and virtual elements in an interactive manner. Its application in education has demonstrated great potential in enhancing students' interest, motivation, and academic performance. AR positively impacts students' learning outcomes by creating more contextual and visual learning environments. (Bakim & Abdul Hanid, 2024). In particular, the use of AR in geometry topics has successfully increased students' interest and understanding of abstract concepts (Ahmad Farish, 2021). This proves that AR not only captures students' attention but also strengthens their ability to build deeper mathematical understanding through immersive learning experiences.

AR Applications in Mathematics Teaching and Learning

Applications such as GeoGebra and Merge Cube are among the AR applications used in mathematics teaching and learning. These applications can help students understand complex concepts, such as geometric shapes and spatial structures. A previous study conducted by Salleh & Md Salleh (2020) developed a 3D Math application based on constructivism and cognitive theory, focusing on 3D geometric shapes. Their findings showed an increase in student achievement and interest in mathematics. In the context of secondary education, Shahudin and Mohd. Nordin (2024) found that the use of AR among Form 2 students had a positive effect on the understanding of 3D geometry concepts, and they were more focused during T&L. The use of AR learning media among primary school students has significantly improved their knowledge of mathematical concepts (Apriza et

al., 2024). These findings support the integration of AR as an effective teaching aid in mathematics, particularly in enhancing students' conceptual knowledge.

Overall, mathematics education plays a crucial role in developing students' ability to think logically, solve problems, and make rational decisions in everyday life. The integration of technology, such as AR, was seen as a teaching medium that supports the development of students' conceptual knowledge of mathematics in a more visual, interactive, and contextual way. In addition, AR also helps increase students' interest and motivation in mathematics subjects. Teachers need to diversify their mathematics teaching methods by integrating AR, which will make the classroom environment more conducive to learning. Findings from previous studies (Salleh & Md Salleh, 2020; Apriza et al., 2024; Shahudin & Mohd Nordin, 2024) provide a solid foundation for exploring the integration of AR as a teaching approach that can strengthen students' conceptual understanding of mathematics. This supports the need to design comprehensive technology-based interventions that are relevant to today's educational needs (Ai & Abdul Karim, 2023).

Issues In Teaching and Learning of Mathematics

Figure 2 shows Malaysia's average achievement scores in Trends in International Mathematics and Science Study (TIMSS) from 1999 to 2023. The findings indicate that the achievement level of Malaysian students in mathematics exhibits a worrying trend. This report shows that Malaysia was ranked 35th out of 42 countries, with an average score of 411. Malaysia's achievement in TIMSS decreased by 50 points from 461 in 2019, falling below the international average of 500 points (Ministry of Education Malaysia, 2023). This was among the lowest achievements since the country began participating in TIMSS in 1999.

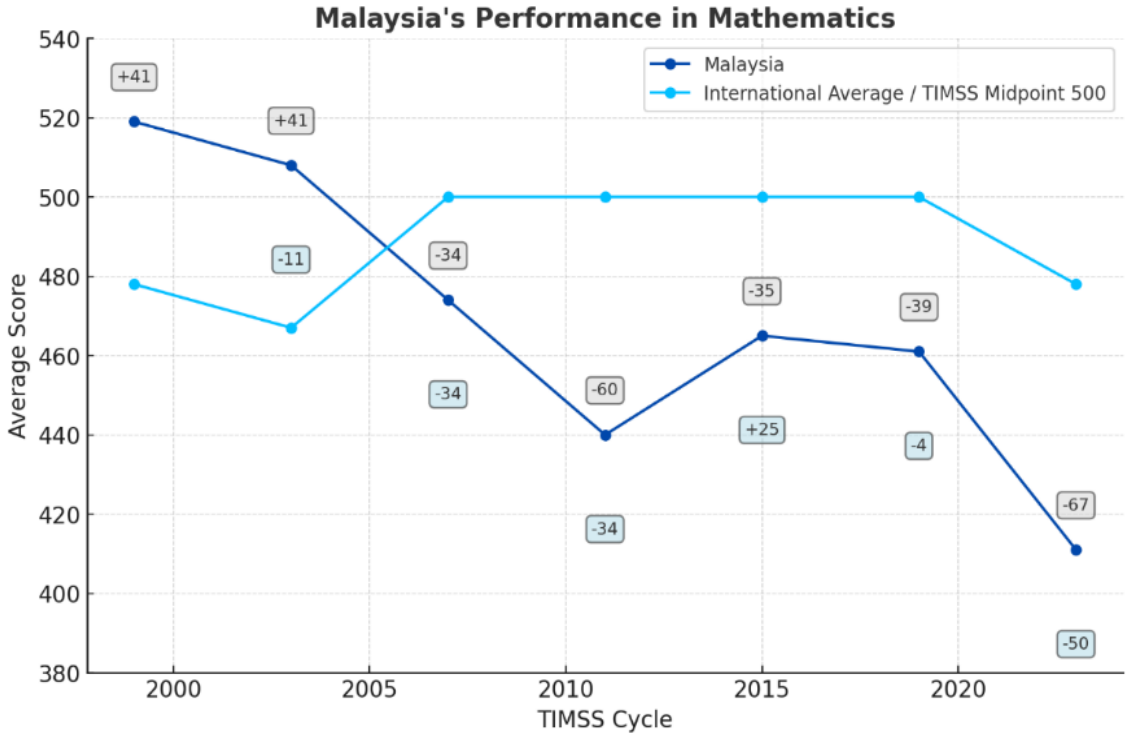

Figure 2 Malaysia's Average Achievement Scores in TIMSS – Source: Ministry of Education Malaysia, 2023

Student weaknesses were also identified across various content domains, including Number, Algebra, Geometry, Measurement, and Data and Probability. The 2024 *Sijil Pelajaran Malaysia* (*SPM*) results for Mathematics recorded a failure rate of 84,025 students, which was 22%. This number was significant, considering that Mathematics is a core subject. This situation illustrates the difficulty students face in mastering mathematical conceptual knowledge as a whole, leading to an increase in the number of students failing mathematics.

Furthermore, another factor contributing to this problem was the traditional and teacher-centered teaching approach. Mathematics teachers continue to employ traditional teaching methods, such as the use of whiteboards and textbooks, as teaching aids in the classroom (Ramli & Mohd Tajudin, 2021). This approach was less

interactive and did not emphasize 21st-century learning, which was needed in the context of today's education. Mathematics teachers need to shift to teaching methods that are collaborative, student-centered, and utilize current technology (Christopher Jerry & Jamaludin, 2021). In this regard, integrating AR technology into mathematics teaching is seen as an innovative approach that aligns with the principles of 21st-century learning, as it can provide a more active, visual, and contextual learning environment.

The low level of motivation and interest among students in Mathematics also contributes to their weakness in mastering conceptual knowledge in this subject. Teaching methods that lack engagement and fail to stimulate students' interest make it difficult for them to grasp mathematical concepts. A study by Salleh and Md Salleh (2020) showed that the use of 3D mathematics applications can increase students' achievement and interest in Mathematics. The use of AR can increase students' motivation, active involvement, and understanding of complex mathematical concepts (Apriza et al., 2024). This finding was supported by Shahudin and Mohd Nordin (2024), who reported that the use of Augmented Reality (AR)-based applications can increase students' interest and knowledge in Mathematics. Therefore, integrating AR into mathematics teaching and learning should be considered a high-impact pedagogical strategy to address declining achievement, pedagogical constraints, and low student motivation in mathematics education.

The Impact of Ar Integration

The integration of Augmented Reality (AR) in mathematics education has gained increasing attention among researchers and educators due to its high potential and significant impact on student achievement. The integration of AR in mathematics learning helps students enhance their conceptual understanding, particularly in grasping abstract and visual concepts. AR can project 3D objects, such as geometric shapes, graphs, and functions, to appear realistic and manipulable. For example, students can observe geometric transformations, such as reflections, rotations, and translations, directly on the screen. They can interact with 3D models by adjusting their size, viewing angle, or exploring them from multiple perspectives. This process allows students to strengthen their understanding of challenging mathematical concepts.

The use of AR also helps students build explicit visual representations of structures and relationships in mathematical topics, such as 2D and 3D geometry, which can be difficult to grasp through conventional teaching methods (Mohd Fadzil & Mohd Noor, 2023). Visual and interactive learning approaches offer students opportunities to explore, manipulate, and construct their conceptual understanding independently and in context. This aligns with the constructivist approach, which emphasizes building new knowledge through learners' prior experiences. Such learning experiences enhance memory retention and long-term understanding, while also indirectly increasing students' interest and motivation in mathematics. Bakim and Abdul Hanid (2024) found that AR not only enhances academic achievement but also encourages active and meaningful learning, supporting more profound conceptual mastery. Additionally, AR has the potential to address misconceptions and misunderstandings in mathematics through interactive and manipulative visual representations. Previous studies indicated that visual representations within a constructivist framework can help overcome misconceptions in fractions and significantly improve students' conceptual understanding (Ai & Abdul Karim, 2023).

The integration of AR also benefits teachers by enabling more effective and interactive instruction. AR assists teachers in explaining abstract mathematical concepts that are often difficult for students to understand, while stimulating classroom questioning and discussions. This results in continuous two-way interaction between teachers and students as they explore mathematical concepts. AR can be used as a teaching aid to visually and progressively explain challenging mathematical concepts, allowing teachers to better holistically assess students' understanding (Apriza et al., 2024). Beyond diversifying teaching methods, AR also supports 21st-century Learning and digital-based mathematics education. Technologically literate teachers are better prepared to create conducive and responsive mathematics learning environments that cater to students from diverse backgrounds. (Chandrasegaran & Maat, 2023). The integration of AR encourages teachers to design lessons that leverage technology to improve students' conceptual knowledge while promoting exploration, discussion, and collaboration. As a result, teachers can become more effective, creative, innovative, and relevant in meeting the current needs of teaching and learning. Ultimately, mathematics instruction becomes more engaging, impactful, and transformative.

Overall, integrating AR in mathematics teaching and learning can build a strong foundation of mathematical conceptual knowledge through visual and interactive approaches. The use of AR is no longer an option but a necessity to make mathematics learning more effective, engaging, and aligned with the needs of today's Alpha generation students.

Challenges Of Using Ar

Although Augmented Reality (AR) offers numerous advantages in improving the understanding and mastery of mathematical conceptual knowledge, its implementation in the Malaysian education context still faces several challenges. These challenges can be categorized into three main components of the education system: students, teachers, and schools, which serve as implementing institutions. The main challenge faced by students is the lack of readiness in technological access and uneven digital skills. Some students struggle to connect what they see through AR with actual mathematical concepts. While AR can display 3D geometric shapes, some students may be more fascinated by the visual effects than by the mathematical concepts being conveyed.

Furthermore, students with weak mathematical foundations may struggle to adapt to AR technology, which can hinder their ability to develop strong conceptual knowledge. Not all students can explore technology independently or possess the intrinsic motivation required for active learning in virtual environments. This affects the effectiveness of conceptual learning.

Teachers face challenges due to limited knowledge and skills in integrating AR into mathematics teaching. Not all teachers possess the expertise to effectively apply AR in their lessons. Some teachers apply AR merely to display objects or animations without linking them to essential concepts such as relationships, structures, or mathematical properties. Teachers also need a deep understanding of mathematical conceptual knowledge to ensure that AR truly supports student learning (Abdullah, 2020). Many teachers have not received formal training on AR applications in mathematics, particularly in visually demanding and abstract topics such as 3D shapes, geometry, fractions, space, and functions. Constraints such as time, workload, and lack of confidence in using advanced technology hinder the optimal integration of AR in daily teaching practices. However, some teachers perceive technology as merely an additional tool rather than a primary means of building mathematical understanding.

These challenges should not be seen as barriers but as opportunities to assess the actual needs of the education system in providing a conducive and responsive learning environment. Emphasis on digital literacy, professional training for teachers, and comprehensive educational technology policies must be prioritized to ensure effective AR-based learning. With holistic support from all stakeholders, AR has the potential to become a key pedagogical tool in strengthening students' conceptual knowledge in mathematics, thereby improving both performance and motivation.

Implications Of Ar

In the 21st-century era of education, which emphasizes active learning and the integration of digital technology, the use of AR in mathematics teaching and learning is seen as an innovative way to enhance students' conceptual understanding. Conceptual understanding in mathematics refers to a profound grasp of principles, relationships, and structures that goes beyond simply memorizing procedures. While AR offers numerous benefits in terms of visualization and interactivity, its implementation also raises various implications for students, teachers, and schools, both positive and negative.

The use of AR provides students with opportunities to explore mathematical concepts visually and concretely, particularly in abstract topics such as three-dimensional geometry, transformations, and function graphs. Through direct interaction with virtual objects, students can improve their conceptual understanding, particularly for complex topics. Additionally, AR promotes logical reasoning and higher-order thinking skills (HOTS) in mathematics.

AR integration makes math teaching and learning more active and student-centered. Enjoyable and interactive experiences boost students' interest and motivation in tackling complex mathematics topics. This increased interest and motivation led to a better understanding and higher performance in mathematics. However, negative

implications also need to be taken into consideration. Students' dependency on AR may affect their learning attitudes. For those with limited technological skills or weak mathematical foundations, interacting with AR applications can lead to confusion and misconceptions. Furthermore, AR may distract some students, as they focus more on visuals rather than the intended mathematical content. This situation risks shallow understanding and failure to build long-term conceptual mastery (Nadzri et al., 2023).

The integration of AR in mathematics instruction offers positive implications for teachers by enabling them to help students visualize abstract concepts, such as geometric transformations or function mapping, more concretely. Besides serving as a pedagogical innovation, AR supports constructivist and inquiry-based teaching approaches, indirectly enhancing the integration of higher-order thinking skills in mathematics classrooms.

Nevertheless, a lack of knowledge about AR technology can hinder its effective implementation. Without proper training and support, teachers may end up using technology merely as a presentation tool rather than linking it to meaningful mathematical learning outcomes (Chandrasegaran & Maat, 2023). However, developing AR-based teaching materials requires time, creativity, and additional effort, which can be burdensome for teachers if not supported by relevant institutions. The lack of AR software or applications that align closely with curriculum objectives also makes it challenging for teachers to fully maximize AR in strengthening students' conceptual knowledge.

Comparing AR-based and traditional teaching methods reveals significant differences in students' engagement, understanding, and motivation. Traditional mathematics instruction often emphasises procedural fluency and teacher-centered delivery, while AR-based approaches encourage experiential and interactive learning. Apriza et al. (2024) found that students exposed to AR environments demonstrated greater conceptual retention and enthusiasm compared to those in traditional settings. Similarly, Salleh and Md Salleh (2020) reported that integrating AR in three-dimensional geometry improved students' performance and engagement. Shahudin and Mohd Nordin (2024) also showed that AR applications supported a deeper understanding of geometric principles, as learners could manipulate and visualize 3D objects directly. These findings suggest that AR integration can complement traditional pedagogy by fostering active knowledge construction rather than passive information reception.

The use of AR in mathematics education aligns with key pedagogical frameworks such as Bloom's Taxonomy and the Technological Pedagogical Content Knowledge (TPACK) model. Through AR, students can progress beyond basic levels of remembering and understanding to higher-order thinking skills like applying, analysing, and creating (Bakim & Abdul Hanid, 2024). For educators, AR integration enhances the TPACK framework by improving teachers' ability to effectively combine technological tools, pedagogical strategies, and mathematical content (Chandrasegaran & Maat, 2023). By unifying these three domains, teachers can design lessons that engage students in exploring mathematical concepts more deeply, connecting virtual representations to abstract reasoning (Ramli & Mohd Tajudin, 2021). This pedagogical alignment ensures that AR functions not just as a visual aid but as an instructional medium that promotes critical thinking and problem-solving.

Despite its pedagogical potential, the scalability of AR implementation in Malaysian schools is hindered by issues of cost, infrastructure, and accessibility. Developing AR-based lessons demands devices, reliable internet access, and technical support, which are unevenly distributed between urban and rural schools (Mat Adam et al., 2022). Moreover, teachers may require ongoing professional development to integrate AR effectively into mathematics lessons. To improve feasibility, schools can adopt affordable measures such as using open-source AR applications (e.g., GeoGebra AR, Merge EDU) and establishing digital-sharing networks among educators. Collaborating with local universities and technology companies can also support the provision of resources and training (Chandrasegaran & Maat, 2023). Addressing these infrastructural and financial obstacles is essential to ensuring equitable access and sustainable AR integration across Malaysian educational settings.

Recommendations For Improving Ar Integration In Enhancing Mathematical Conceptual Knowledge

The integration of Augmented Reality (AR) technology in mathematics education has opened new opportunities for more interactive, visual, and engaging learning experiences (Mohd Fadzil & Mohd Noor, 2023). However,

its implementation still faces several challenges that can affect the effectiveness of AR in building mathematical conceptual knowledge among students (Mat Adam et al., 2022; Bakim & Abdul Hanid, 2024). Therefore, several improvement suggestions can be put forward to ensure that AR integration has a positive and optimal impact on students and teachers.

From the student's perspective, emphasis should be placed on developing fundamental skills in using AR technology in mathematics learning. Students need gradual exposure through training and guidance, especially in connecting the visual elements of AR to core mathematical concepts, as highlighted by Nadzri and Ayub (2023). This support is crucial because effective AR use involves students interpreting 3D visual representations and linking them to symbolic mathematical expressions, which enhances higher-order conceptual understanding. Interactive modules that combine gamification elements with student-centered learning can be introduced to boost motivation and improve understanding of abstract mathematical concepts such as 3D shapes, functions, and spatial transformations (Salleh & Md Salleh, 2020; Shahudin & Mohd Nordin, 2024). The use of gamified AR tasks has also been shown to foster curiosity and persistence, supporting long-term retention of mathematical knowledge. Additionally, students with weak mathematical foundations should receive extra support, such as guided practice, reinforcement activities, and tasks emphasizing visual and manipulative higher-order thinking (Apriza et al., 2024).

For teachers, improvements can be made through continuous professional training that is practical and focuses on integrating AR in mathematics topics, especially those that are difficult and abstract. This training should combine technical, pedagogical, and content aspects (TPACK) so that teachers are not only skilled in using technology, but also understand how to relate it directly to the mathematical concepts being taught (Chandrasegaran & Maat, 2023). The integration of TPACK ensures that AR was used not as a novelty but as a meaningful pedagogical tool aligned with curriculum objectives and students' cognitive development. In addition, sharing good practices in mathematics teaching among teachers can become a platform for exchanging resources, experiences, and effective AR-based teaching strategies (Christopher Jerry & Jamaludin, 2021). Teachers need to be involved in the development of AR materials or modules so that they better understand the pedagogical potential that can be applied in the classroom (Ramli & Mohd Tajudin, 2021). Teacher participation in content creation also enhances ownership, contextual relevance, and pedagogical alignment of AR resources with students' learning needs.

CONCLUSION

Overall, integrating Augmented Reality (AR) technology into mathematics teaching and learning presents an innovative approach that can significantly enhance students' conceptual understanding in a more effective, visual, and interactive way. AR not only helps students grasp abstract mathematical ideas such as three-dimensional geometry, functions, and spatial transformations, but also promotes student-centered, collaborative, active, and meaningful learning. Its use has been demonstrated to positively influence students' achievement, interest, and motivation, thereby contributing to the improvement of mathematics education quality. However, implementing AR in mathematics education still faces various challenges, including students' digital readiness, teachers' competence, and institutional limitations related to infrastructure and policy support. Therefore, systematic and comprehensive efforts must involve students, teachers, and school administrations to maximize the effectiveness of AR integration. This includes targeted professional development training for teachers, creating interactive modules aligned with the curriculum, and establishing clear guidelines for AR implementation. In conclusion, AR integration is no longer merely a technological option; it has become a necessity for realizing the aspirations of 21st-century mathematics education, which emphasises deep conceptual mastery, higher-order thinking skills, and preparedness to meet the challenges of the Fourth Industrial Revolution (IR 4.0). With careful planning and extensive support, AR has the potential to drive a transformation in school-based mathematics education, particularly in enhancing students' conceptual understanding of mathematics.

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REFERENCES

1. Abdullah, N. A. (2020). Pengetahuan konseptual algebra guru matematik: Satu kajian literatur. Sains Humanika,12(1), 19-30. https://doi.org/10.11113/sh.v12n1.1048
2. Ahmad Farish, N. A. (2021). Keberkesanan penggunaan realiti terimbuh terhadap minat dan pencapaian pelajar dalam topik ruang. Universiti Teknologi Malaysia: Fakulti Sains Sosial dan Kemanusiaan.
3. Ahmad Sabri , S., & Othman, N. (2014). Matematik dan disseminasi ilmu: Tinjauan persepsi pelajar pengurusan. Proceeding of the 1st International Conference on Management and Muamalah 2014, (pp. 220-225). Kolej Universiti Islam Antarabangsa Selangor.
4. Ai, C. M., & Abdul Karim, A. (2023). Penerapan teori konstruktivisme bagi menangani miskonsepsi pengetahuan konseptual pecahan dalam murid Tahun Tiga. Malaysian Journal of Social Sciences and Humanities (MJSSH), 8(5), 1-18. https://doi.org/10.47405/mjssh.v8i5.2325
5. Azlan, M. I. (2019). Matematik dan realiti: Satu penelitian terhadap takrif-takrif matematik. Journal of Islam and the Contemporary World, 12(1), 109–143. https://doi.org/10.56389/tafhim.vol12no1.5
6. Bakim, N. N., & Abdul Hanid, M. F. (2024). Kesan penggunaan teknologi realiti terimbuh terhadap pencapaian akademik pelajar : Sebuah kajian literatur sistematik. Journal Of Research, Innovation, And Strategies For Education, 1(1), 17-28. https://doi.org/10.70148/rise1
7. Apriza, B., Suprapto, I., & Mahendra, Y. (2024). The influence of augmented reality-based learning media on the understanding of mathematical concepts in elementary school children. West Science Interdisciplinary Studies, 2(3), 502-508. https://doi.org/10.58812/wsis.v2i03.694
8. Chandrasegaran , G., & Maat, S. M. (2023). Kompetensi guru matematik dalam penggunaan teknologi untuk meningkatkan kefahaman matematik. Jurnal Dunia Pendidikan, 5(4), 23-32.
9. Christopher Jerry, F., & Jamaludin, K. A. (2021). Pelaksanaan pembelajaran berasaskan inkuiri kritis dalam mata pelajaran matematik. Jurnal Dunia Pendidikan, 3(2), 386-400.
10. Hui, E. X., & Rosli, R. (2021). Kebimbangan dan efikasi kendiri terhadap pembelajaran matematik dalam kalangan pelajar tingkatan empat. Malaysian Journal of Social Sciences and Humanities (MJSSH), 6(3), 41–53. https://doi.org/10.47405/mjssh.v6i3.690
11. Leong, T. G., Raja Maamor Shah, R. L., & Mohd Idrus, N. (2020). Analisis keperluan bagi pembangunan modul matematik Tingkatan 1 untuk pengekalan pengetahuan konseptual dan prosedural. Journal of Science and Mathematics Letters, 8(2), 86–99. https://doi.org/10.37134/jsml.vol8.2.11.2020
12. Mat Adam, N., Raja Maamur Shah, R. N., & Adnan, M. (2022). Manfaat dan cabaran pengintegrasian teknologi maklumat dan komunikasi dalam pengajaran dan pembelajaran matematik : Sorotan literatur bersistematik. Jurnal Pendidikan Bitara UPSI, 15(1), 41-49. https://doi.org/10.37134/bitara.vol15.1.5.202
13. Mohd Fadzil, M. Z., & Mohd Noor, N. A. (2023). Mengintegrasikan augmented reality dalam pembelajaran bentuk 2D dan 3D. Journal of Engineering, Technology & Applied Science, 5(1), 12–22. https://doi.org/10.36079/lamintang.jetas-0501.500
14. Nadzri, A., & Ayub, A. (2023). Implications of ar modules on geometry conceptual and procedural knowledge among primary school students. Malaysian Journal of Mathematical Sciences, 18(1), 51–72. https://doi.org/10.47836/mjms.18.1.04
15. Poddar, K., Deepak, Pathania, M., & Sing, C. P. (2024). Efficacy of an augmented reality application for enhanced learning of 3D geometric shapes. International Conference on Emerging Smart Computing and Informatics (ESCI). Punjab, India. https://doi.org/10.1109/ESCI59607.2024.10497394
16. Ramli, S. M., & Mohd Tajudin, N. (2021). Analisis keperluan untuk membangunkan modul pembelajaran berasaskan challenge dalam mempelajari matematik bagi murid tingkatan 4. Jurnal Pendidikan Sains & Matematik Malaysia, 11(special issue), 50-58. https://doi.org/10.37134/jpsmm.vol11.sp.5.2021
17. Salleh, F., & Md Salleh, S. (2020). Pembangunan aplikasi pembelajaran 3D maths untuk topik bentuk geometri 3 dimensi berasaskan android. Innovative Teaching and Learning Journal, 3(2), 80–91.
18. Shahudin;, F., & Mohd. Nordin, N. (2024). Aplikasi augmented reality (ar) bagi topik bentuk geometri 3D dalam kalangan pelajar tingkatan 2. Prosiding The 3rd Malaysia International Convention on Education Research, (pp. 79-90). Universiti Kebangsaan Malaysia,Selangor, Malaysia.