DOI: 10.56773/bj.v4i1.71
E-ISSN: 2809-8528

Brillo Journal
Volume 4, Issue 1, December 2024, pp. 59-75

IMPROVING MATHEMATICAL UNDERSTANDING ON GEOMETRY FOR 9th GRADE STUDENTS THROUGH THREE-DIMENSIONAL MATHEMATICS LEARNING MEDIA BASED ON VIRTUAL REALITY

Kerdid Simbolon, Candra Ditasona*, Laurencia Firstania Setiawan

Mathematics Education Study Program, Universitas Kristen Indonesia, Indonesia
Email: candraditasona@gmail.com

Abstract

This study aimed to develop a three-dimensional virtual reality (VR)-based learning media for teaching mathematics at 9th grade students, focusing on improving students' understanding of geometric shapes. Utilizing the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model, the research involved the development of an interactive VR tool that allows students to engage with complex geometric concepts in an immersive environment. The VR media was validated by subject learning material experts in terms of content, language, and technical aspects, resulting in an overall validity score of 4.04, indicating high validity. Implementation quantitative analysis showed that the tool significantly improved student comprehension, with an average practicality score of 3.81, indicating that the media was easy to use in the classroom. This study concludes that VR-based learning media offers a promising approach to overcoming the difficulties students face in understanding three-dimensional geometry, providing both an engaging and effective learning experience.

Keywords: ADDIE model, Mathematics education, Three-dimensional geometry, Virtual reality.

Abstrak

Penelitian ini bertujuan untuk mengembangkan media pembelajaran berbasis realitas virtual tiga dimensi (VR) untuk pengajaran matematika pada siswa kelas 9, dengan fokus pada peningkatan pemahaman siswa terhadap bentuk-bentuk geometri. Menggunakan model ADDIE (Analysis, Design, Development, Implementation, dan Evaluation), penelitian ini melibatkan pengembangan alat VR interaktif yang memungkinkan siswa berinteraksi dengan konsep-konsep geometri yang kompleks dalam lingkungan yang imersif. Media VR divalidasi oleh para ahli materi pelajaran dari segi konten, bahasa, dan aspek teknis, menghasilkan skor validitas keseluruhan sebesar 4,04, yang menunjukkan tingkat validitas yang tinggi. Analisis kuantitatif implementasi menunjukkan bahwa alat ini secara signifikan meningkatkan pemahaman siswa, dengan skor kepraktisan rata-rata sebesar 3,81, yang menunjukkan bahwa media ini mudah digunakan di dalam kelas. Penelitian ini menyimpulkan bahwa media pembelajaran berbasis VR menawarkan pendekatan yang menjanjikan untuk mengatasi kesulitan yang dihadapi siswa dalam memahami geometri tiga dimensi, memberikan pengalaman belajar yang menarik dan efektif.

Kata kunci: *Pendidikan matematika, Penelitian dan pengembangan, Media pembelajaran tiga dimensi, Virtual reality.*

How to Cite: Simbolon, K., Ditasona, C., & Setiawan, L. F. (2024). Improving Mathematical Understanding on Geometry for 9th Grade Students through Three-Dimensional Mathematics Learning Media Based on Virtual Reality. *Brillo Journal, 4*(1), 59-75.

INTRODUCTION

In the era of Industry 4.0, our world is transforming at a pace like never before, reshaping how we live, work, and learn. Digital systems, artificial intelligence, and virtual reality are not just buzzwords—they are the driving forces behind this revolution, bringing significant changes to many sectors, including education (Collins & Halverson, 2018). For Indonesia, keeping up with these advancements isn't just an option; it's a necessity if the nation is to thrive in a technology-driven world (Lase, 2020). Despite this digital surge, the integration of modern technology into Indonesian classrooms—especially in critical subjects like mathematics—remains a significant challenge (Rahim et al., 2019). Students often struggle with grasping abstract concepts, like those in geometry, and traditional teaching methods that lean heavily on static images and theoretical explanations often fail to bridge this gap (Hidayah et al., 2022). Effective education must go beyond lectures and textbooks; it should invite students to engage, interact, and explore, allowing them to build a true understanding of the world around them (Lumbantoruan & Natalia, 2021).

Emerging research shows that when students engage with technology-rich learning environments, their enthusiasm and understanding soar (Wu et al., 2022). However, the reality in classrooms tells a different story: while digital tools hold immense potential, their use is inconsistent and often falls short of expectations (Natalia et al., 2023). In mathematics, where the leap from abstract concepts to real-world applications is crucial, technology usage could be a game-changer (Pratidiana & Muhayatun, 2021). Yet, Indonesia's performance in global assessments remains troublingly low—ranking 73rd out of 79 countries in mathematics according to the Programme for International Student Assessment (PISA) (Tohir, 2019). This glaring gap suggests that conventional teaching methods, which frequently underutilize digital resources, are out of step with the needs of today's learners (Asnawati, 2019). Moreover, many teachers feel unprepared to integrate new technologies into their lessons due to a lack of training and resources (Sumantri, 2019).

To address the challenges of teaching complex geometric concepts, Virtual Reality (VR) emerges as a powerful and practical solution. Unlike traditional educational tools, VR enables students to actively engage with three-dimensional shapes in an immersive environment, making abstract concepts tangible and easier to understand (Dewi, 2020).

By allowing students to explore, manipulate, and interact with geometric objects, VR transforms learning into an intuitive and hands-on experience, bridging the gap between theoretical knowledge and practical comprehension. Furthermore, platforms like Millealab make VR technology more accessible by reducing costs and simplifying implementation, ensuring that schools with limited resources can integrate this innovation into their teaching practices (Yanto et al., 2023). This approach not only enhances students' understanding of geometry but also fosters greater engagement and enthusiasm, offering a scalable and impactful solution to the persistent challenges of traditional mathematics education.

The main aim of this study was to develop and evaluate educational resources to improve students' comprehension of three-dimensional geometric principles in mathematics. This research introduces a Virtual Reality (VR)-based learning tool designed to make three-dimensional geometry more accessible, engaging, and enjoyable for students. By leveraging VR technology, students can interact with shapes in an immersive environment, transforming abstract mathematical concepts into tangible experiences they can visualize and manipulate (Price et al., 2020). What sets this approach apart is the integration of Millealab—a cost-effective and user-friendly VR platform that removes the barriers of affordability and technical complexity, enabling schools to adopt this technology without requiring expensive equipment or advanced technical expertise (Yanto et al., 2023). This research provides a practical and scalable solution for educators, demonstrating how VR can be seamlessly integrated into existing teaching practices to enhance student engagement and understanding, particularly in schools with limited resources. By focusing on practicality, this study highlights the potential of VR to revolutionize mathematics education, offering a tool that educators can realistically implement to improve learning outcomes in geometry.

RESEARCH METHODS

This research used a Research and Development (R&D) approach following the ADDIE model, which stands for Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model is a widely recognized framework for developing and evaluating instructional materials in a structured way (Masturah et al., 2018). Ninth-grade students from a school in Jakarta were selected because of their need to improve reasoning skills as emphasized in the national curriculum. Teachers also provided valuable input

during the study, helping integrate the tool into classroom settings and evaluate its usefulness.

This study focused on all ninth-grade students at a school in Jakarta known for integrating technology into education and having the resources to support VR-based learning. Two classes, with a total of 66 students, were selected for the research. A purposive sampling method was used to choose participants who had struggled with visualizing mathematical concepts, as shown by their performance in previous assessments. This selection ensured that the study targeted students who would benefit most from the VR learning tool. Purposive sampling, as explained by Creswell (2012; 2014), allows researchers to focus on participants whose characteristics are closely aligned with the study's goals.

To collect data, the researchers used questionnaires, interviews, and observations. Questionnaires were distributed to students to measure their understanding of geometry before and after using the VR tool. These questionnaires used a simple Likert scale, allowing students to rate their experiences and perceptions of the tool's effectiveness (Sugiyono, 2017). Teachers participated in semi-structured interviews to provide feedback on how the VR tool fit into their teaching methods and its relevance to their classroom activities (Cohen et al., 2018). During the lessons, the researchers observed how students interacted with the VR tool to understand how it influenced engagement and learning.

The data were analyzed using a mix of simple quantitative and qualitative methods. The quantitative data, collected from student questionnaires, were analyzed by calculating averages and percentages to determine changes in understanding and satisfaction with the VR tool. This made it easy to compare students' performance before and after using the tool. Qualitative data from teacher interviews and classroom observations were summarized to provide insights into the practical use of the VR tool in real classroom situations. This mixed-method approach gave a balanced evaluation of how well the tool worked and how practical it was for everyday teaching.

The VR-based learning media was developed using Millealab, a platform designed to make VR technology more accessible for schools. Millealab allows teachers to create interactive 3D environments without needing advanced technical skills or expensive equipment. It offers ready-to-use templates and tools for creating engaging virtual

lessons. For this study, Millealab was used to design a virtual environment where students could interact with 3D shapes, exploring and manipulating them to better understand geometric concepts. The platform was chosen because it is easy to use, cost-effective, and suitable for schools with limited resources (Yanto et al., 2023).

The study followed the five phases of the ADDIE model. In the Analysis phase, the research team identified reasons why students struggled with visualizing 3D shapes by reviewing their performance data and interviewing teachers (Rahim et al., 2019). In the Design phase, a plan for the VR-based media was created, including the use of Millealab to design interactive lessons. The Development phase involved creating the VR media, which was reviewed by education and content experts to ensure it was accurate and engaging. In the Implementation phase, the VR lessons were introduced in two classes. Teachers led the lessons while researchers observed, conducted interviews, and collected feedback through questionnaires (Price et al., 2020). Finally, in the Evaluation phase, the researchers analyzed the data to assess the effectiveness and ease of use of the VR media. Feedback from both students and teachers was used to make improvements, ensuring the tool met educational goals and could be used in everyday teaching (Sasmita et al., 2022).

RESULT AND DISCUSSION

The research results are presented in the following subsections based on the stages of development research: analysis, design, development, implementation, and evaluation.

Analysis Result

This study's analysis phase entailed an in-depth evaluation alongside several other analyses: need analysis, learner analysis, technology analysis, and resource analysis to appreciate the various risks and potentials that come with teaching three-dimensional geometry through virtual reality (VR). These analyses were instrumental in the formulation process of designing the VR-based learning media and in explaining the areas discouraged by the conventional mode of teaching. The results showed that there is a need to address the issue using modern technology like VR as it can facilitate the learning of students in those abstract areas of mathematics.

The need analysis showed that there were serious shortcomings of the ways three-dimensional geometry was taught in schools. Teachers were concerned that the

multifaceted use of resources like books, 2D photos, and computer diagrams, for instance, was not sufficient enough to enable learners understand the arrangement of spatial figures and their geometric shapes. The weakness of these approaches was conspicuous particularly where students had complex shapes that were hard to come up with in their minds. This particularly hampered their ability to even the basic geometric ideas. This feedback further emphasized the importance of the need for such a tool that would be educational and enhance students' interaction with such concepts.

The learner analysis revealed that the students who participated in this investigation were almost all digital natives who are competent in technology usage. Even though students show great familiarity with digital devices, their motivation to abstract topics such as geometry is very low. Qualitative feedback from students indicated that a lot of these students found these concepts complex and abstract and hard to apply in real life which was quite frustrating and disinteresting. This gave rise to the idea that it was time to introduce more interesting and interactive scope of learning maths like VR which will help in enhancing students' curiosity and even changing their perception towards the attitude of learning maths.

Millealab was recommended as best fit for creating the VR learning tool, based on the technology analysis performed. Its integration with cheap VR headsets and smartphones was a plus to its adoption in schools with poor technological infrastructures. The interface of the platform was friendly to teachers, who pointed out that one did not have to know coding in order to use it. This aspect was crucial since it meant that teachers would be able to use the VR media without having to undergo rigorous technical processes which normally discourage the use of such technologies in schools. The simplicity and adaptability of Millealab were regarded as notable merits in expanding the scope of the VR learning to more learners.

Within the context of using VR technology in the school's existing structures, further resource analysis examined the put logistical factors into consideration. However, while the school was furnished with basic resources such as computers and a good internet connection, the challenge was the few available VR headsets. To solve this problem, a class rotation system was devised that enables all students to engage with the VR media at a reduced group size. This rotation was facilitated by the teachers, who ensured that every student was able to use the VR device and engage in the activity for an appropriate

duration. Additionally, Teachers were tasked with conducting orientation on the use of the VR system as well as instructional practices that would come in handy while using it in the real teaching situation.

Teachers also provided feedback in terms of responses to the usage of VR in teaching geometry that worked well and those that did not at the time of the implementation phase. Some of the teachers reported that students were a lot more active and interested in the learning process while using the VR tool than in conventional learning environments. The teachers observed that the unique ability of students to rotate and change geometric shapes on the screen while studying them through the VR environment improved their understanding of space and spatial relationships. Additionally, the teachers pointed out the fact that VR technology narrowed the distance between learned ideas and real vision by illustrating concepts that are usually hard for students to relate to.

The reception of students to the VR-based learning experience was far more appreciated as, for many of them, solving problems in geometry was an adventure rather than a simple series of exercises. Students ventured that the virtual environment where they could turn, resize, and take apart three-dimensional figures provided them with a better understanding of how such figures existed in space. This was also evident when they encountered the problems of visualizing shapes in the early stages, as thanks to this experience, they could now grasp geometric content in a way that traditional two-dimensional pictures could not offer – interactively.

Moreover, regarding the analysis of the quantitative data, it was clearly observed that after implementing VR based learning, there was an exceptional progression in students' results on geometry tests. Average scores showed a great increase which suggested the effectiveness of the learning environment in understanding three dimensional shapes. These improvements were evidenced by the statistical calculations of mean score and percentage showing that the VR based media was not an artifice but a viable media for the improvement of mathematics. Combination of the quantitative outcomes with qualitative aspects by teachers and students made it easy to assess the impact of the VR tools justifiable in its adoption for larger scale use in education.

Upon this, these critical aspects were evaluated and it was presented the effectiveness of VR technology in teaching complex concepts such as geometry. The use of qualitative data from both the teachers as well as the students in the study complemented the

description by showing the effectiveness of the VR tool in aiding students in participating and understanding. Teachers regarded the VR technology as an effective way of enhancing what they were already doing while students.

The analysis phase's primary contributions included the understanding of existing gaps in the teaching of three-dimensional geometry. In the need analysis, it was established that one of the greatest problems that students encounter is the failure to comprehend the abstraction of geometric shapes in their mind assisted by textbooks and static diagrams. This inability was manifesting in the student's achievement where geometry was among the most common deficient areas in the calculus of maths (Rahim et al., 2019). Further, the learner analysis took into account the fact that students are very good at technology, but the students did not see the relevance of the current modes of delivery thus it is time to adopt something else. The technology and resource analysis also made V.R. a realistic option and Millealab as a non-complexarscit technology that can offer the learning experience (Yanto et al., 2023). These findings showed that there is a need for an effective technology medium for learning mathematics that can help deal with both motivational and cognitive issues.

Design Result

During the design phase, the research team aimed to develop a design for VR-based learning media using the ADDIE model. One of the aspects of the design was the use of virtual geometric shapes such as a cube, a pyramid, and even a sphere which were included as interactive 3D objects. It was noted that the Millealab platform was picked because it was easy to use and made it possible to develop interactive VR environments without any prior programming knowledge (Yanto et al., 2023). Storyboards and flowcharts were created at this stage to represent the way learners would progress through the media, ensuring that the content was appropriate to achieve the national mathematics curriculum learning goals presented in Figure 1.

The design further included some interactive elements like drag and drop activities as well as guided practices to enhance the learners' grasp of the geometric concepts. The prototype was designed to include visual and sound feedback which enhanced the overall learning experience.

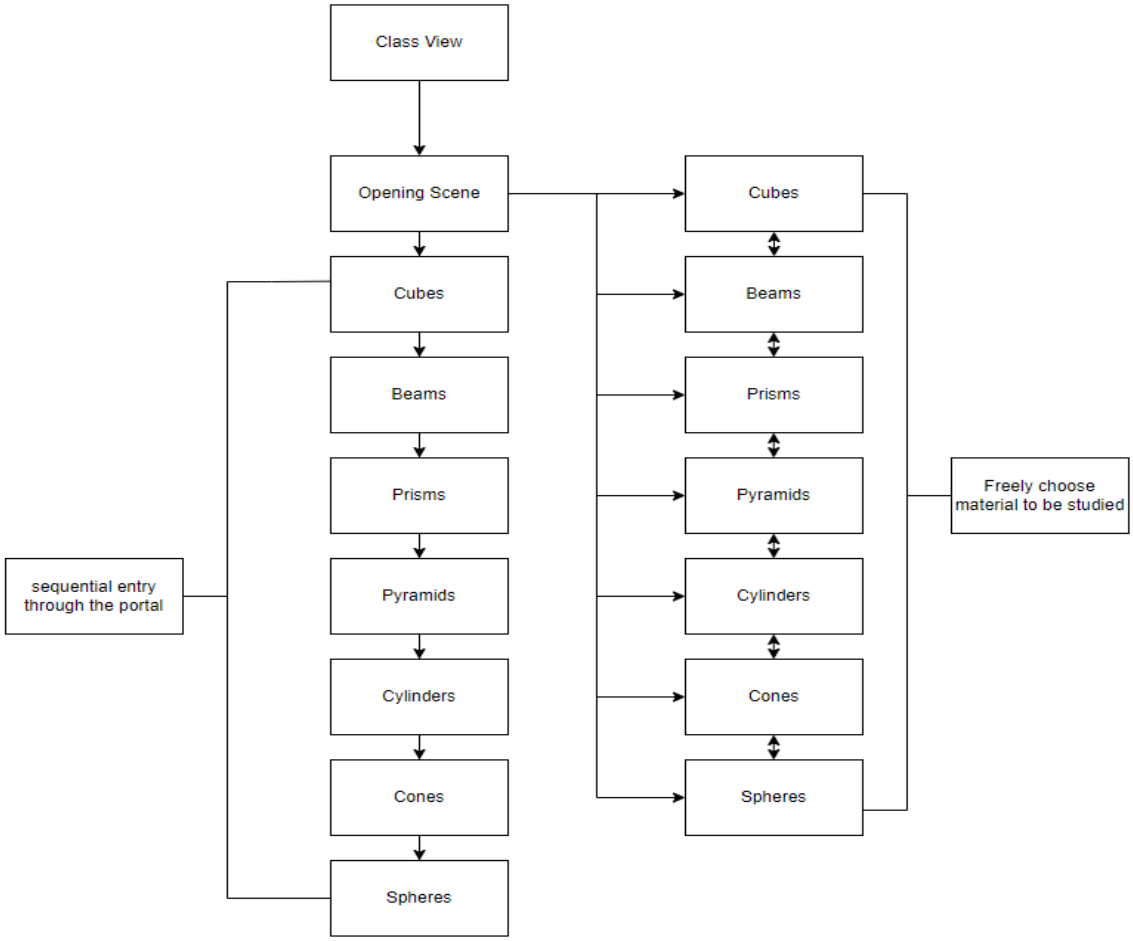


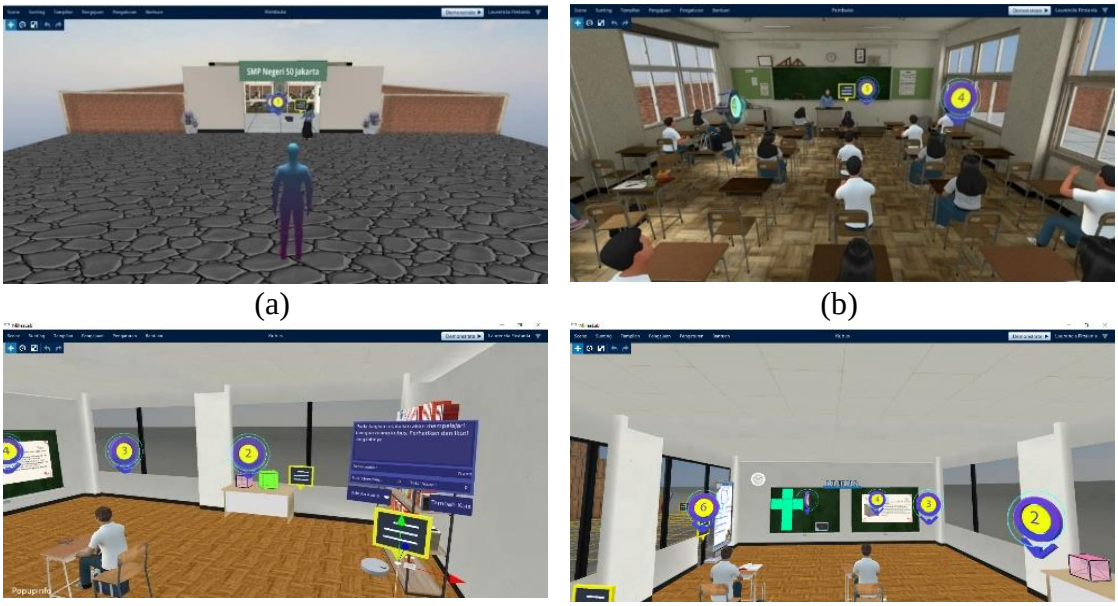
Figure 1. Learning Media Flowchart

The design also included more than one sensorial feature in addition to visual information and sound to enhance different modes of learning and improve the cognitive processing of the students. The contributions of educators during the design phase gave a more polished version of the storyboard particularly in the pacing of instructional content to ensure students had ample time to interact with each geometric object. The use of Millealab allowed for a streamlined design process, making it easier to integrate interactivity and adjust based on expert feedback. The design phase also highlighted the need for intuitive navigation and clear instructional guidance within the VR tool to prevent cognitive overload for students unfamiliar with the technology.

Development Result

At this stage, the VR media has been developed according to the design specifications as a part of the production process. With the help of Millealab, the research group has come up with an immersive learning environment, where the students could manipulate three-

dimensional figures as they move around the space. The development process also involved looking for lifelike images of geometric bodies and adding features that permitted the students to turn, change the size and tear apart the objects in order to learn the characteristics of the bodies. The producto is shown by Figure 2.



(a) (b)

(c) (d)

Figure 2. Virtual Classroom from User Point of View

The product was then validated by subject learning material experts, including a mathematics educator, a language expert, and a media specialist. The result is shown in Table 1.

Table 1. Learning Material Validation Result

Aspects	Number of Statements	Validator 1		Validator 2	
		Total Score	Average	Total Score	Average
Learning Design	2	10	5	10	5
Presentation of Material	6	28	4.7	27	4.5
Language	2	8	4	10	5

Table 1 shows the validation result on the learning material within the learning media. The results, as evaluated by subject matter experts, focused on the accuracy and relevance of the VR-based learning content in teaching three-dimensional geometry. The table scores indicate a high level of validity. This high score reflects the tool's alignment with curriculum objectives, as well as its ability to effectively convey geometric concepts in an immersive manner. Among the evaluated aspects, "Learning Design" scored higher

than "Language". This disparity may be due to the tool's strong emphasis on delivering precise mathematical design, rather than communicating it in an easier method.

Table 2. Media Validation Result

Aspects	Number of Statements	Validator 1		Validator 2	
		Total Score	Average	Total Score	Average
Presentation of Media	6	27	4,5	21	3,5
Audio	1	5	5	4	4
Navigation	1	4	4	3	3
Compatibility	4	18	4,5	16	4
Visualization	5	23	4,6	14	2,8
Practicality	5	24	4,8	14	2,8

The media validation results assessed the technical and interactive aspects of the VR tool, such as usability, visual quality, and functionality. The overall score was 4.25, signifying that the VR media was highly effective in engaging students and facilitating learning. Factors like high-quality 3D models and user-friendly navigation contributed to this strong performance. However, lower scores in "Visualization" compared to "Compatibility" indicate hardware limitations are not the problem. Rather, how a shape is visualized might need some improvements. These results highlight the tool's strengths in creating visually appealing and accessible content while emphasizing the need to address technical compatibility issues for broader adoption.

Table 3. Language Validation Result

Aspects	Number of Statements	Validator 1		Validator 2	
		Total Score	Average	Total Score	Average
Appropriateness in Writing	6	29	4.8	24	4
Rules of Language Usage	4	20	5	16	4

The language validation results, focusing on the clarity and appropriateness of the instructional language, yielded an overall score of 4.45. This result reflects the VR tool's effective communication of geometric concepts in language suitable for ninth-grade students. Some instructions might require further simplification or restructuring to enhance their usability during self-directed learning. The findings underscore the importance of refining instructional texts to ensure they are not only accurate but also accessible and easy to follow, especially for students encountering VR tools for the first time.

Feedback from validators also led to minor revisions, such as improving the clarity

of instructional audio and optimizing the user interface for smoother navigation. Minor adjustments, such as enhancing the clarity of instructional audio and refining the interactivity of the shapes, were made based on validator feedback. These improvements were crucial in ensuring that the tool not only met educational standards but also maintained user engagement. The high validity score confirmed that the VR-based tool was both pedagogically sound and technically functional.

Implementation Result

The implementation of the Virtual Reality (VR) media in two ninth-grade classes of SMP Negeri 50 Jakarta involving 66 students. For three sequential meetings of mathematics classes, the VR media was utilized as a supplement for the topics. Three dimenstional geometry was the focus of the lesson. In those lessons, students were equipped with VR devices which allowed them to move around in a learning space and view and handle various geometric figures. Based on the classroom observation, there was a higher level of student participation compared to the conventional teaching methods adopted. Rather, students were more participative, actively asking questions and demonstrating high levels of curiosity with the aid of the VR device in trying to understand the complex geometry concepts, which made it easier for the students to internalize geometry.

Qualitative comments of both learners and instructors acknowledged the immersive VR media to have transformed the learning process. The students were proclaiming that the incorporation of VR would definitely enhance the student's enjoyment of the lesson and lessen his or her fear because even the dull baked intrusions with dreadful geometric concepts were now made vivid and comprehensible. One example, a student, shared "I could understand how the shapes fit in together at last and not just looking at it on the small flat image in the textbook". The teachers also experienced an enriching VR media incursion that promoted learning in a student embracing and productive manner. They avowed that even students who found geometry very difficult and were reluctant to approach it became very active and keen to use the VR technology as if it were easy to comprehend, suggesting that it could help overcome the divide between the theory that is learned and the pictures that are seen. The practicality test for the qualitative feedback made Table 4.

The insights shared by teachers reiterated how effective the VR tool was in almost

every aspect. They liked the fact that it needed very little technical training in the use of the media thus integrating it in their teaching practices was not disruptive to the lessons being taught. However, teachers also pointed out that the use of the VR tool enabled them to adopt a more interactive teaching style whereby lectures were not the only basis for students engaging in geometric explorations. This was beneficial for the students who were able to comprehend the lessons more and also for the teachers who were able to instruct students in a specific manner in response to challenges that arose in lessons. Overall, the integration of the VR element was well accepted by the students and the teachers alike. They considered it as an invaluable element that enhanced the teaching and learning of mathematics and facilitated better understanding of three-dimensional shapes among the learners.

Table 4. Practicality Test Result

Aspects	Number of Statements	Total Score	Average
Efficiency	4	539	3.96
Operationality	6	810	3.97
User Experience	4	526	3.86
Originality	3	427	4.18

The implementation stage also offered useful information regarding the use of the classroom VR media and its effectiveness in real classroom situations. The tool was used with two ninth-year classes attended by 66 pupils altogether. The data collection methods included questionnaires, teacher's interviews, and observation of classes. The findings showed that there was a marked improvement in the students' understanding of the concept of shapes and their involved psychiatric levels as illustrated by post-test performance and participation rates (Bata & Anggipranoto, 2023). A mean of 3.81 was also depicted that there was no much problem encountered by both teachers and pupils orally using the VR apparatus and therefore scored high levels if practicality. Some of the comments received were qualitatively added in creating abstract geometric shapes more tangible and easier to understand.

Evaluation Result

In the evaluation phase, every step from analysis to implementation was evaluated. In the evaluation phase, the effectiveness of the VR tool was assessed using both quantitative and qualitative data. The quantitative evaluation focused on students' improved

understanding of three-dimensional geometry, as measured by their performance on pretests and posttests. The results showed a notable increase in scores, indicating that the VR tool effectively enhanced students' comprehension of geometric concepts. Students reported higher engagement levels when using the VR media, as captured through questionnaire responses on a Likert scale. The validity score of 4.04 and the practicality score of 3.81 further demonstrated the effectiveness and feasibility of the tool for teaching purposes.

The practicality of the VR tool was evaluated based on feedback from both students and teachers. Students expressed enthusiasm about the interactive features of the tool, noting that it made learning more engaging and intuitive. However, some students encountered challenges due to device limitations, such as low memory capacity and incompatibility with the VR application. Teachers highlighted the tool's potential to transform abstract geometric concepts into visual and manipulable experiences, making it easier for students to grasp the material. Observations during the implementation phase revealed that the tool was easy to integrate into classroom activities, though teachers emphasized the need for more training to fully utilize the tool's capabilities.

Despite its success, the study faced several limitations. Technological restrictions were a significant challenge, as some students were unable to use the VR tool effectively due to hardware issues, such as outdated devices or connectivity problems. The study was also limited in scope, focusing on a single school and involving only 66 participants. This restricts the generalizability of the findings to other educational settings. Furthermore, the short duration of the implementation phase posed challenges in assessing the long-term impact of the VR tool on student learning and retention. Future research should address these limitations by expanding the participant pool, including more schools, and conducting longitudinal studies to evaluate the sustained effects of VR-based learning tools on mathematics education.

This research demonstrates the potential of VR-based learning tools to revolutionize mathematics education by making abstract concepts, such as three-dimensional geometry, more accessible and engaging for students. By integrating VR into the curriculum, educators can provide immersive and interactive experiences that enhance spatial reasoning and cater to diverse learning styles. However, challenges such as limited funding, hardware compatibility issues, and insufficient teacher training may hinder

widespread adoption, especially in resource-constrained schools. To address these barriers, cost-effective platforms like Millealab can be utilized, as they work with low-specification devices and require minimal technical expertise. Additionally, schools can seek partnerships with educational technology providers and government initiatives to secure funding and support. Equipping teachers with adequate training is essential to ensure they can effectively integrate VR tools into their teaching practices. With careful planning and resource allocation, VR-based learning can become a viable and transformative addition to modern mathematics curriculum.

CONCLUSION

This study successfully developed and evaluated a 3D virtual reality (VR) teaching aid for enhancing students' understanding of geometric concepts in mathematics. Using the ADDIE framework, an interactive VR model was created to help students visualize and manipulate shapes within a three-dimensional space. The VR media demonstrated a high validity score of 4.04, confirming its suitability for educational use. During implementation, students showed improved engagement and understanding, as evidenced by their performance in assessments and classroom activities. These findings highlight the potential of VR-based learning tools to address challenges in teaching abstract concepts in mathematics, offering a more interactive and effective alternative to traditional methods.

On the future course of the study, while this research validates the feasibility of the interactive E-Module, its effectiveness in improving students' geometry learning outcomes has not yet been fully tested. Therefore, it is recommended that future research conduct broader trials to evaluate the product's impact on student performance and conceptual understanding of geometry. These trials should involve diverse student populations across various educational settings to ensure the findings are generalizable. Teachers should be provided with proper orientation and training to effectively integrate the E-Module into their teaching practices, enhancing traditional methods rather than replacing them. Schools should also consider investing in additional resources, such as virtual reality (VR) tools or other supportive technologies, to further enrich the learning experience. Evaluating the long-term effectiveness of the E-Module, along with its potential integration with VR-based learning tools, could provide valuable insights into

the role of technology in advancing mathematics education.

ACKNOWLEDGMENT

The author would like to thank all those individuals and institutions who assisted in one way or another towards the entire accomplishment of this research work. The author would like to express his deepest gratitude to the faculty and staff of SMP Negeri 50 Jakarta for their support and collaboration during the study. Gratitude is also due to the validators who provided the developers till the end of the VR based learning media development and to the students and teachers who were involved in the research process.

REFERENCES

Asnawati, R. (2019). Upaya Peningkatan Kemampuan Guru untuk Menggunakan Media Pembelajaran dalam Proses Pembelajaran melalui Supervisi Akademik Kepala Sekolah SD Negeri 63 Pekanbaru. *Perspektif Pendidikan dan Keguruan, 10*(1), 44–58. https://doi.org/10.25299/perspektif.2019.vol10(1).3098.

Bata, A., & Anggipranoto, R. (2023). Pengembangan Aplikasi Virtual Reality untuk Pembelajaran Bangun Ruang Kelas V Sekolah Dasar menggunakan Model ADDIE. *JIIP-Jurnal Ilmiah Ilmu Pendidikan, 6*(2), 826–832. https://doi.org/10.54371/jiip.v6i2.1536

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge.

Collins, A., & Halverson, R. (2018). *Rethinking education in the age of technology: The digital revolution and schooling in America*. Teachers College Press.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson Education.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Sage.

Dewi, R. K. (2020). Pemanafaatan Media 3 Dimensi Berbasis Virtual Reality untuk Meningkatkan Minat dan Hasil Belajar IPA Siswa Kelas V SD. *Jurnal Pendidikan, 21*(1), 28–37. https://doi.org/10.33830/jp.v21i1.732.2020

Hidayah, S., Sumarwiyah, A., Abdurrohim, H., Hasanah, F. W., & Hasan, Z. (2022). Pendampingan Belajar Matematika Menggunakan Media Pembelajaran Berbasis Game Android. *Community Development Journal : Jurnal Pengabdian Masyarakat, 3*(2), 812–818. https://doi.org/10.31004/cdj.v3i2.4759

Lase, D. (2020). Pendidikan di Era Revolusi Industri 4.0 Education. *Jurnal Teknologi Industri Dan Rekayasa (JTIR), 1*(1), 43–48.

Lumbantoruan, J. H., & Natalia, S. (2021). Development of a constructivism-based statistics module for class VIII junior high school students. *Solid State Technology, 64*(2), 4427-4444.

Masturah, N., Mahadewi, L. P. P., & Simamora, A. H. (2018). Pengembangan Media Pembelajaran Pop-Up Book pada Mata Pelajaran IPA Kelas III Sekolah Dasar. *Jurnal EDUTECH Univrsitas Pendidikan Ganesha, 6*(2), 212–221. https://doi.org/10.23887/jeu.v6i2.20294

Natalia, S., Purba, S. C., Darhim, D., & Yolanda, G. M. (2023). Evaluation of mathematics education curriculum in terms of product on the context, input, process, and product model. *Indomath: Indonesian Mathematics Education, 6*(1), 59-70. http://dx.doi.org/10.30738/indomath.v6i1.49

Pratidiana, D., & Muhayatun, N. (2021). Analisis kelancaran prosedural matematis siswa dalam menyelesaikan soal program linear. *UNION: Jurnal Ilmiah Pendidikan Matematika, 9*(2), 189-201. https://doi.org/10.30738/union.v9i2.9369

Price, S., Yiannoutsou, N., & Vezzoli, Y. (2020). Making the body tangible: Elementary geometry learning through VR. *Digital Experiences in Mathematics Education*, *6*(2), 213-232. https://doi.org/10.1007/s40751-020-00071-7

Rahim, F. R., Suherman, D. S., & Murtiani, M. (2019). Analisis Kompetensi Guru dalam Mempersiapkan Media Pembelajaran Berbasis Teknologi Informasi Era Revolusi Industri 4.0. *Jurnal Eksakta Pendidikan (JEP), 3*(2), 133. https://doi.org/10.24036/jep/vol3-iss2/367.

Sasmita, I. W. K., Putrama, I. M., & Santyadiputra, G. S. (2022). Pengembangan Virtual Reality Untuk Digitalisasi Mandala 2 Di Pura Besakih. *KARMAPATI (Kumpulan Artikel Mahasiswa Pendidikan Teknik Informatika), 11*(1), 1-11. https://doi.org/10.23887/karmapati.v11i1.39449

Sugiyono, S. (2017). *Metode penelitian kuantitatif, kualitatif dan R&D* (2nd ed.). Alfabeta.

Sumantri, B. A. (2019). Pengembangan Kurikulum Di Indonesia Menghadapi Tuntutan Kompetensi Abad 21. *At-Ta'lim : Media Informasi Pendidikan Islam, 18*(1), 27-50. https://doi.org/10.29300/attalim.v18i1.1614

Tohir, M. (2019). Hasil PISA Indonesia Tahun 2018 Turun Dibanding Tahun 2015. *Paper of Matematohir, 2*(1), 1–2.

Wu, L., Hsieh, P. J., & Wu, S. M. (2022). Developing effective e-learning environments through e-learning use mediating technology affordance and constructivist learning aspects for performance impacts: Moderator of learner involvement. *The Internet and Higher Education, 55,* 100871. https://doi.org/10.1016/j.iheduc.2022.100871

Yanto, B., Mustafa, S. R., Supriyanto, A., & Risnofiardi, R. (2023). Pelatihan Peningkatan Inovasi Virtual Reality (VR) Millealab Bagi Guru SDN 05 Kampung Jawa Kota Solok. *Communnity Development Journal, 4*(2), 1782–1788. https://doi.org/10.31004/cdj.v4i2.13505