ENHACING MATHEMATICAL COMPETENCE THROUGH AUGMANTED REALITY : AN EXPLORATORY STUDY USING BEST AR IN GEOMETRY LEARNING

ARTIKEL

Diajukan Guna Melengkapi Tugas-tugas dan Memenuhi Syarat-syarat
Guna Mencapai Gelar Sarjana Pendidikan (S.Pd.)
Program Studi Pendidikan Matematika

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Bilamana dikemudian hari ditemukan ketidaksesuaian dengan pernyataan ini maka saya bersedia dituntut dan diproses sesuai dengan ketentuan yang berlaku di Univesitas Muhammadiyah Sumatera Utara.

Demikian pernyataan ini dengan sesungguhnya dan dengan yang sebenar-benarnya.

Hormat saya
Yang membuat pernyataan,

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ENHANCING MATHEMATICAL COMPETENCE THROUGH AUGMENTED REALITY: AN EXPLORATORY STUDY USING BEST AR IN GEOMETRY LEARNING

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ABSTRACT The integration of digital technology in mathematics education holds immense potential to transform abstract concepts into concrete experiences. This study explores the impact of an Augmented Reality (AR)-based learning application, *Best AR*, on enhancing the mathematical competence of fifth-grade students in Malaysia. Conducted in a tutoring center using an exploratory qualitative approach, the research investigates how the interactive features of *Best AR*—including 3D object simulations, mini-games, and quizzes—support conceptual understanding, engagement, and problem-solving skills, particularly in learning three-dimensional geometry. Data were collected through interviews, observations, and documentation, and analyzed thematically. The findings reveal that *Best AR* improved students' ability to visualize and manipulate geometric objects, fostered collaboration, increased motivation, and enhanced logical reasoning. The application's mobile accessibility and adaptive feedback promoted self-regulated learning, while its gamified elements made mathematics more engaging and enjoyable. Despite challenges in device access and teacher preparedness, the study underscores the potential of AR to bridge gaps in technology integration and enrich mathematics instruction. Implications for curriculum alignment, teacher training, and scalable adoption of AR media in informal learning contexts are discussed.

Keywords: augmented reality, mathematical competence, geometry learning, gamification, educational technology

ABSTRAK Integrasi teknologi digital dalam pendidikan matematika memiliki potensi besar untuk mentransformasi konsep-konsep abstrak menjadi pengalaman belajar yang konkret. Penelitian ini bertujuan untuk mengeksplorasi pengaruh media pembelajaran berbasis Augmented Reality (AR) bernama *Best AR* terhadap peningkatan kompetensi matematis siswa kelas V di Malaysia. Studi ini dilaksanakan di sebuah pusat bimbingan belajar dengan pendekatan kualitatif eksploratif, untuk menelusuri bagaimana fitur interaktif *Best AR*—seperti simulasi objek 3D, mini-games, dan kuis—mendukung pemahaman konsep, keterlibatan, dan keterampilan pemecahan masalah, khususnya dalam pembelajaran geometri bangun ruang. Data dikumpulkan melalui wawancara, observasi, dan dokumentasi hasil belajar, kemudian dianalisis secara tematik. Temuan menunjukkan bahwa *Best AR*

meningkatkan kemampuan siswa dalam memvisualisasikan dan memanipulasi objek geometri, mendorong kolaborasi, meningkatkan motivasi, serta memperkuat penalaran logis. Aksesibilitas aplikasi melalui perangkat seluler dan fitur umpan balik adaptif mendukung pembelajaran mandiri, sementara elemen gamifikasi membuat pembelajaran matematika lebih menarik dan menyenangkan. Meskipun terdapat tantangan seperti keterbatasan perangkat dan kesiapan guru, studi ini menegaskan potensi AR dalam menjembatani kesenjangan integrasi teknologi dan memperkaya pembelajaran matematika. Implikasi bagi keselarasan kurikulum, pelatihan guru, dan adopsi media AR secara luas dalam konteks pembelajaran informal turut dibahas.

Kata-kata kunci: augmented reality, kompetensi matematis, pembelajaran geometri, gamifikasi, teknologi pendidikan

INTRODUCTION

The integration of technology in mathematics education has become increasingly important in the digital era. It enhances the flexibility and accessibility of learning, allowing students to study at their own pace, anytime and anywhere (Elfrianto & Tanjung, 2022; Hidayat & Firmanti, 2024). Moreover, the advancement of digital technologies requires students to continuously adapt to new tools and environments, placing demands on education systems to evolve accordingly (Rosnelli et al., 2024; Tanjung et al., 2023).

Internationally, various countries have demonstrated how technology improves mathematics teaching and learning. In South Africa, the mathematics curriculum has been aligned with science and technology to strengthen formal education and improve teacher competencies (Le, 2010). In Australia, the use of ICT in mathematics classrooms has made students more proactive, helping to overcome barriers to learning (Voss et al., 2023). In Singapore, technology integration has been linked to improved student performance (Goh et al., 2024). Similarly, in Korea and Zimbabwe, teachers' innovations in instructional media have significantly influenced student engagement and achievement (Lee & Shin, 2023; Polly, 2017).

Beyond technical mastery, digital-age learners are also expected to develop social and communication skills that allow them to engage actively in class. These competencies help students present content, manage their time, and collaborate effectively. Miller and Bernacki (2019) emphasize that self-regulated learning is key to developing a theoretical understanding of mathematics applicable to real-world contexts. Students must be able to plan, monitor, and evaluate their learning processes to achieve optimal results (Göller et al., 2024; Rosnelli & Ristiana, 2023). However, motivating students through verbal instruction alone remains a challenge (Rosnelli, 2024).

Research has shown that enjoyable, engaging experiences—particularly when supported by gamification and ICT—can foster motivation and deepen mathematical understanding (Rosnelli et al., 2024). Students trained to evaluate tasks, set goals, apply cognitive strategies, and reflect on their progress tend to perform better (El et al., 2024; Rosnelli & Ristiana, 2023). ICT tools provide

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personalized learning by offering differentiated questions and real-time feedback (Göller et al., 2024), and have been shown to improve outcomes compared to conventional instruction (Fathurrohman et al., 2021; Miller & Bernacki, 2019). They also promote collaboration and shared problem-solving experiences (Abrori et al., 2024; Weinhandl et al., 2024), and are highly compatible with project- and problem-based learning models (Charalambous & Charalambous, 2023; Dahl, 2018; Tural-Sonmez, 2023).

In Malaysia, despite efforts to enhance digital competencies in education (Chia & Zhang, 2023; Shanmugam et al., 2024), observations conducted at a tutoring center in Kepong revealed that mathematics teaching remains largely manual, with minimal integration of digital learning tools. This gap between technological potential and actual classroom practices underscores the need for accessible and engaging digital learning media.

To address this issue, the researcher developed an Augmented Reality (AR)-based learning media called "Best AR", designed to strengthen students' mathematical competence through interactive, visually rich, and adaptive features (Davenport et al., 2023). Best AR enables students to explore three-dimensional geometric objects such as cubes, cuboids, prisms, cones, cylinders, and spheres, supporting deep conceptual understanding through manipulation and visual engagement.

Figure 1. Best AR Learning Media Application

The media includes a range of interactive features, such as mini-games, simulations, and quizzes that align with curricular content and allow students to adjust the level of difficulty based on their abilities. These features also offer real-time feedback, facilitating self-directed learning and collaboration.

Best AR supports students in mastering key mathematical skills, particularly in geometry topics related to three-dimensional shapes. Learning outcomes include the ability to accurately apply volume formulas, interpret and describe geometrical elements such as faces, edges, and vertices, and relate abstract mathematical concepts to real-life contexts such as calculating surface area or capacity (Miller & Bernacki, 2019; Polly, 2017; Shriki & Patkin, 2016; Yulianti & Mukminin, 2021).

Students using Best AR demonstrate increased motivation and confidence in tackling complex mathematical problems, supported by digital simulations and game-based experiences (Ra et al., 2019; Varas-Pavez et al., 2024). The interactive media environment enables learners to collaborate through digital platforms, visualize mathematical ideas, and engage in critical and analytical thinking (Abidin et al., 2017; Rosnelli & Ristiana, 2023).

Moreover, the integration of Best AR promotes improvement in students' logical reasoning, accuracy in mathematical operations, and problem-solving abilities. It offers a dynamic alternative to traditional methods by reducing time spent on routine calculation and allowing more focus on higher-order skills. Teachers also benefit from features such as automatic feedback and performance tracking tools (Zambak et al., 2024), supporting more efficient evaluation and individualized instruction.

Figure 4. Scope content presented in Best AR learning media

Moreover, the integration of Best AR promotes improvement in students' logical reasoning, accuracy in mathematical operations, and problem-solving abilities. It offers a dynamic alternative to traditional methods by reducing time spent on routine calculation and allowing more focus on higher-order skills. Teachers also benefit from features such as automatic feedback and performance tracking tools (Zambak et al., 2024), supporting more efficient evaluation and individualized instruction. Therefore, this study aims to explore students' perceptions of the Best AR learning media and to examine how its use influences their mathematical competence. Specifically, it investigates students' experiences with the Best AR application and the extent to which the media contributes to the development of their mathematical competence.

METHODS

This research was conducted at a tutoring center for fifth-grade elementary school students located in Kuala Lumpur, Malaysia. The study employed an exploratory qualitative design (Braun & Clarke, 2006), aiming to investigate students'

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experiences in learning mathematics using the Best AR learning media developed by the researcher. The purpose of this study is to explore how this media enhances students' mathematical competence, particularly in a context where technology integration in tutoring practices remains limited. The study is considered novel due to the limited number of similar investigations in the field, especially involving the use of augmented reality in informal learning settings.

The implementation of the Best AR learning media took place in September 2024, and data collection was completed in October 2024. The participants included all five students enrolled at the tutoring center, selected using a total sampling technique. Given that the entire student population was included, the findings are considered valid and representative of the setting. Data were collected through semi-structured interviews, informal discussions, observation notes, and documentation of students' mathematics learning outcomes. This triangulation strategy ensured that the data obtained were rich, complete, and deeply reflective of the students' experiences (Bryman, 2016; Clandinin & Huber, 2010).

Semi-structured interviews were chosen to allow flexibility in exploring participants' responses and to uncover emerging themes. Each interview lasted approximately 50 to 90 minutes and was designed to elicit in-depth information regarding the use of the BEST AR media in mathematics learning. The guiding questions used during the interviews included:

1. How do students describe their experiences in using the Best AR application during mathematics learning?
2. To what extent does the Best AR media enhance students' understanding of mathematical concepts?
3. How does the Best AR media support the development of students' problem-solving skills in mathematics?
4. In what ways does the use of Best AR promote interaction and engagement among students during mathematics learning? And
5. How do students perceive the convenience and overall usability of the BEST AR learning media in learning mathematics?

These questions were adapted throughout the interview process to follow up on participants' unique perspectives and experiences. When no new insights were emerging during the data collection process, theoretical saturation was considered to have been reached (Russell & Kelly, 2002).

All interview data were audio-recorded and transcribed verbatim. Thematic analysis, as described by Braun and Clarke (2006), was employed to identify recurring patterns and themes in the data. The process began with repeated listening to the recordings, followed by careful transcription, initial coding, and theme development. The researcher interpreted and reconstructed the data based on emerging meanings and confirmed interpretations with each participant to ensure representational accuracy. This member-checking process supported the credibility

of the findings (Mukminin et al., 2022). In addition, the researcher conducted follow-up reviews with participants to validate that the analysis accurately reflected their intended meanings (Wald et al., 2024). The accuracy of the information extracted from participants' experiences in using the Best AR media for mathematics learning was verified through reflective dialogue and mutual agreement (Ashworth, 2003; Mukminin & McMahon, 2013; Yin, 2014). All participants gave their informed consent to use their interview data in this study.

FINDING AND DISCUSSION

The implementation of the Best AR learning media allowed students to access mathematics materials anytime and anywhere, thereby enhancing learning flexibility. Field observations and interview data revealed that abstract mathematical concepts—especially those involving three-dimensional objects—became easier to understand through interactive visualizations (Bray & Tangney, 2017; Chandra & Briskey, 2012). The application also provided teachers with analytical data to monitor student progress and identify areas requiring instructional adjustment (Amam et al., 2017). This supported students in developing logical reasoning and problem-solving abilities in accordance with established learning competencies (Aliyu et al., 2021). Moreover, the presence of diverse learning resources such as exercises, quizzes, and mini-games made the learning process more engaging and comprehensive. Since the application can be accessed via mobile technology, students were able to explore mathematical concepts from various perspectives (Abidin et al., 2017).

Mini-games and quiz features embedded in the Best AR application encouraged students to experiment with different shapes and sizes and observe changes interactively (Chandra & Briskey, 2012; Cooper, 2011). These features also stimulated creative thinking by challenging students to find efficient solutions in a gamified environment. The integration of gamification and logic-based challenges promoted healthy competition and motivated students to develop innovative thinking strategies (Charalambous & Charalambous, 2023). For example, students learned geometry by designing virtual objects, creating classroom layouts, or developing scaled floor plans—activities that helped connect abstract geometry with real-life applications (Tural-Sonmez & Erbas, 2023; Weinhandl et al., 2024).

One participant stated that learning with Best AR made them more enthusiastic and improved their understanding of mathematical concepts. According to the student, the teacher's detailed guidance enhanced their ability to use the application, which in turn facilitated comprehension and enjoyment in solving mathematics problems. They also emphasized that the application supported visualization and calculation, especially when working with flat and curved 3D shapes. This experience marked a shift from traditional methods, demonstrating that learning mathematics could be both effective and enjoyable.

Another student explained that their conceptual understanding improved after using the AR-based mini-games to compare the volume of 3D objects. By analyzing

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differences between shapes with similar heights but varying dimensions, students reported becoming more focused on mathematical analysis and more critical in problem solving. This aligns with the goal of promoting higher-order thinking through visual and interactive learning tasks.

Regarding problem-solving skills, one student noted that the use of Best AR helped them become more motivated when responding to teacher-given tasks. They mentioned being able to solve volume and surface area problems more easily, particularly for both flat and curved 3D objects. The interactive nature of the application made mathematics feel more approachable and engaging.

Improvements were also seen in student interaction and engagement. A participant highlighted that the application's quiz and collaborative features encouraged active participation during virtual discussions and joint activities. The social dimension of gamified learning led students to enjoy studying mathematics together, which fostered a stronger sense of academic collaboration and peer support.

Another student emphasized that using Best AR made mathematics feel easier and faster to complete. Although initially skeptical about technology-based learning, they found the application intuitive and efficient after the teacher's explanation. They appreciated that the application reduced the time needed for manual calculations and allowed on-demand access to learning materials via mobile phones. This flexibility significantly contributed to a more positive learning experience and increased confidence in mathematics.

Overall, the results indicate that Best AR supported the development of mathematical competence by improving students' understanding of concepts, fostering problem-solving abilities, promoting engagement, and enabling more flexible and enjoyable learning experiences. These findings reinforce the potential of augmented reality to transform mathematics education through interactivity, gamification, and mobile accessibility.

The integration of technology in mathematics education requires strategic planning to ensure effective instruction and improved learning outcomes (Abidin et al., 2017). A critical factor in technology selection is the alignment of digital tools with students' learning needs and curricular objectives (Goh et al., 2024). In this study, the use of the Best AR application—designed specifically to support the teaching of three-dimensional geometric concepts—demonstrated how interactive and visually rich tools can increase engagement through built-in mini-games and quizzes. These features allowed students to visualize abstract ideas such as volume and surface area, thereby improving conceptual understanding.

Initial technology exposure through calculators and instructional videos may serve as a foundation for integrating more advanced applications such as mathematical modeling software and AR-based simulations (Habibi et al., 2024; Hidayat & Firmanti, 2024). In the current study, students utilized Best AR to explore geometric properties, manipulate 3D objects, and engage in interactive problem-solving

activities. The results confirmed that students not only gained access to dynamic representations of geometric figures but were also motivated to complete tasks and share ideas with peers, consistent with the findings of Mukminin et al. (2023) and Ra et al. (2019).

The incorporation of gamification in Best AR proved particularly effective in capturing student attention and enhancing enthusiasm toward mathematics. This aligns with the learner-centered approach, where instructional delivery is personalized to accommodate diverse learning styles (Russell & Kelly, 2002; Weinhandl et al., 2024). Gamified learning tasks enabled students to progress at their own pace while receiving timely feedback, which improved retention and self-regulation (Abrori et al., 2024; Aliyu et al., 2021). Moreover, the application's 3D visualizations helped demystify abstract content, supporting findings by Davenport et al. (2023) and Göller et al. (2023).

Teacher guidance remained essential during implementation. Students relied on instructional support to navigate application features, such as video tutorials and simulations, before independently solving geometry-based problems (Chandra & Briskey, 2012; Fathurrohman et al., 2021). The application's step-by-step feedback and real-time rendering of geometric solids—cubes, pyramids, spheres, cones, and cylinders—facilitated a flexible, mobile learning experience beyond the classroom environment (Hidayat & Firmanti, 2024; Lebeničnik & Istenic, 2024).

The study also highlighted Best AR's role in enhancing collaborative learning. Through shared tasks and group projects, students exchanged ideas and problem-solving strategies, reinforcing peer learning (Amam et al., 2017; Abrori et al., 2024). This collaborative dimension was further strengthened by narrative animations and interactive features that supported visual, auditory, and kinesthetic learning styles (Charalambous & Charalambous, 2023; El Bedewy et al., 2024). Teachers facilitated this process by guiding students in team-based assignments and encouraging equitable participation, even among more reserved learners (Cooper, 2011; Davenport et al., 2023).

The Best AR application also contributed to students' cognitive development. By engaging in low-pressure, exploratory environments, students practiced monitoring their progress and applying logical, critical, and analytical thinking (Lee & Shin, 2023; Miller & Bernacki, 2019; Rosnelli & Ristiana, 2023). Visualizing complex mathematical problems fostered innovation and deeper conceptual connections, consistent with the findings of Bray & Tangney (2017) and Chandra & Briskey (2012). Additionally, the use of project-based learning tasks—such as designing scaled floor plans or modeling 3D parks—encouraged students to make data-driven decisions and reflect on real-world applications of mathematics (Weinhandl et al., 2024; Zambak et al., 2024).

Despite these benefits, challenges in implementing Best AR were also observed. Limited access to digital devices and internet connectivity posed barriers to

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consistent use. Some students required substantial guidance to operate the app effectively, and not all teachers were fully equipped to integrate AR technology without additional training. These findings underscore the importance of adequate infrastructure, digital literacy, and sustained professional development for successful implementation.

Nevertheless, Best AR demonstrated its potential to promote student agency and experimentation. Teachers used gamification and structured feedback to support independent learning while monitoring performance data to provide targeted support (Mukminin et al., 2022; Rosnelli & Ristiana, 2023). The app's analytical tools allowed teachers to track progress, identify misconceptions, and intervene when necessary (Charalambous & Charalambous, 2023; Amam et al., 2017).

By encouraging active participation through competition, quizzes, and collaborative design challenges, Best AR helped transform mathematics into an accessible and enjoyable subject. The application's user-friendly interface and adaptive features supported diverse learners, reinforcing the notion that technology, when thoughtfully integrated, can bridge the gap between abstract content and meaningful student experiences.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings, the use of Best AR learning media significantly enhanced students' mathematical competence, particularly in understanding three-dimensional objects. The application enabled students to visualize abstract geometric shapes—such as cubes, prisms, cones, and spheres—through simulations, animations, quizzes, and mini-games. These features supported deeper conceptual understanding and allowed students to engage actively in solving mathematics problems presented by the teacher. The learning atmosphere became more enjoyable, enabling students to adapt to various levels of question difficulty based on their individual abilities.

The flexibility of Best AR, which allows students to access learning materials anytime and anywhere via mobile devices, contributed to increased autonomy and motivation. Students could study at their own pace, which helped develop their problem-solving skills and fostered a more personalized learning experience. The application's integration with gamified elements further stimulated students' interest and motivation to explore mathematical content.

This research implies that well-designed AR-based learning media, when aligned with the curriculum and mathematical competence standards, can support teachers in delivering more engaging and effective mathematics instruction. Moreover, the Best AR app demonstrates potential as a scalable learning tool that addresses both cognitive and affective domains in mathematics education. Its use can help overcome students' negative perceptions of mathematics by making the subject more accessible, interactive, and enjoyable.

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Penulis	:	Puspita Dewi, Tua Halomoan Harahap, & Surya Wisada Dach
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Ratri Isharyadi

DEVELOPMENT OF BEST AR LEARNING MEDIA FOR MATHEMATICS LEARNING: STUDENTS' PERCEPTIONS ON KEPONG GUIDANCE IN MALAYSIA

ABSTRACT This research aims For explore improvement Best AR media mastery for increasing competence mathematics students in a center guidance studying in Kuala Lumpur Malaysia reviewed from students perception. This research is of a qualitative exploratory with participants totaling 5 people. The results of the interview data analysis show that there is improvement in the results of Study mathematics students. In addition, participants feel that Study mathematics is fun things. Activities students in learning more active Because can interact directly with materials, for example through simulations, quizzes, or mini games so that understanding draft mathematics becomes ore deep For do question mathematics given by the teacher. The advantages of the Best AR learning media are when students do question can strengthen their understanding about draft mathematics because of they can adapt the difficulty of the question with his abilities, so that in the end can increase the competence of the mathematics with a fun way. Implications study is gamification from Best AR learning media to motivate student challenges For Keep going Study For develop skills breakdown mathematics problems.

Keywords *: Learning Media; Mathematics; Mini Games; Quiz*

ABSTRACT This research aims to For explore improvement Best AR media mastery for increase competence mathematics students in a center guidance studying in Kuala Lumpur Malaysia reviewed from perception students . This research is of a qualitative explorative with participants totaling 5 people. The results of the interview data analysis show that there is improvement results Study mathematics students . In addition, participants feel that Study mathematics is fun things . Activities student in learning more active Because can interact direct with materials , for example through simulations , quizzes , or mini games so that understanding draft mathematics become more deep For do question mathematics given by the teacher. The advantages of the Best AR learning media are when student do question can strengthen understanding they about draft mathematics because of they can adapt difficulty question with his abilities , so that in the end can increase competence the mathematics with a fun way . Implications study is gamification from Best AR learning media to motivating challenge student For Keep going Study For develop skills breakdown problem mathematics .

Keywords *: Learning Media ; Mathematics ; Mini Games; Quiz*

Commented [ABS1]: The abstract contains numerous grammatical errors and awkward sentence constructions that affect clarity and readability. It is recommended to revise the abstract using correct and formal academic English to ensure that the purpose, methodology, findings, and implications of the study are communicated clearly and professionally.

Commented [ABS2]: Include an Indonesian version of the abstract

Introduction

Commented [ABS3]: 1. Pay close attention to the correct use of punctuation, particularly periods and commas.
2. Revise the text for grammatical accuracy and reorganize the content into a more structured narrative: starting with the general importance of math education, followed by challenges in learning math, the role of AR and gamification, and ending with the rationale for the current study

Development of learning media based on technology become very important in learning mathematics in the digital age because can increase flexibility and accessibility of the learning process (Elfrianto & Tanjung, 2022; Hidayat & Firmanti , 2024). In addition, the development of digital technology demands student For Keep going adapt with change the (Rosnelli et al., 2024; Tanjung et al., 2023) For example , in South Africa, changes curriculum mathematics has integrated with knowledge nature and technology For support formal education , as well as increase teacher competence in face challenge education (Le, 2010). Utilization technology in education allow students and teachers access material mathematics anytime and anywhere, so that student can Study in accordance with character and speed of each if governance school can accomplished with good (Darma et al., 2023). They can too repeat difficult concepts For increase ability breakdown problem so that they truly understand it (Dachi et al., 2024; Harahap et al., 2021; Rosnelli & Ristiana , 2023; Varas-Pavez et al., 2024). Teacher as facilitator learning can also push activity interactive in learning based on problem For increase motivation Study students with utilise simulation , animation and games education ICT -based (Dachi & Batubara, 2020; Rosnelli , 2024).

Education in the world has Lots implement learning with take advantage of technology , for example in Australia, the use of ICT in learning allow student more proactive so that can remove obstacle in the learning process mathematics (Voss et al., 2023). In addition, in Singapore, ICT has been shown to can increase performance Study student (Goh et al., 2024). This technology makes draft abstract mathematics become more concrete and easy understood , at the same time increase motivation Study students . Next utilization of ICT can give opportunity for teachers to develop approach supportive pedagogical student in understand draft abstract and thinking critical (Chandra & Briskey, 2012). In Turkey, the United States , Costa Rica, and Malaysia , teachers who implemented technology in learning beneficial For increase teaching mathematics . But there is also challenges that need to be overcome searched for the solution For integrate technology in a way effective into teaching mathematics in effort improvement teacher and student competition (Kholid et al., 2023).

In Indonesia integration diverse technologies in education mathematics , there is improving the learning process , improving skills solve problems , and improvements understanding , and can highlight benefit overall from integration technology . However , still there is challenge like problem availability device mobile and limitations digital tools , so that required effort strategic For overcome limitations infrastructure (Hidayat & Firmanti , 2024). In Bangladesh it is recommended results evaluation readiness use of ICT in learning contribute to graduates who have more ICT skills Ready enter the world of work , progress research . Although so party academics , faculty , university, creator policies , and officials government in the future Still required For facilitate equipment ICT -based learning (Alam & Ogawa, 2024). Condition the disclose that integration technology in education become the more important its utilization in the learning process For increase competence graduates For face futility future work (Goh et al., 2024).

In Malaysia the use of technology in learning mathematics is also a rewarding challenge For increase teacher competence in the learning process For facilitate in effort improvement competence his students (Chia & Zhang, 2023; Shanmugam et al., 2024). Meanwhile the results

observation in the studio guidance in Kepoh , Malaysia, shows that learning mathematics Still done manually and not yet utilise application based on technology . Based on this observation , the researcher First develop Best AR learning media for increase competence mathematics through utilization meia Best AR. With Thus this media is designed For support settlement problem mathematics and collaboration learning , so that students can adapt with development technology in the digital era (Davenport et al., 2023). This media also provides question with level measurable difficulty , equipped with bait come back specific and real-time so that learning mathematics become more enjoyable (Göller et al., 2024). Questions main proposed in This research is : how condition student after follow learning mathematics with using Best AR learning media for increase competence the math ?

Literature Review

Commented [ABS4]: Improve grammar and sentence structure

Transformation ongoing technology fast currently carrying change big on type the work to be done faced by candidates graduate of education , including graduate of educational program mathematics . Although automation technology potential replace a number of work , this also creates opportunity work new that is needed anticipated by graduates education mathematics (Voss et al., 2023). Collaboration between university and school in implement learning mathematics through practice in class give impact positive to improvement performance students and teachers (Polly, 2017). In Korea, teachers' efforts in develop learning media show influence significant to improvement activity student (Lee & Shin, 2023). In addition, the approach learning mathematics in school the basis in Zimbabwe becomes inspiration for other teachers For evaluate method they in convey material lesson use increase achievement student (Lee & Shin, 2023).

In the digital era, learners sued No only control technology but also has skills good social and communication . This will help they convey material in a way effective , saving time , and facilitate management activity discussion in the learning process . Miller Bernacki's study (2019) highlights importance skills Study independent in develop understanding theory mathematics that can applied in settlement problem real . Students need own ability plan , monitor , and adjust the learning process For reach objective learning optimally (Göller et al., 2024; Rosnelli & Ristiana , 2023). Teachers as facilitator class also has not quite enough answer For increase motivation student through effective verbal persuasion (Rosnelli , 2024).

Student with ability tall in apply theory integrated mathematics with ICT in life daily tend more easy adapt to various situation . Experience fun learning can increase motivation student For Keep going increase his competence in face development technology (Rosnelli et al., 2024). Students who were trained For evaluate task , make plans , using cognitive strategies , and monitor learning they show results Study more mathematics effective (El et al., 2024; Rosnelli & Ristiana , 2023). In classroom learning , teachers need utilizing learning media based on technology For Motivate students , for example through application android based which is increasingly sophisticated . Studies show that students who study with utilizing ICT has more results Good compared to with students who study use method traditional (Fathurrohman et al., 2021; Miller & Bernacki, 2019; Rosnelli , 2024). This technology platform enables personalized learning with

provide appropriate questions level difficulties , and give bait come back specific in a way direct (Göller et al., 2024).

In addition, ICT also allows student For Work in a way collaborative , sharing ideas, and solving problems problem mathematics together , so that support development skills social and communication they (Abrori et al., 2024; Weinhandl et al., 2024). Approach based on project or problem fits perfectly For prepare student face future professions , especially in mathematics applied (Charalambous & Charalambous, 2023; Dahl, 2018; Tural-Sonmez, 2023). Therefore , mathematics teachers also need to increase his knowledge and skills For support success learning student (Shriki & Patkin, 2016).

Best AR Learning Media

Best AR is a learning media designed as tool Supporter in learning mathematics . This media offers approach new through technology 21st century , allowing student explore object mathematics in 3D format build room flat like cube , block , prism and other shapes room arch like cone , cylinder , sphere. With using Best AR, students pushed For think critical , analytical and innovative moment observe object real related with lesson mathematics (Abidin et al., 2017; Aliyu et al., 2021; Amam et al., 2017).

Best AR presents materials and questions that train ability think critical and creative students . Interactive mini games are offered give experience fun and stimulating learning student For Keep going Study even outside of class hours . Students can repeat material in a way independent or cooperate with friends they in finish the problem presented through mini games (Fathurrohman et al., 2021). This creates experience interesting learning Because integration technology new in the learning process (Bray & Tangney, 2017; Cooper, 2011). Best AR applications are easy used both by teachers and students , so that become solution effective in learning mathematics . This media builds interest student For Study mathematics at a time increase ability think critical and creative they .

Figure 1. Best AR Learning Media Application

The Best AR learning media application contains about the benefits of the media For learning mathematics that can increase think critical and analytical as well as innovative . Condition the show that

learning media the is a learning media that integrates technology in learning mathematics (Hidayat, A., & Firmanti , P. (2024). Best learning media application as shown in the picture following .

Figure 2. Benefits of Best AR Learning Media

The Best AR learning media application is also available profile researchers who have create learning media For facilitate student in the learning process mathematics For grade 5 school based on one of the studio study in Kuala Lumpur Malaysia like picture following .

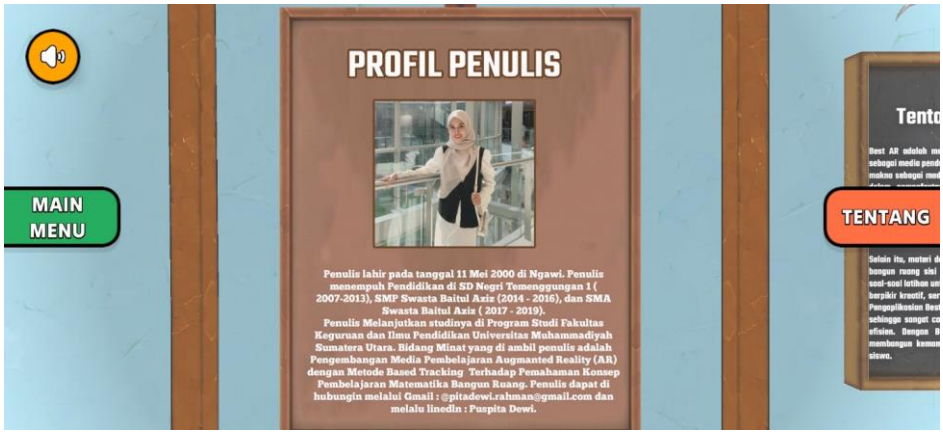

Figure 3. Profile Best AR Learning Media Creator

In the Best AR learning media application , it also provides room scope the material presented in a way detailed and detailed about 3D side material flat and side curved . Apart from that, there are also source fun learning such as mini games, interesting and fun quizzes For studied students . Conditions the directing learning student become comfortable and enjoyable that can increase skills students (Ra et al., 2019). With Thus the Best AR learning media can make it easier student For access his through directions from his teacher with material that has been in accordance with curriculum school in the learning process mathematics (Aliyu et al., 2021). The content material in Best AR apps like picture following .

Figure 4. Scope content presented in Best AR learning media

In the Best AR learning media application , it also provides room scope material about good 3D side space flat and side the curve that is presented in a way detailed and detailed, so that make it easier student For access the appropriate with material that can discussed in the learning process mathematics . Conditions the show that that Best AR app can Motivate student For increase performance mathematics use learning based on digital games (Varas-Pavez et al. 2024). The material mathematics in Best AR app can seen in the picture following .

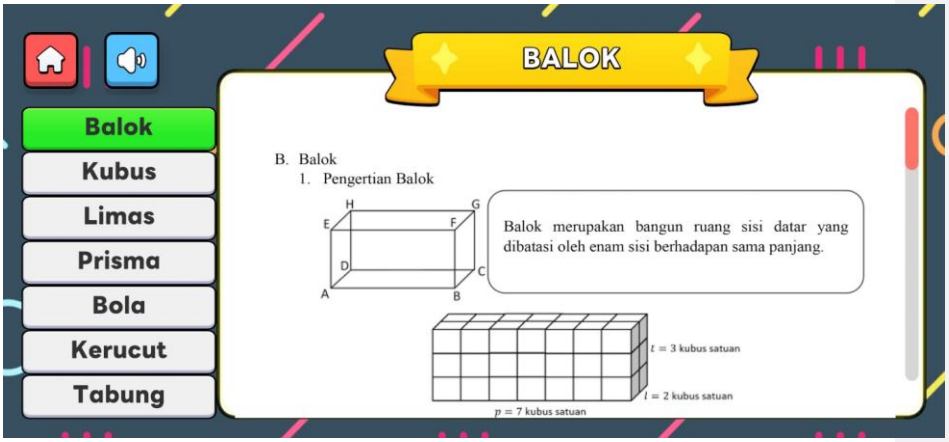

Figure 4. Scope material 3D Space Building Flat Sides and Curved Sides in Best AR

Learning Outcome Student With Leveraging Best AR Media

Learning outcomes mathematics at the level school base describe how far students succeed understand , master , and apply various draft mathematics taught based on applicable curriculum (Davenport et al., 2023). By general , results Study mathematics show level understanding student to draft base mathematics (Lee & Shin, 2023), such as operation counting , numbers , measurement , geometry , and comparison (Polly, 2017). Activities This learning is also

purposeful For develop ability think logical and analytical through settlement questions that require thinking critical , logical , and systematic (Charalambous & Charalambous, 2023; Ra et al., 2019).

Attitude positive to mathematics , such as thoroughness , curiosity knowledge , patience , and perseverance , also become part from results learning (Habibie et al., 2023; Habibi et al., 2024). Evaluation results Study usually done through test written , assignment , practice directly , or observation by the teacher, which is then shown in form mark or competencies achieved students (Mukminin 2012; Mukminin 2019). Mastery competence student to get up 3D building space room side flat like cube , cuboid , and prism as well as side arch like cones , cylinders , and spheres, can measured through a number of indicator following (Lee & Shin, 2023; Polly, 2017; Shriki & Patkin, 2016; Varas-Pavez et al., 2024; Zambak et al., 2024; Yulianti & Mukminin , 2021). They capable count with accurate and evaluative validity results calculation in accordance context question (Miller & Bernacki, 2019).

Student can use volume formula for get up room like cube , cuboid , prism , cone , cylinder , and sphere. They are also capable of to describe steps taken in the volume calculation process . They are also able to explain element important such as base, sides and height of a geometric figure room said . Conditions the show that student can explain attribute like amount side , point angles , and edges on a shape room side flat (Miller & Bernacki, 2029; Hidayat & Firmnti , 2024; Ra et al., 2019; Weinhandi et al.,2024). They are also capable of differentiate characteristics get up room side flat and side curved . With thus student can finish questions based on life real involving volume calculation or wide surface , such as count capacity tube or wide surface box . They can also to hook draft get up room with its implementation in life everyday life (Chandra & Briskey, 2012; Davenvort et al., 2023).

Improvement Best AR mastery that can increase Competence Mathematics Student .

Use of technology media in learning mathematics can contribute For increase competence students (Chandra & Briskey, 2012). Educators who are able use device technology like computer , tablet, or device interactive in teach material mathematics can facilitate students to be proficient use multimedia features , such as video tutorials, simulations interactive , and educational games , for support the learning process (Fathurrohman et al., 2021). Improvement ability student in connect theory mathematics with implementation practical through simulation technology or activity based on project contribute to the improvement think critical and analytical students (Polly, 2017; Voss et al., 2023) . Students who routinely use application Best AR learning for study and complete question mathematics , such as application can facilitate they in matter counting , drawing graph , or finish equations . Students who are able to utilise technology For analyze and solve problem complex mathematics , for example with use device soft modeling mathematics can help student develop ability think logical and systematic through visualization draft abstract (Abidin et al., 2017; Rosnelli & Ristiana , 2023).

Best AR technology media allows student more active participate in learning , for example with follow online quiz or virtual discussion based material mathematics.condition the show that student motivated more big in Study mathematics because of learning media based on technology designed interesting and interactive (Ashworth, 2003; Chandra & Briskey, 2012). Teachers who use tool evaluation based on technology For evaluate progress students , such as automatic online test , tracking time workmanship questions and analysis results evaluation can

reflect results Study students through report automatically generated by learning media (Zambak et al., 2024). The use of learning -based media technology reduce time spent for manual calculation process , so that student can focus on analysis concept . Students and teachers can access material learning When just through digital platforms, increasing flexibility in learning (Bray & Tangney, 2017; Chandra & Briskey, 2012). Students capable cooperate in project mathematics based on technology , such as 3D modeling , programming mathematics simple , or multimedia presentation about draft Mathematics . Condition the show that the teacher encourages collaboration using online platforms to share mathematical materials and ideas .

Research Methodology

research was conducted on one of the studio guidance For student school base 5th grade in Kuala Lumpur Malaysia. This research is study exploratory (Braun & Clarke, 2006). Research intended For explore new areas in learning mathematics that is learning mathematics using the BEST AR learning media created researcher For increase competence mathematics results Study student said . Condition the show that study the Not yet Lots studied . Case study The use of BEST AR learning media begins studied in September 2024 and the results study obtained in October 2024. This study uses total sample because students who study at one of the studio guidance in kuala the Malaysian mud totaling 5 people. With thus results This research can it is said worthy and valid because overall his students made into sample research . Report This research is of a nature narrative from results semi- structured interviews , and discussions as well as observation documentation results Study mathematics his students , so that information extracted become more complete and in-depth (Bryman, 2016; Clandinin & Huber, 2010). Semi- structured interviews , as well as analysis document intended For dig up data about results Study student with utilizing learning media BEST AR mathematics on one of the studio guidance in Kuala Lumpur Malaysia. When it doesn't There is outlook new from results interview and discussion with participants means saturation theoretical achieved and research considered completed (Russell & Kelly, 2002).

Data collection

Research data collected through semi- structured interview so that allow question new can submitted Again based on argument participants . Conditions the make it possible For explore perspective participants in a way more free and deep . Interviewa for each participant around 50 to 90 minutes . The questions asked to participants is as following .

1. How is it? Best AR usage for learning mathematics ?
2. How improvement understanding draft mathematics student after using Best AR learning media ?
3. How is it? improvement skills breakdown problems given by teachers to students in learning that utilizes Best AR app ?
4. What is happen improvement interaction and engagement between student in learning that implements Best AR apps in learning mathematics ?
5. How convenience learning mathematics with take advantage of Best AR?

Data analysis

Interview results about the role of BEST AR learning media for Study mathematics student grade 5 school based on one of the studio study in Kuala Lumpur Malaysia for increase competence result study mathematics audio recorded and transcribed For analyzed word by word that is expressed participants . Result data interview analyzed use analysis thematic which is qualitative data analysis For identify pattern or find theme (Braun & Clarke, 2006). Procedure data analysis begins from listen results recording interview in a way repeat . Next analyzed For produce theme through through stages form data or transcribe it with using the correct format . Then interpret data and reproduce or building data and communicating back to participants so that the data in accordance with Meaning participants . At this stage end build data credibility , so that narrative in article This scientific is appropriate with what is stated participants . All participants agree results interview use so that can ensure the data in a way accurate reflect perception participants . With thus the data has fulfil credibility and validity research (Mukminin et al., 2022). Then researcher review repeat results interview with participants so that can confirmed that that the data analyzed has in harmony with statement participants (Wald et al., 2024). The information extracted from experience participants about Utilization of BEST AR learning media for increase competence results Study mathematics student has verified its accuracy (Ashworth, 2003; Mukminin & McMahon, 2013; Yin, 2014). Finally , participants agree use of interview data For report this research .

Findings

Best AR learning media created by teachers enables student access material When anywhere and everywhere . Results of field data analysis show that draft mathematics , such as 3D objects sometimes difficult understood in a way abstract become easy for students (Bray & Tangney, 2017; Chandra & Briskey, 2012). Utilization of learning media the allows teachers to monitor development and difficulties student through analytical data , so can help teachers identify areas in need improvement and adjustment of learning strategies with need students (Amam et al., 2017). Conditions the can Motivate his students For breakdown problem or ability think logical , which must be relevant and appropriate with standard applicable competencies (Aliyu et al., 2021). Best AR learning media also has diverse source Study like exercise questions , and mini games on the application . Source This varied learning facilitates more learning interesting and comprehensive , and can applied to technology soluler so that student can learn concepts mathematics from various corner point of view (Abidin et al., 2017).

mini games and quiz applications displayed by the Best AR learning media can Motivate student For try various form or size and view change in a way directly (Chandra & Briskey, 2012; Cooper 2011). In addition, the variety of mini games displayed push student For think creative in finish question or look for the fastest and easiest way in mathematics . Media that combines gamification and challenges logic increase Power competition student in think innovative and seeking settlement unique (Charalambous & Charalambous, 2023). Best AR learning media for students can Study about draft geometry (such as get up flat , area , circumference , and volume) with method make building or to design park play . For example , students can requested designing layout class or make floor plan House in scale small (Tural-Sonmez & Erbas, 2023; Weinhandl et al., 2024).

1. How is it? Best AR usage for Learning Mathematics ?

Participant #1 explains that use of Best AR learning media in learning mathematics make they enthusiastic in learn and create understanding mathematics those who are increasingly Good in settlement task mathematics . In addition, participants to reveal that with utilizing the Best AR learning media to create they happy Study mathematics.i

> *Our teachers are passionate give guidance to us in person detailed and detailed, so that we are also excited For use application Best AR learning . Finally we can understand it and apply it For study and complete question mathematics . Best AR application can facilitate counting , drawing 3D objects for object side flat and side arch . Learning with this Best AR media yet we have ever received during learning mathematics , it turns out with best AR learning math is fun .*
>
> *(Participant #1)*

Statement Participant #2 shows that they can control use of Best AR learning media for learning mathematics . Even learning mathematics the with utilizing the Best AR learning media to become pleasant atmosphere in activity his learning .

Commented [ABS5]: ?

2. How improvement understanding draft mathematics student after using Best AR learning media ?

Participant #3 expressed that happen improvement understanding draft mathematics they after using Best AR learning media .

> *Best AR Apps in learning mathematics own feature for games so we can use it For analyze the volume of each 3D object shown in the game , so that can trigger think our critical and analytical in determine which one has more volume big , medium and small although the object shown is its form vary . We can differentiate Contents from 3D objects for side flat and side arch although the height is the same as second object the . Using this Best AR media lesson the mathematics we experience become more focus on analysis draft mathematics .*
>
> *(Participant #3)*

Statement Participant #3 shows that improvement understanding draft mathematics they through games feature on the Best AR learning media that creates think critical and analytical they increase moment finish problem the mathematics he faced .

3. How is it? improvement skills breakdown problems given by teachers to students in learning that utilizes Best AR app ?

Participant #2 expressed that happen improvement skills breakdown problems given by teachers to students in learning mathematics that utilizes Best AR app .

> *Best AR learning media always used For learning mathematics , which enables us to enthusiastic when the teacher gives the issues concerned with question mathematics facilitated in the Best AR application . We are able to finish problems raised by teachers especially For count area and content from 3D objects for side flat and side curved . It turns out settlement problem more 3D objects easy with use Best AR apps and learning become pleasant .*

(Participant #2)

Statement Participant #2 shows that settlement problem 3D objects for side flat and side arch more easy with use Best AR app so learning mathematics become more pleasant .

4. What is happen improvement interaction and engagement between student in learning that implements Best AR apps in learning mathematics ?

Participant #4 expressed that happen improvement interaction and engagement between student in learning that implements Best AR apps in learning mathematics .

> *With using the Best AR media allows us students more active participate in learning , for example with follow online quiz or virtual discussion based material mathematics given by the teacher. This makes our interest in Study together friends garden about mathematics become more big because this Best AR learning media also facilitates For Study together especially in the games section that is designed interesting and interactive .*

Statement Participant #4 shows that they more active participate in learning , virtual discussions and completing online quizzes are given by the teacher, so interest Study they For learn together friends garden become more big especially Because the existence of interesting and interactive games .

5. How Convenience Learning with take advantage of Best AR?

Participant #5 expressed that Study mathematics it turns out more easy with utilizing Best AR learning media .

> *With using learning media based on technology , initially we thought learning our mathematics becomes more difficult . It turns out after explained by the teacher detailed and detailed it turns out The use of Best AR media in learning mathematics , then his learning become more easy and more fast finish problem mathematics given by the teacher. So it reduces time Study mathematics spent for the calculation process manually . In addition we can access material learning When just through cellphone , so that become nature flexibility in Study .*

(Participant 5)

Statement Participant #5 shows that learning mathematics become easy with utilizing the Best AR learning media . In addition to settlement problem mathematics become more easy and more A little time used and they can access material learning mathematics When just through the mobile phone that creates learning mathematician mentioned become flexible .

Commented [ABS6]: In the results section, only one student's response is presented for each interview question, even though five students participated in the study. The rationale for this selective presentation is not explained.

Discussion

Commented [ABS7]: Present a balanced view by discussing not only benefits but also limitations experienced during the implementation.

Applying technology in learning mathematics requires a planned strategy in order to be able to increase effectiveness teaching and results Study students (Abidin et al., 2017). One of the right strategies in election technology For implemented in activities learning mathematics For student is with started do identification need learning (Goh et al., 2024). This is to choose

appropriate technology with the material taught , such as for example Best AR application created by math teacher For build room so that make learning more interesting thanksgiving in application the there is quiz interactive . Start with introduction technology simple , like use calculator chart or learning videos . Upgrade to use technology level continue , such as device soft modeling mathematics or programming program For Topic certain conditions (Habibi et al., 2024; Hidayat & Firmanti , 2024). Then to be continued with push student For use digital tools for presenting results project they , like presentation interactive or data visualizations they create based on settlement assignments that refer to the curriculum learning them (Mukminin et al., 2023; Ra et al., 2019).

Best AR application in it there are games for interesting students to be enthusiastic in learning mathematics . Next the teacher does attention - focused learning each individual students to happen improvement competence individual in each group (Russell & Kelly, 2002; Weinhandl et al., 2024). Learning that focuses on individuals allow student Study with speed they Alone based on ability individual . So the teacher becomes easy For give bait come back in accordance work individual (Abrori et al., 2024; Aliyu et al., 2021). In addition, it can also visualize function , graph to material presented by the teacher so that the learning is become more interesting attention students (Davenport et al., 2023; Göller et al., 2023). Direct student For use Best AR apps for learning mathematics on the device they . Condition the show that the teacher understands method integrate Best AR technology in teaching those who are visible from teacher activity provides guide or tutorial to student For utilise Best AR technology in effective in learning . Next, the teacher does evaluation to results learning mathematics (Hizon., 2024).

With the strategy that done by the teacher when learning mathematics that uses This Best AR application , can become effective tool For increase involvement students , deepen understanding concept , and develop skills mathematics 21st century . Teachers give task based on Best AR technology , such as question assisted device soft or project collaborative using digital media with utilise device technology like computer , tablet, or device hand tree in teach material mathematics (Abidin et al., 2017; Abrori et al., 2024; Bray & Tangney, 2017). Through intensive teacher guidance so student can operating learning media based on Best AR technology , such as device existing software at school For learning students (Aliyu et al., 2021). Situation the create student can proficient use Best AR learning media features such as such as video tutorials, simulations interactive , and educational games as well as completing the tests available on the Best AR application (Chandra & Briskey, 2012; Davenport., 2023; Fathurrohman et al., 2021).

Use application Best AR technology in learning mathematics can in a way significant increase understanding student to concepts mathematics , visualizing draft abstract like 3D objects side curve and side straight like cuboid , cube , pyramid , prism , sphere, cone and cylinder , because student conditioned can see change in real-time. In addition, students can Study When anywhere and everywhere , repeating material until truly understand it without limitation time class (Hidayat & Firmanti , 2024; Lebeničnik & Istenič, 2024). The Best AR application makes student more interested with merge element game in study . Students can try various scenarios , such as change parameters in chart or test formula in application , which allows exploration without risk make error large (Lee & Shin, 2023; Mukminin et al., 2019; Ra et al., 2019; Chandra & Briskey, 2012; Charalambous & Charalambous, 2023). Best AR application provides answer at a time steps settlement question , help student understand the process . The Best AR application can make

student become more proceed in matter give analysis thinking that shows strength as well as weakness them , so that teachers can direct they for areas that require it repair .

Best AR app can also Facilitate student For collaboration is possible they Work together For finish project , improve understanding through discussion and work group . Condition discuss in their group the can facilitate student For ask and discuss with Friend or teacher (Abrori et al., 2024; Amam et al., 2017; Chandra & Briskey, 2012). The Best AR application combines video tutorials, animations , and narration that can help student with various style learning (visual, auditory , or kinesthetic). The Best AR application can give experience learn more deep about 3D objects For side straight and side arch (Charalambous & Charalambous, 2023; Cooper, 2011). The Best AR application presents material with structured sequence , starting from theory base until question level continue , ensure student understand draft in a way gradually . Students can repeat the hard part in the application until they truly understand it (Dahl, 2018; Davenport et al., 2023; El Bedewy et al., 2024).

Study through Best AR app allows student Study without pressure from the teacher or Friend class , so that more focus on understanding . Conditions the can direct student For track development students , so that they can see improvement understanding they from over time (Lee & Shin, 2023; Lee & Shin, 2023 ; Miller & Bernacki, 2019). This encourages student For think logical , critical and analytical in learning (Ra et al., 2019; Rosnelli & Ristiana , 2023). In addition, teachers can use various approach For integrate technology and drive ability student in finish problem mathematics (Abidin et al., 2017; Abrori et al., 2024; Aliyu et al., 2021). Teacher strategies in use Best AR apps for visualize problem complex mathematics , such as 3D objects For object side straight and curved . Condition the can Motivate students so that they more easy understand connection intervariable 3D objects and concepts the underlying basis problem , so that increase ability they For solve problem through improvement think creativity (Bray & Tangney, 2017; Chandra & Briskey, 2012; Charalambous & Charalambous, 2023). Condition the impact on activities Study student For connect draft mathematics with application practical , which trains they in apply theory For solve problem real .

Best AR app encourages student For try various approach breakdown problem use technology For finish questions given by the teacher. Conditions the show bring student can develop pattern think explorative and critical , as well as Study from results experiment them (Abrori et al., 2024; Charalambous & Charalambous, 2023). Condition the can direct student For hone skills , communication , sharing ideas, and thinking critical in a way collective For finish problems (Dahl, 2018; El., 2024). Students can quick know error they understand steps correct solution , and improve ability they in a way sustainable (Göller et al., 2024; Hidayat & Firmanti , 2024). Conditions the make student used to with various type problems and learning implementing different strategies For complete it (El et al., 2024; Le et al., 2010). Teachers who use Best AR application integrates element game 3D objects so that can Motivate student For finish problem Because atmosphere fun and challenging learning also provides . Teachers utilize application that provides explanation step by step so that student No only know answer end , but also understand method settlement in a way systematically (Mukminin et al., 2022; Rosnelli & Ristiana , 2023).

The teacher gives problem open or based on project use technology , such as design get up 3D space with volume calculation or analysis statistics For 3D objects side straight and side arch like cuboid , cube , pyramid , prism , sphere, cone and cylinder . Students trained For think critical

, seeking solution creative , and take decision based on data (Weinhandl et al., 2024; Zambak et al., 2024). Teachers monitor progress student through analytical data from application learning , such as report results workmanship question or pattern error (Hizon et al., 2024; Lebeničnik & Istenič, 2024). Teachers can give guidance special to students who are having difficulties , so that ability breakdown problem they increase individually (Amam et al., 2017; Charalambous & Charalambous, 2023). Condition the indicates that the learning media implemented help student develop ability think logical and systematic through visualization draft abstract (Chandra & Briskey, 2012; Charalambous & Charalambous, 2023: Habibi et al., 2024; Habibi et al., 2023). Use application Best AR technology in learning mathematics can increase interaction and engagement between student in a way significant .

Improvement activity interaction between students and collaborate make student shy more brave participate through digital media because can create atmosphere competitive For student in effort improvement performance student through mutual activities Motivate For reach score best (Cooper, 2011; Davenport et al., 2023; Goh et al., 2024). Interaction between student increase when they discuss about method finish questions given by the teacher through playing strategies (Hidayat & Firmanti , 2024; Lebeničnik & Istenič, 2024; Lee & Shin, 2023). Students work together to finish task project those in the learning process value opinion friends and understanding various approach settlement problems (Charalambous & Charalambous, 2023; Dahl, 2018; Goh et al., 2024). The Best AR application allows student share notes , videos, or the graph they created with friends they . Students more active in help a friend in trouble so that happen improvement involvement Because student feel responsible answer For contribute (Miller & Bernacki, 2019; Mukminin et al., 2019; Ra et al., 2029).

Best AR application implemented by teachers becomes challenge learning in a way independent and based team , for make student Work in group . Interaction between student increase when they try finish challenge together . Students Study For share not quite enough answer and complete problem in a way collective (Miller & Bernacki, 2019; Abrori et al., 2024). Students who are less believe self in speaking in front of class can participate through feature anonymous or through applications that do not need interaction look at advance direct in do quiz so that all student feel more comfortable participate and create participation overall in class increasing (Amam et al 2017; Davenport et al., 2023). The teacher arranges competition based on team through Best AR apps that direct student For work together to answer Questions . Conditions the show that student each other support For reach objective together and visible that happen improvement Spirit cooperation and togetherness (Aliyu et al., 2021; Fathurrohman et al., 2021). The Best AR application can give bait come back direct so that student can see results Work Friend in real-time, pushing discussion For repair or increase Solution . Students more involved in evaluate and study method think Friend them (Charalambous et al., 2023; Göller et al., 2024). They feel more valued when their ideas used or discussed .

Best AR app provides facilitation question mathematics 3 dimensional objects side straight and side the curve that makes student more enthusiastic in learn , even they No feel like currently Study Because game feel fun (El., 2024; Göller et al., 2024). The Best AR application uses a combination of visuals, audio, and interactivity that can facilitate student with various style learning (visual, auditory , kinesthetic) can understand material with more good . With thus utilization Best AR application allows teachers to make evaluation automatic and get analysis results in a way directly . Condition the make teachers able to know with fast about weakness

students and adjust learning they so that can to give student feedback in accordance with his needs that can be increase performance students (Aliyu., 2021; Fathurrohman et al., 2021; Goh., 2024). The Best AR application is designed with attractive and friendly interface users , so that make student more interested Study mathematics . With that's how it was at first student consider previous mathematics considered difficult become more fun and can accessible to all student .

Conclusions and Implications

Based on data analysis results interview that condition students at one of the studio guidance studied in Kuala Lumpur Malaysia after follow the learning process mathematics with utilizing the Best AR learning media is the occurrence improvement results Study mathematics his students . This is looks from mark results Study the mathematics happen improvement become more good . The unique condition of Best AR learning media For show 3D shape objects room side flat and shape room side arch allow student For interact direct with materials , for example through simulations , quizzes , or mini games so that understanding draft mathematics become more deep For do question mathematics given by the teacher. One of The advantages of Best AR learning media are when student do question can strengthen understanding they about draft mathematics Because they Study with pleasant atmosphere . Condition the created because of they can adapt difficulty question in accordance with ability students , so that can help student Study in accordance with his abilities , which ultimately can increase competence they in mathematics with a fun way .

Best AR learning media created by teachers makes it possible student access material When anywhere and anytime . This flexibility supports Study independent and develop skills breakdown problem Because student can Study in accordance needs and speed they alone . Condition the can create motivation student in learning mathematics in the studio guidance Study The Best AR learning media that displays and visualizes form animation like condition 3D objects like cuboid , cube , pyramid , prism , sphere, cone and cylinder make student more easy For apply it to the solution problem related mathematics content in the real world . Implications his research is the Best AR learning media designed with elements gamification , so that become motivating challenge student For Keep going Study using it . Improvement this interest is very important For make student more interested learn mathematics , which is often considered difficult . In addition , the Best AR learning media is integrated with curriculum and appropriate with competence base mathematics that wants achieved so can utilized by teachers in the learning process mathematics in effort improvement competence his students .

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ENHANCING MATHEMATICAL COMPETENCE THROUGH AUGMENTED REALITY: AN EXPLORATORY STUDY USING BEST AR IN GEOMETRY LEARNING

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ABSTRACT The integration of digital technology in mathematics education holds immense potential to transform abstract concepts into concrete experiences. This study explores the impact of an Augmented Reality (AR)-based learning application, *Best AR*, on enhancing the mathematical competence of fifth-grade students in Malaysia. Conducted in a tutoring center using an exploratory qualitative approach, the research investigates how the interactive features of *Best AR*—including 3D object simulations, mini-games, and quizzes—support conceptual understanding, engagement, and problem-solving skills, particularly in learning three-dimensional geometry. Data were collected through interviews, observations, and documentation, and analyzed thematically. The findings reveal that *Best AR* improved students' ability to visualize and manipulate geometric objects, fostered collaboration, increased motivation, and enhanced logical reasoning. The application's mobile accessibility and adaptive feedback promoted self-regulated learning, while its gamified elements made mathematics more engaging and enjoyable. Despite challenges in device access and teacher preparedness, the study underscores the potential of AR to bridge gaps in technology integration and enrich mathematics instruction. Implications for curriculum alignment, teacher training, and scalable adoption of AR media in informal learning contexts are discussed.

Keywords: augmented reality, mathematical competence, geometry learning, gamification, educational technology

ABSTRAK Integrasi teknologi digital dalam pendidikan matematika memiliki potensi besar untuk mentransformasi konsep-konsep abstrak menjadi pengalaman belajar yang konkret. Penelitian ini bertujuan untuk mengeksplorasi pengaruh media pembelajaran berbasis Augmented Reality (AR) bernama *Best AR* terhadap peningkatan kompetensi matematis siswa kelas V di Malaysia. Studi ini dilaksanakan di sebuah pusat bimbingan belajar dengan pendekatan kualitatif eksploratif, untuk menelusuri bagaimana fitur interaktif *Best AR*—seperti simulasi objek 3D, mini-games, dan kuis—mendukung pemahaman konsep, keterlibatan, dan keterampilan pemecahan masalah, khususnya dalam pembelajaran geometri bangun ruang. Data dikumpulkan melalui wawancara, observasi, dan dokumentasi hasil belajar, kemudian dianalisis secara tematik. Temuan menunjukkan bahwa *Best AR*

meningkatkan kemampuan siswa dalam memvisualisasikan dan memanipulasi objek geometri, mendorong kolaborasi, meningkatkan motivasi, serta memperkuat penalaran logis. Aksesibilitas aplikasi melalui perangkat seluler dan fitur umpan balik adaptif mendukung pembelajaran mandiri, sementara elemen gamifikasi membuat pembelajaran matematika lebih menarik dan menyenangkan. Meskipun terdapat tantangan seperti keterbatasan perangkat dan kesiapan guru, studi ini menegaskan potensi AR dalam menjembatani kesenjangan integrasi teknologi dan memperkaya pembelajaran matematika. Implikasi bagi keselarasan kurikulum, pelatihan guru, dan adopsi media AR secara luas dalam konteks pembelajaran informal turut dibahas.

Kata-kata kunci: augmented reality, kompetensi matematis, pembelajaran geometri, gamifikasi, teknologi pendidikan

INTRODUCTION

The integration of technology in mathematics education has become increasingly important in the digital era. It enhances the flexibility and accessibility of learning, allowing students to study at their own pace, anytime and anywhere (Elfrianto & Tanjung, 2022; Hidayat & Firmanti, 2024). Moreover, the advancement of digital technologies requires students to continuously adapt to new tools and environments, placing demands on education systems to evolve accordingly (Rosnelli et al., 2024; Tanjung et al., 2023).

Internationally, various countries have demonstrated how technology improves mathematics teaching and learning. In South Africa, the mathematics curriculum has been aligned with science and technology to strengthen formal education and improve teacher competencies (Le, 2010). In Australia, the use of ICT in mathematics classrooms has made students more proactive, helping to overcome barriers to learning (Voss et al., 2023). In Singapore, technology integration has been linked to improved student performance (Goh et al., 2024). Similarly, in Korea and Zimbabwe, teachers' innovations in instructional media have significantly influenced student engagement and achievement (Lee & Shin, 2023; Polly, 2017).

Beyond technical mastery, digital-age learners are also expected to develop social and communication skills that allow them to engage actively in class. These competencies help students present content, manage their time, and collaborate effectively. Miller and Bernacki (2019) emphasize that self-regulated learning is key to developing a theoretical understanding of mathematics applicable to real-world contexts. Students must be able to plan, monitor, and evaluate their learning processes to achieve optimal results (Göller et al., 2024; Rosnelli & Ristiana, 2023). However, motivating students through verbal instruction alone remains a challenge (Rosnelli, 2024).

Research has shown that enjoyable, engaging experiences—particularly when supported by gamification and ICT—can foster motivation and deepen mathematical understanding (Rosnelli et al., 2024). Students trained to evaluate tasks, set goals, apply cognitive strategies, and reflect on their progress tend to perform better (El et al., 2024; Rosnelli & Ristiana, 2023). ICT tools provide

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personalized learning by offering differentiated questions and real-time feedback (Göller et al., 2024), and have been shown to improve outcomes compared to conventional instruction (Fathurrohman et al., 2021; Miller & Bernacki, 2019). They also promote collaboration and shared problem-solving experiences (Abrori et al., 2024; Weinhandl et al., 2024), and are highly compatible with project- and problem-based learning models (Charalambous & Charalambous, 2023; Dahl, 2018; Tural-Sonmez, 2023).

In Malaysia, despite efforts to enhance digital competencies in education (Chia & Zhang, 2023; Shanmugam et al., 2024), observations conducted at a tutoring center in Kepong revealed that mathematics teaching remains largely manual, with minimal integration of digital learning tools. This gap between technological potential and actual classroom practices underscores the need for accessible and engaging digital learning media.

To address this issue, the researcher developed an Augmented Reality (AR)-based learning media called "Best AR", designed to strengthen students' mathematical competence through interactive, visually rich, and adaptive features (Davenport et al., 2023). Best AR enables students to explore three-dimensional geometric objects such as cubes, cuboids, prisms, cones, cylinders, and spheres, supporting deep conceptual understanding through manipulation and visual engagement.

Figure 1. Best AR Learning Media Application

The media includes a range of interactive features, such as mini-games, simulations, and quizzes that align with curricular content and allow students to adjust the level of difficulty based on their abilities. These features also offer real-time feedback, facilitating self-directed learning and collaboration.

Best AR supports students in mastering key mathematical skills, particularly in geometry topics related to three-dimensional shapes. Learning outcomes include the ability to accurately apply volume formulas, interpret and describe geometrical elements such as faces, edges, and vertices, and relate abstract mathematical concepts to real-life contexts such as calculating surface area or capacity (Miller & Bernacki, 2019; Polly, 2017; Shriki & Patkin, 2016; Yulianti & Mukminin, 2021).

Students using Best AR demonstrate increased motivation and confidence in tackling complex mathematical problems, supported by digital simulations and game-based experiences (Ra et al., 2019; Varas-Pavez et al., 2024). The interactive media environment enables learners to collaborate through digital platforms, visualize mathematical ideas, and engage in critical and analytical thinking (Abidin et al., 2017; Rosnelli & Ristiana, 2023).

Moreover, the integration of Best AR promotes improvement in students' logical reasoning, accuracy in mathematical operations, and problem-solving abilities. It offers a dynamic alternative to traditional methods by reducing time spent on routine calculation and allowing more focus on higher-order skills. Teachers also benefit from features such as automatic feedback and performance tracking tools (Zambak et al., 2024), supporting more efficient evaluation and individualized instruction.

Figure 4. Scope content presented in Best AR learning media

Moreover, the integration of Best AR promotes improvement in students' logical reasoning, accuracy in mathematical operations, and problem-solving abilities. It offers a dynamic alternative to traditional methods by reducing time spent on routine calculation and allowing more focus on higher-order skills. Teachers also benefit from features such as automatic feedback and performance tracking tools (Zambak et al., 2024) supporting more efficient evaluation and individualized instruction. Therefore, this study aims to explore students' perceptions of the Best AR learning media and to examine how its use influences their mathematical competence. Specifically, it investigates students' experiences with the Best AR application and the extent to which the media contributes to the development of their mathematical competence.

METHODS

This research was conducted at a tutoring center for fifth-grade elementary school students located in Kuala Lumpur, Malaysia. The study employed an exploratory qualitative design (Braun & Clarke, 2006), aiming to investigate students'

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experiences in learning mathematics using the Best AR learning media developed by the researcher. The purpose of this study is to explore how this media enhances students' mathematical competence, particularly in a context where technology integration in tutoring practices remains limited. The study is considered novel due to the limited number of similar investigations in the field, especially involving the use of augmented reality in informal learning settings.

The implementation of the Best AR learning media took place in September 2024, and data collection was completed in October 2024. The participants included all five students enrolled at the tutoring center, selected using a total sampling technique. Given that the entire student population was included, the findings are considered valid and representative of the setting. Data were collected through semi-structured interviews, informal discussions, observation notes, and documentation of students' mathematics learning outcomes. This triangulation strategy ensured that the data obtained were rich, complete, and deeply reflective of the students' experiences (Bryman, 2016; Clandinin & Huber, 2010).

Semi-structured interviews were chosen to allow flexibility in exploring participants' responses and to uncover emerging themes. Each interview lasted approximately 50 to 90 minutes and was designed to elicit in-depth information regarding the use of the BEST AR media in mathematics learning. The guiding questions used during the interviews included:

1. How do students describe their experiences in using the Best AR application during mathematics learning?
2. To what extent does the Best AR media enhance students' understanding of mathematical concepts?
3. How does the Best AR media support the development of students' problem-solving skills in mathematics?
4. In what ways does the use of Best AR promote interaction and engagement among students during mathematics learning? And
5. How do students perceive the convenience and overall usability of the BEST AR learning media in learning mathematics?

These questions were adapted throughout the interview process to follow up on participants' unique perspectives and experiences. When no new insights were emerging during the data collection process, theoretical saturation was considered to have been reached (Russell & Kelly, 2002).

All interview data were audio-recorded and transcribed verbatim. Thematic analysis, as described by Braun and Clarke (2006), was employed to identify recurring patterns and themes in the data. The process began with repeated listening to the recordings, followed by careful transcription, initial coding, and theme development. The researcher interpreted and reconstructed the data based on emerging meanings and confirmed interpretations with each participant to ensure representational accuracy. This member-checking process supported the credibility

of the findings (Mukminin et al., 2022). In addition, the researcher conducted follow-up reviews with participants to validate that the analysis accurately reflected their intended meanings (Wald et al., 2024). The accuracy of the information extracted from participants' experiences in using the Best AR media for mathematics learning was verified through reflective dialogue and mutual agreement (Ashworth, 2003; Mukminin & McMahon, 2013; Yin, 2014). All participants gave their informed consent to use their interview data in this study.

FINDING AND DISCUSSION

The implementation of the Best AR learning media allowed students to access mathematics materials anytime and anywhere, thereby enhancing learning flexibility. Field observations and interview data revealed that abstract mathematical concepts—especially those involving three-dimensional objects—became easier to understand through interactive visualizations (Bray & Tangney, 2017; Chandra & Briskey, 2012). The application also provided teachers with analytical data to monitor student progress and identify areas requiring instructional adjustment (Amam et al., 2017). This supported students in developing logical reasoning and problem-solving abilities in accordance with established learning competencies (Aliyu et al., 2021). Moreover, the presence of diverse learning resources such as exercises, quizzes, and mini-games made the learning process more engaging and comprehensive. Since the application can be accessed via mobile technology, students were able to explore mathematical concepts from various perspectives (Abidin et al., 2017).

Mini-games and quiz features embedded in the Best AR application encouraged students to experiment with different shapes and sizes and observe changes interactively (Chandra & Briskey, 2012; Cooper, 2011). These features also stimulated creative thinking by challenging students to find efficient solutions in a gamified environment. The integration of gamification and logic-based challenges promoted healthy competition and motivated students to develop innovative thinking strategies (Charalambous & Charalambous, 2023). For example, students learned geometry by designing virtual objects, creating classroom layouts, or developing scaled floor plans—activities that helped connect abstract geometry with real-life applications (Tural-Sonmez & Erbas, 2023; Weinhandl et al., 2024).

One participant stated that learning with Best AR made them more enthusiastic and improved their understanding of mathematical concepts. According to the student, the teacher's detailed guidance enhanced their ability to use the application, which in turn facilitated comprehension and enjoyment in solving mathematics problems. They also emphasized that the application supported visualization and calculation, especially when working with flat and curved 3D shapes. This experience marked a shift from traditional methods, demonstrating that learning mathematics could be both effective and enjoyable.

Another student explained that their conceptual understanding improved after using the AR-based mini-games to compare the volume of 3D objects. By analyzing

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differences between shapes with similar heights but varying dimensions, students reported becoming more focused on mathematical analysis and more critical in problem solving. This aligns with the goal of promoting higher-order thinking through visual and interactive learning tasks.

Regarding problem-solving skills, one student noted that the use of Best AR helped them become more motivated when responding to teacher-given tasks. They mentioned being able to solve volume and surface area problems more easily, particularly for both flat and curved 3D objects. The interactive nature of the application made mathematics feel more approachable and engaging.

Improvements were also seen in student interaction and engagement. A participant highlighted that the application's quiz and collaborative features encouraged active participation during virtual discussions and joint activities. The social dimension of gamified learning led students to enjoy studying mathematics together, which fostered a stronger sense of academic collaboration and peer support.

Another student emphasized that using Best AR made mathematics feel easier and faster to complete. Although initially skeptical about technology-based learning, they found the application intuitive and efficient after the teacher's explanation. They appreciated that the application reduced the time needed for manual calculations and allowed on-demand access to learning materials via mobile phones. This flexibility significantly contributed to a more positive learning experience and increased confidence in mathematics.

Overall, the results indicate that Best AR supported the development of mathematical competence by improving students' understanding of concepts, fostering problem-solving abilities, promoting engagement, and enabling more flexible and enjoyable learning experiences. These findings reinforce the potential of augmented reality to transform mathematics education through interactivity, gamification, and mobile accessibility.

The integration of technology in mathematics education requires strategic planning to ensure effective instruction and improved learning outcomes (Abidin et al., 2017). A critical factor in technology selection is the alignment of digital tools with students' learning needs and curricular objectives (Goh et al., 2024). In this study, the use of the Best AR application—designed specifically to support the teaching of three-dimensional geometric concepts—demonstrated how interactive and visually rich tools can increase engagement through built-in mini-games and quizzes. These features allowed students to visualize abstract ideas such as volume and surface area, thereby improving conceptual understanding.

Initial technology exposure through calculators and instructional videos may serve as a foundation for integrating more advanced applications such as mathematical modeling software and AR-based simulations (Habibi et al., 2024; Hidayat & Firmanti, 2024). In the current study, students utilized Best AR to explore geometric properties, manipulate 3D objects, and engage in interactive problem-solving

activities. The results confirmed that students not only gained access to dynamic representations of geometric figures but were also motivated to complete tasks and share ideas with peers, consistent with the findings of Mukminin et al. (2023) and Ra et al. (2019).

The incorporation of gamification in Best AR proved particularly effective in capturing student attention and enhancing enthusiasm toward mathematics. This aligns with the learner-centered approach, where instructional delivery is personalized to accommodate diverse learning styles (Russell & Kelly, 2002; Weinhandl et al., 2024). Gamified learning tasks enabled students to progress at their own pace while receiving timely feedback, which improved retention and self-regulation (Abrori et al., 2024; Aliyu et al., 2021). Moreover, the application's 3D visualizations helped demystify abstract content, supporting findings by Davenport et al. (2023) and Göller et al. (2023).

Teacher guidance remained essential during implementation. Students relied on instructional support to navigate application features, such as video tutorials and simulations, before independently solving geometry-based problems (Chandra & Briskey, 2012; Fathurrohman et al., 2021). The application's step-by-step feedback and real-time rendering of geometric solids—cubes, pyramids, spheres, cones, and cylinders—facilitated a flexible, mobile learning experience beyond the classroom environment (Hidayat & Firmanti, 2024; Lebeničnik & Istenic, 2024).

The study also highlighted Best AR's role in enhancing collaborative learning. Through shared tasks and group projects, students exchanged ideas and problem-solving strategies, reinforcing peer learning (Amam et al., 2017; Abrori et al., 2024). This collaborative dimension was further strengthened by narrative animations and interactive features that supported visual, auditory, and kinesthetic learning styles (Charalambous & Charalambous, 2023; El Bedewy et al., 2024). Teachers facilitated this process by guiding students in team-based assignments and encouraging equitable participation, even among more reserved learners (Cooper, 2011; Davenport et al., 2023).

The Best AR application also contributed to students' cognitive development. By engaging in low-pressure, exploratory environments, students practiced monitoring their progress and applying logical, critical, and analytical thinking (Lee & Shin, 2023; Miller & Bernacki, 2019; Rosnelli & Ristiana, 2023). Visualizing complex mathematical problems fostered innovation and deeper conceptual connections, consistent with the findings of Bray & Tangney (2017) and Chandra & Briskey (2012). Additionally, the use of project-based learning tasks—such as designing scaled floor plans or modeling 3D parks—encouraged students to make data-driven decisions and reflect on real-world applications of mathematics (Weinhandl et al., 2024; Zambak et al., 2024).

Despite these benefits, challenges in implementing Best AR were also observed. Limited access to digital devices and internet connectivity posed barriers to

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consistent use. Some students required substantial guidance to operate the app effectively, and not all teachers were fully equipped to integrate AR technology without additional training. These findings underscore the importance of adequate infrastructure, digital literacy, and sustained professional development for successful implementation.

Nevertheless, Best AR demonstrated its potential to promote student agency and experimentation. Teachers used gamification and structured feedback to support independent learning while monitoring performance data to provide targeted support (Mukminin et al., 2022; Rosnelli & Ristiana, 2023). The app's analytical tools allowed teachers to track progress, identify misconceptions, and intervene when necessary (Charalambous & Charalambous, 2023; Amam et al., 2017).

By encouraging active participation through competition, quizzes, and collaborative design challenges, Best AR helped transform mathematics into an accessible and enjoyable subject. The application's user-friendly interface and adaptive features supported diverse learners, reinforcing the notion that technology, when thoughtfully integrated, can bridge the gap between abstract content and meaningful student experiences.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings, the use of Best AR learning media significantly enhanced students' mathematical competence, particularly in understanding three-dimensional objects. The application enabled students to visualize abstract geometric shapes—such as cubes, prisms, cones, and spheres—through simulations, animations, quizzes, and mini-games. These features supported deeper conceptual understanding and allowed students to engage actively in solving mathematics problems presented by the teacher. The learning atmosphere became more enjoyable, enabling students to adapt to various levels of question difficulty based on their individual abilities.

The flexibility of Best AR, which allows students to access learning materials anytime and anywhere via mobile devices, contributed to increased autonomy and motivation. Students could study at their own pace, which helped develop their problem-solving skills and fostered a more personalized learning experience. The application's integration with gamified elements further stimulated students' interest and motivation to explore mathematical content.

This research implies that well-designed AR-based learning media, when aligned with the curriculum and mathematical competence standards, can support teachers in delivering more engaging and effective mathematics instruction. Moreover, the Best AR app demonstrates potential as a scalable learning tool that addresses both cognitive and affective domains in mathematics education. Its use can help overcome students' negative perceptions of mathematics by making the subject more accessible, interactive, and enjoyable.

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