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Developing an RME-based 3D storybook with AR technology to enhance spatial ability

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ABSTRACT

This research aims to develop a 3D storybook using realistic mathematics education (RME) approach and augmented reality (AR) technology to enhance students' spatial ability. We used the 'Analysis, Design, Development, Implementation, and Evaluation' (ADDIE) development model and involved 34 eighth-grade students of SMP N 15 Yogyakarta – a public junior high school in Indonesia. During the development, we underwent several interviews, observations, asking experts' validation to the content and the media, asking students' response to the product, and tests related to the students' spatial ability. The results suggest that the content validation got an average score of 109 (good criteria), the media validation got an average score of 48.16 (good criteria), and the students response got an average score of 78.36 (very good criteria). At the end of the stage, there are still found an obstacle during the testing of the 3D storybook, namely the time required to load the 3D content. It makes some students encounter difficulty to access it, indicating the need for further development. However, the final product could facilitate the students to exercise their spatial ability using the 3D storybook while learning geometry.

Introduction

Spatial ability is a spatial thinking concept that encompasses spatial concepts, representation tools, and reasoning processes (Atit et al., 2022). Spatial ability consists of spatial perception, mental rotation, and spatial visualization. These three categories of spatial ability need to be accommodated in geometry education in classrooms according to curriculum requirements and mathematics content standards (Adams et al., 2023). Therefore, in the context of mathematics, especially geometry, spatial ability is crucial to enhance.

Geometry is a branch of mathematics that studies visual patterns, such as transformations of plane or spatial figures (Izard et al., 2022). Many mathematical concepts can be demonstrated through geometric representations. Additionally, geometry is a subject that contains numerous abstract concepts/ideas requiring learners to imagine and visualize. Geometry is important for students as it connects mathematics to the physical shapes of the real world and allows mathematical ideas to be visualized.

In the current digital era, technological advancements play a significant role in the development of education (Legi et al., 2023). Various technologies are being integrated to support the learning process, ranging from the use of multimedia, internet, social web, e-learning, to the use of mobile devices and immersive technologies such as games, virtual reality, and augmented reality (AR) (AlGerafi et al., 2023; Zhao et al., 2023). The widespread ownership of mobile devices among students has led to an increased interest in integrating the benefits of mobile learning and applications like AR to support these learning processes (Eom, 2023).

According to Alam and Mohanty (2023) and Fernández-Batanero et al. (2022), the AR is a new technology whose application has great potential and impact on learning and pedagogy. With AR, the user's perception of reality, in this case the student, can be further enriched and not completely replaced as in a virtual environment (Marougkas et al., 2024). Furthermore, according to Andriyani et al, the important basis of AR which combines reality and virtual objects can be used to increase students' ability to visualize objects that are being studied and were previously difficult to imagine.

The AR presents dynamic situations in real world contexts through the layering of coherent locations or virtual information adapted to the context (Klopfer & Squire, 2008). In addition, according to (Mirza, 2024; Nur et al., 2022), AR adds virtual objects to real scenes, making it possible to add information that is missing in real life. Seeing the enormous function of AR as a form of novelty in the development of learning media, the use of AR promises to increase students' involvement and level of understanding of the learning context (Faqih & Jaradat, 2021; Scavarelli et al., 2021).

In connection with providing learning experiences and realistic learning environments, theoretically the Realistic Mathematic Education (RME) learning method is a learning method which in principle can provide opportunities for students to experience for themselves the process of concept discovery through solving contextual problems that are linked to a real life phenomenon (Lubis et al., 2023; Muchtar et al., 2020). Situations used as learning topics will be applied through investigative activities, so that various applications to anticipate obstacles during learning can emerge. Furthermore, Muchtar et al. (2020) explained that the applications that are widely used by students are mathematical models that are developed by students themselves to bridge the gap between informal knowledge and formal mathematics with examples of cube-shaped shapes such as rubrics, snakes and ladders dice, participant charity boxes. Students can observe that the three examples have the same characteristics, such as the same edge length, the same number of corner points.

The importance of learning experiences and the involvement of realistic learning environments during learning will stimulate student activity and interaction during learning. Most learning orientations still tend to treat students as learning objects, while teachers hold the highest scientific and indoctrinary authority by teaching subject-oriented material (Cao et al., 2023). This is in line with the results of our initial research at SMP N 15 Yogyakarta—a public junior high school in Yogyakarta, Indonesia.

Based on the results of observations and interviews with mathematics teachers at SMP N 15 Yogyakarta, it is known that teachers still tend to teach material by lecturing, then giving examples and exercises. On the other hand, students only listen, take notes, and do the exercises given by the teacher. The teacher's way of teaching is carried out in almost all mathematics material, including when teaching the topic of polyhedron. Polyhedron include spatial shapes which are a branch of 3D-geometry whose objects are abstract (Kusuma et al., 2023; Munir et al., 2022). The objects in the spatial material are obtained through an abstraction process from concrete objects

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that are often found in everyday life (Zhu et al., 2023). The abstractness of geometric concepts can be understood through students' direct experience by manipulating real objects that become models of geometric spatial objects, until students' abstractions are formed (Breive, 2022; Utomo et al., 2023).

Students' difficulties in abstracting the concept of polyhedron and problems were also experienced by students at SMP N 15 Yogyakarta. Some students had difficulty in imagining spatial concepts or reasoning about spatial problems related to polyhedron. Moreover, when introducing concepts, the teacher only shows pictures to illustrate the building model, followed by a verbal explanation. In fact, a person's perception of an object or image is influenced by the orientation of the object, so that to be able to recognize objects/images correctly, spatial abilities are needed (Bosco et al., 2023). In geometry, including polyhedron material, there are elements of the use of visualization, spatial reasoning and modelling (Aulia et al., 2023).

Based on the results of the initial test on students' spatial abilities at SMP N 15 Yogyakarta, it is known that students' spatial abilities are still relatively low because students are only able to fulfill 1 indicator. The low spatial ability of students on average is related to students' difficulty in visualizing objects and their relevant rules. Apart from that, students also experience difficulty in understanding the arrangement of objects and their parts, as well as their relationships with each other. This condition shows the need for a learning model that is both theoretically and applicable to improve students' spatial abilities in learning this polyhedron structure material.

Several studies show an increase in mathematical abilities after using RME in learning, including an increase in the spatial abilities of students taught using the RME approach compared to the conventional approach (Heuvel-Panhuizen & Drijvers, 2014). Increasing students' understanding of geometry with the RME approach (Fauzana et al., 2020). Increasing mathematical reasoning, communication, achievement and positive attitudes with the RME approach (Paroqi et al., 2020). Looking at the research results related to the application of RME and to minimize the implications of educational practices that can isolate students from real life, RME can be used as an alternative learning model for polyhedron building materials where direct learning still does not provide direct experience and is of a discovery nature.

Apart from requiring an appropriate learning approach, teaching materials or supporting learning media have a significant role in improving students' spatial abilities. Increasing students' spatial abilities can be done by using AR technology. The use of AR technology which is also based on presenting real-world dynamic contexts or situations through visual displays is expected to help students illustrate geometric concepts that were previously difficult to imagine (Haas et al., 2023). By integrating real world context in RME and visualizations that contain reality context in AR technology, teachers can present more interesting learning and stimulate students' spatial abilities. This integration strategy allows students to be more active and free to express their ideas, and can enjoy learning mathematics if it is not possible to gain direct field experience.

The results of further interviews with students and mathematics teachers at SMP N 15 Yogyakarta also showed that students were experiencing boredom with learning in class which they thought was monotonous and less interactive, apart from learning materials in the form of 2013 Curriculum textbooks. Both teachers and students complained about the incompleteness and limitations of material illustrations in the 2013 Curriculum textbooks, so that students were less interested in reading them and students' imaginations in understanding the concepts being taught were hampered (Huda et al., 2024). Empirically, students tend to like picture colourful textbooks and contain realistic or cartoon pictures (Callow, 2020). One alternative that can be used to support these situations and conditions is by using storybooks with AR technology.

According to Marwanti and Sumilah (2022) and Pohan (2022), mathematics storybooks are educational aids that utilize mathematical themes, containing narratives about everyday human life. These storybooks not only incorporate stories but also supported by illustrations. Their function is to assist in explaining the text. Interactive storybooks based on RME and oriented towards spatial ability are used. The RME in these storybooks serves as a model that focuses on learning activities. Therefore, RME's position is in its learning activities. However, in reality, teachers who have developed storybooks in mathematics are very limited. Therefore, supplementary books are required as teaching materials and teaching method applications that support the learning process become more attractive, which is expected to improve students' spatial abilities.

Based on the background consideration previously, it is necessary to develop interesting teaching materials that can be used to facilitate students in developing their spatial abilities. In this study, the teaching tools consist of the storybooks equipped by AR and the RME model to facilitate students in enhancing their's spatial abilities on the topic of polyhedron construction.

Method

This study is a research and development of a 3D storybook that utilizes Augmented Reality (AR) technology combined with the Realistic Mathematics Education (RME) approach to enhance students' spatial abilities in constructing polyhedron. The stages applied in this development model include Analysis, Design, Development, Implementation, and Evaluation (ADDIE model). The subjects of this study are 34 eighth-grade students from SMP N 15 Yogyakarta. Data collection techniques include both test and non-test methods, with tests comprising teacher interviews, questionnaires to measure validity and practicality, and spatial ability tests to measure effectiveness.

Results and discussion

Results

Analysis

Based on the interview results with teachers, it was found that the scope of polyhedron materials taught at SMP N 15 Yogyakarta includes the introduction to cube, cuboid, prism, pyramid, as well as calculations of volume and surface area of cube, cuboid, prism, and pyramid. Generally, mathematics lessons are conducted twice a week, with initial meetings lasting 2 x 45 minutes and later meetings lasting 3 x 45 minutes. The teaching materials used include summaries of materials, formulas, exercises, and daily assessments. The textbooks used lack instructional model syntax, and there are no reviews or adjustments to balance both material summaries and exercises. Initial research continued with an investigation into the required and most suitable teaching materials for the students. Results showed that 40.73% of students chose a storybook, 27% chose a packaged storybook, 15.01% chose modules, and 17.36% chose worksheets.

Based on the above analysis, we developed teaching materials on polyhedron in the form of an augmented reality-based storybook using the realistic mathematics education model as a teaching and student support medium in implementing polyhedron learning. According to the test results, students are still unable to think deeply, rely too much on memorizing formulas, lack detail, and have difficulty in solving spatial assignment problems. In reality, students make mistakes in writing conclusions based on what they have learned when completing given tasks. The results of written test also showed that students vary in their understanding of spatial ability

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indicators student's understanding on spatial ability indicators are diverse. The initial test of student's spatial ability is presented in Table 1.

Table 1. Results of polyhedron pretest for spatial ability

Spatial Ability Indicator	Average Ideal Score	Average Achievement Score
Perception	10	10
Visualization	20	2.47
Rotation	10	8
Relationships	55	29.04
Orientation	5	1.38

Table 1 indicates that the average achievement of spatial ability indicators among students is still low, as almost every almost all the spatial ability indicators remains below the ideal average except for the spatial perception. Based on this result, it can be concluded that the spatial ability of 8th-grade students at SMP N 15 Yogyakarta is still low still lacking since it only reaches one indicator among five existing indicators achieved with achievement in only one out of five indicators. Therefore, in this study, researchers developed a 3D storybook using the RME model to enhance students' spatial abilities in learning polyhedron.

Design

At this stage, we designed a 3D storybook based on the analysis results. The storybook is tailored to include polyhedron for 8th-grade students, using the RME and incorporating spatial ability indicators. The design of the storybook is presented in Figure 1.

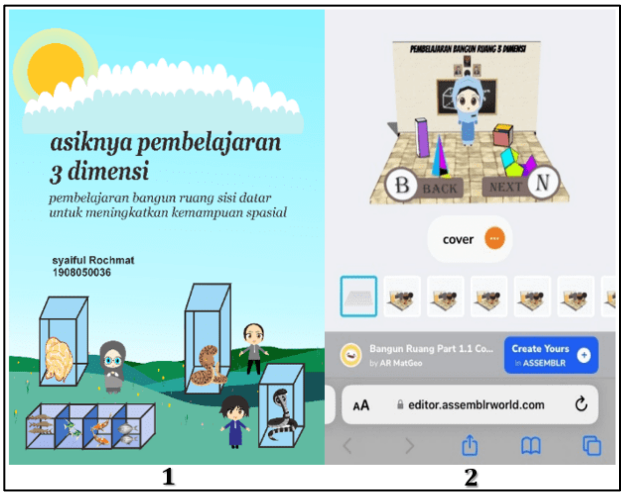

Figure 1. Cover display before being scanned (1) and after bening scanned (2).

In Figure 1, (1) shows the initial cover of the storybook before being scanned using a mobile device by the students, and (2) shows the initial cover of the storybook after the students scan the barcode, making the media visible. Students can choose between "view in 3D" or "view in marker".

Figure 2 contains the material on polyhedron, specifically the cube, which students are to study. In addition to designing the product, the researcher also developed non-test instruments and test instruments at this stage. The non-test instruments include a questionnaire for student responses to the learning media, a material expert validation instrument, and a media expert validation instrument.

Figure 2. Material content in storybook with augmented reality

The material expert instrument is based on the guidelines for developing teaching materials by the Ministry of National Education (Depdiknas, 2008), which include feasibility testing by material experts covering aspects of content feasibility, language, presentation feasibility, and alignment with the characteristics of the model used and the targeted abilities in the learning media. The material expert validation instrument is provided in the appendix. The media expert instrument includes the quality of graphics and design appearance. The media expert validation instrument is also provided in the appendix. The student response questionnaire to the learning media refers to the grid of the student response questionnaire, which includes alignment with the RME learning model, interest, material and presentation, and language. The test instrument, which consists of spatial ability questions, is based on spatial ability indicators. These indicators are spatial perception, visualization, mental rotation, spatial relations, and spatial orientation.

Development

At this stage, the 3D storybook is developed according to the previously designed plans. Initially, the 3D storybook, including characters, the classroom, objects, and polyhedron, is designed using the 3D Blender application, which is exported into the .fbx format. Blender is a computer graphics application that allows for the production or creation of high-quality images or animations using three-dimensional geometry. In the next phase of development, the parts that have been created are uploaded to the 3D Assembler Studio.

During the initial product development process of the 3D storybook with the RME approach, the researcher used the paid version of Assembler Studio, as the free version only supports up to 8 megabytes. The results of the material expert validation can be seen in Table 2.

Table 2. Material expert validation results

Validator	Total Score	Average
Validator 1	118	4.53
Validator 2	98	3.76
Validator 3	98	3.76
Validator 4	87	3.34
Validator 5	127	4.88
Validator 6	126	4.84

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Table 2 shows that the total score from material expert 1 is 118 with a "good" category, the total score from material expert 2 is 98 with a "sufficient" category, the total score from material expert 3 is 98 with a "sufficient" category, the total score from material expert 4 is 87 with a "sufficient" category, the total score from material expert 5 is 127 with a "very good" category, and the total score from material expert 6 is 126 with a "very good" category. Based on the results of the material expert validation, it can be concluded that the developed 3D storybook is considered valid or suitable for use, with an average score of 109.

Table 3. Media expert validation results

Validator	Total Score	Average
Validator 1	51	4.63
Validator 2	43	3.90
Validator 3	43	3.90
Validator 4	50	4.54
Validator 5	48	4.36
Validator 6	54	4.90

Table 3 shows that the total score from media expert 1 is 51 with a "very good" category, the total score from media expert 2 is 43 with a "sufficient" category, the total score from media expert 3 is 43 with a "sufficient" category, the total score from media expert 4 is 50 with a "good" category, the total score from media expert 5 is 48 with a "good" category, and the total score from media expert 6 is 54 with a "very good" category. Based on the results of the media expert validation, it can be concluded that the developed 3D storybook is considered valid or suitable for use from a media perspective, with an average score of 48.16.

Implementation

After the 3D storybook was validated and deemed suitable for use by material and media experts, it was implemented or tested for practicality with students. During implementation, students were first given a book containing barcodes to scan using smartphones (Android or iOS) to display the 3D storybook, employing the RME approach to enhance spatial abilities. This was done with 7 groups, each consisting of 5 students. The implementation of the 3D storybook took place in class VIII A at SMP N 15 Yogyakarta, with a total of 34 students. During use, students engaged with various features, such as visualization of polyhedron, rotation for viewing the figures from different angles, and perception to identify the elements of the figures.

After the implementation, the researcher distributed response questionnaires to the students, as users of the 3D storybook, to assess their interest, the material, and the language used. The results are shown in Table 4.

Table 4. Results of student responses to learning media

	Interest	Material	Language	Total Score
Average	10.48	49.92	17.96	78.36

Based on Table 4, the average score for student response questionnaires is 78.36. This means that the average is in the very good category based on the student response test.

Evaluation

In the evaluation stage, the ADDIE model was used to identify shortcomings from previous processes and to make continuous improvements. This was done to ensure that the resulting 3D storybook was of high quality and suitable for use in learning activities. The evaluation of the augmented reality-based storybook development process began with administering a pretest to students before the implementation stage of the 3D storybook product. The pretest was given to determine the students' spatial abilities prior to the learning activities using the augmented reality-based 3D storybook on the topic of polyhendron.

Discussion

The results of the research indicate that the discussion of polyhedron developed using the ADDIE model in the 3D storybook, based on augmented reality technology, has been effective. The RME approach provided students with the opportunity to actively construct their own understanding and use it as a tool for learning mathematics.

Understanding contextual problems

Understanding contextual problems involves comprehending the issues provided by the teacher that relate to everyday life. In the first step, students align with understanding the given problem to solve it. The presentation of the problem can be illustrated in Figure 3.

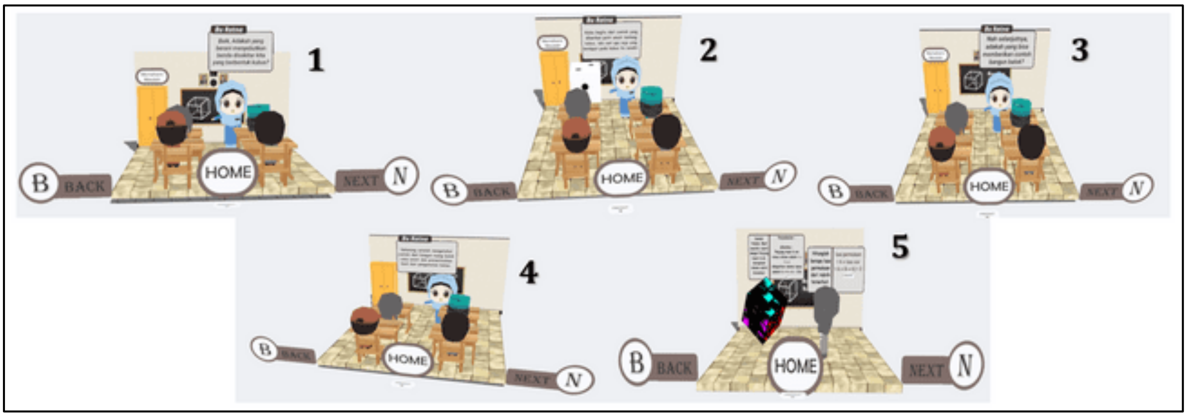

Figure 3. Presentation of problems related to 3D topics

Problem solving

Solving contextual problems involves addressing issues posed by teachers that relate to everyday life, yet without discussing the answers. In the second step, students work to solve the given problems using various approaches (See Figure 4).

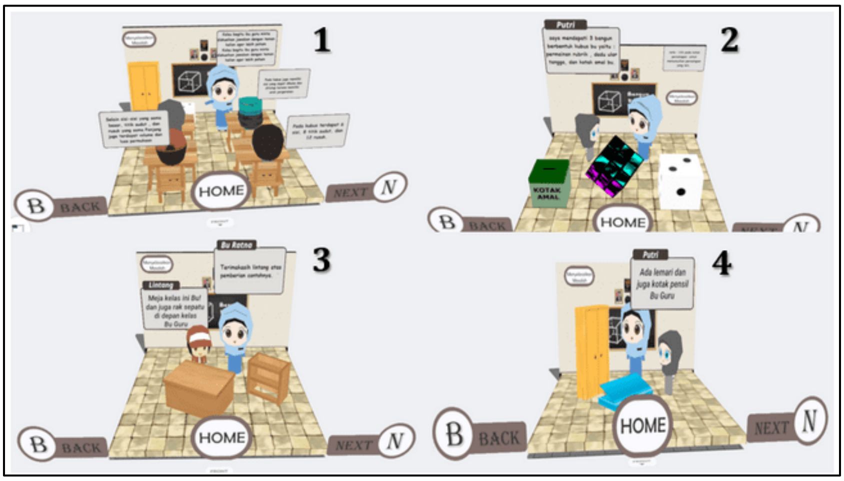

Figure 4. Problem solving

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Discussing answers

Discussing answers means discussing them with friends to find an answer that feels right. In the third step, students discuss the answers with their classmates or with other friends to make the correct conclusion (See Figure 5).

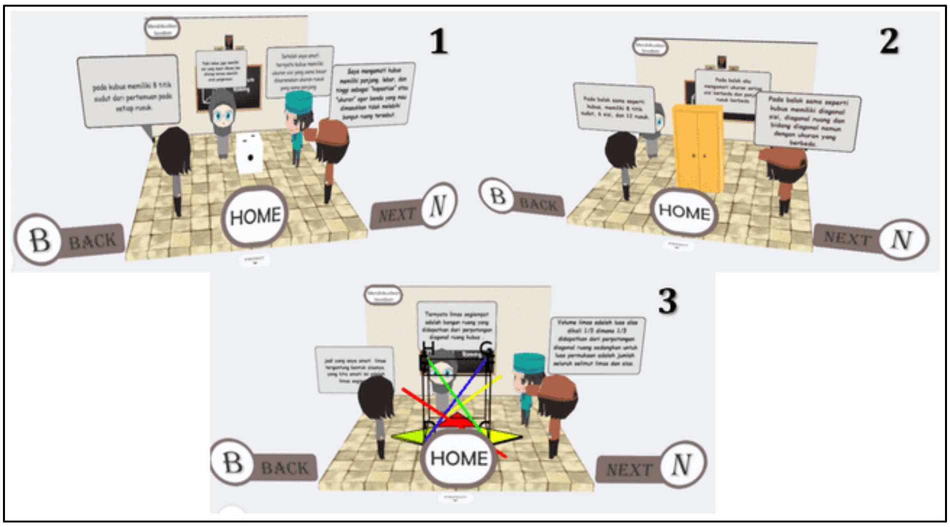

Figure 5. Discussing answers

Summarizing the answers

Concluding an answer is thinking about which is the correct answer to a problem from the discussing stage. In the final step, students can convey the results of the discussion by drawing conclusions on the correct answer. The stage of concluding the answer can be seen in Figure 6**.**

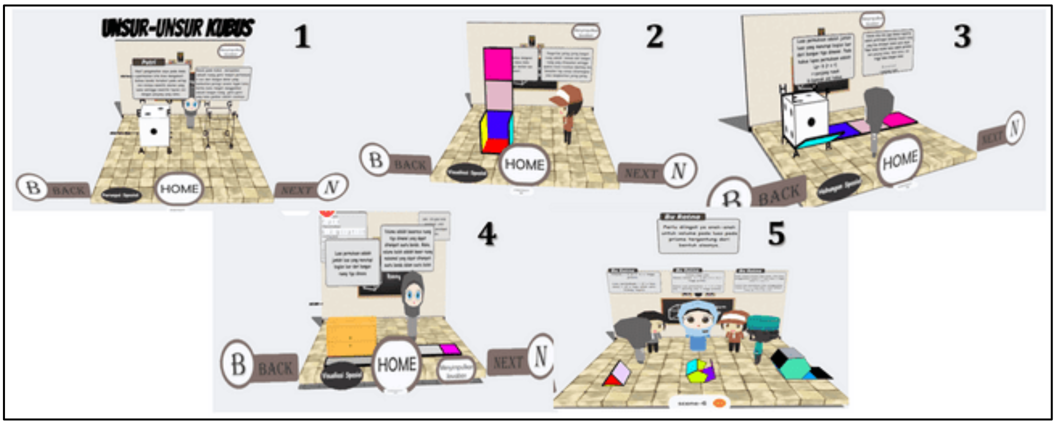

Figure 6. Summarizing the answer

Spatial ability is the capacity to visualize three-dimensional shapes, enabling students to understand spatial structures comprehensively. The spatial ability indicators include perception, visualization, mental rotation, spatial relations, and spatial orientation (Bartlett & Camba, 2023; Szabó et al., 2023). Considering the significant role of Augmented Reality (AR) as an innovative form of instructional media, its use promises enhanced engagement and understanding among students within the learning context (Czok et al., 2023; Familoni & Onyebuchi, 2024; Koumpouros, 2024). The spatial ability indicators present in my instructional media are as follows.

Spatial perception indicator

Spatial perception is the ability to distinguish lines, horizontal planes, and vertical planes within geometric figures. Strengthening spatial perception indicators can be observed in Figure 7.

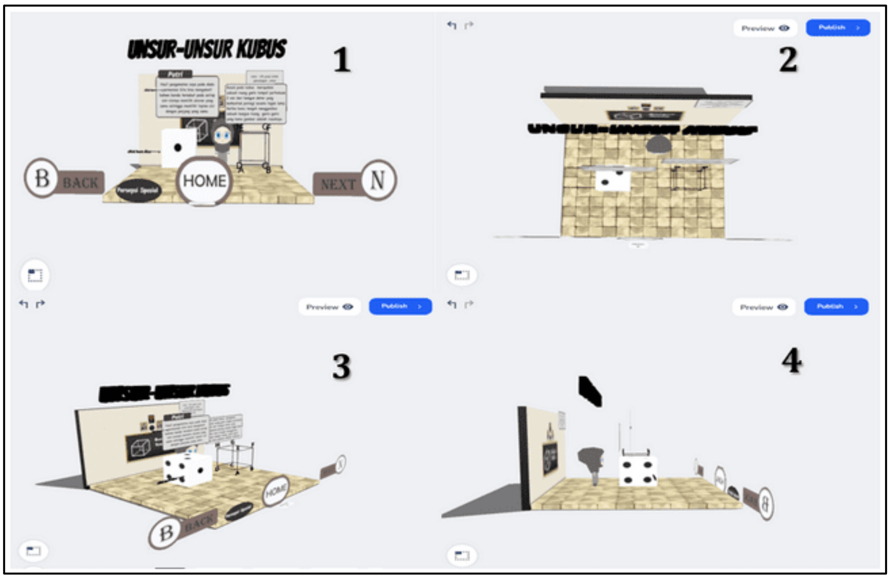

Figure 7. Related image of spatial perception indicators

In Figure 7, you can see the perception of space which can be seen from several points of view, such as (1) is a media image seen from above, (2) is a media image seen from the side, (3) is a media image seen from the left side angle and (4) is a left side view of media image.

Spatial visualization indicator

From this indicator, students can observe visualizations of polyhedron nets such as cube, pyramid, prism, cuboid, and the direction of these movements. The strengthening of spatial visualization indicators can be seen in Figure 8.

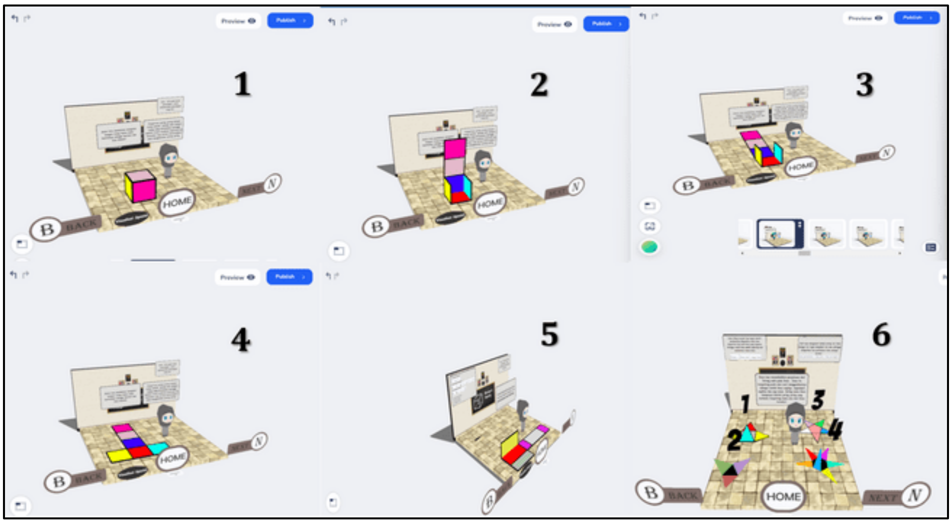

Figure 8. Image related to spatial visualization indicators

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Figure 8 shows that in the media, there are 6 related spatial visualization images as in (1) is an image of a cube net that has not experienced movement, (2) and (3) is an image of movement in a cube net, (4) is an image cube nets after completing all movements, (5) is a picture of cuboid nets after completing all movements, and (6) is a picture of pyramid nets after completing all movements.

Spatial rotation indicator

Spatial rotation is the ability to rotate two-dimensional and three-dimensional objects precisely and accurately. The strengthening of the spatial rotation indicator can be seen in Figure 9.

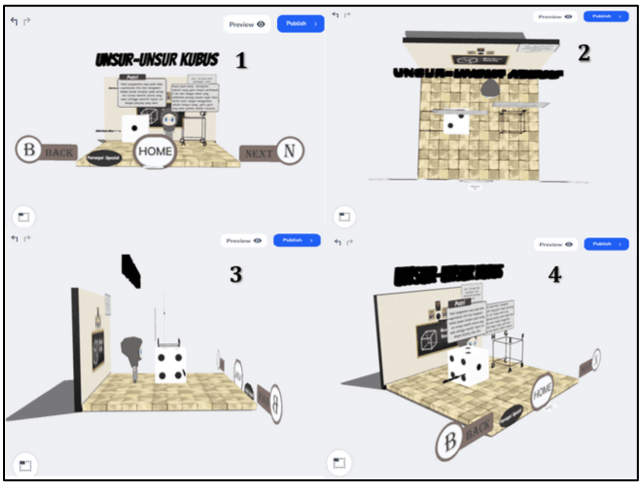

Figure 9. Image related to spatial rotation indicator

Figure 9 shows that in the media, there are 4 related spatial rotation images as in (1) is the image seen from the front before rotation, (2) is the image seen from above after rotating upwards, (3) is the image seen from the side after rotation, (4) is the left side view of the image after rotation.

Spatial relationships indicator

Spatial relation is the ability to understand the arrangement of an object and its parts and their relationship to each other. From this indicator, students can observe spatial relationships, namely the elements found in polyhedron such as corner points, edges, side diagonals, space diagonals and plane diagonals. Strengthening spatial relationships can be seen in Figure 10.

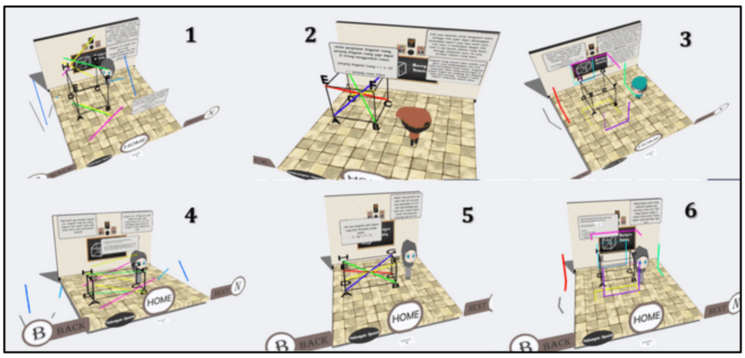

Figure 10. Image related to spatial relationship indicators

Figure 10 shows that in the media, there are 6 related images of spatial rotation as in (1) is a diagnostic image of the side of the cube, (2) is a diagnostic image of the plane of the cube, (3) is an image of the diagonal plane of the cube, (4) is an image side diagnostics on the cuboid, (5) is a space diagnostic on the cuboid, and (6) is an image of the diagnostic plane on the cuboid.

Spatial orientation indicator
Spatial orientation is the ability to observe and identify the shape or position of a geometric object viewed from various points of view. From this indicator, students can rotate the 3Dini storybook so that students will not have difficulty seeing the position of an object. Strengthening spatial orientation indicators can be seen in Figure 11.

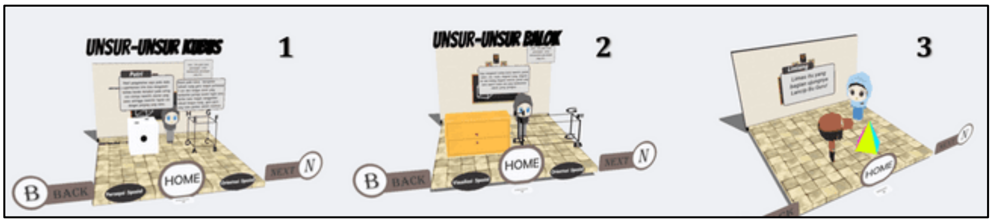

Figure 11. Image related to spatial orientation indicators

Figure 11 shows that in the media, there are 3 related images of spatial rotation as in (1) is an image of the arrangement and shape of a cube, (2) is an image of the arrangement and shape of a cuboid and (3) is an image of the arrangement and shape of a pyramid.

Conclusion

Based on the research results and discussion, the conclusion is that the development of an augmented reality-based storybook with a realistic mathematics model on polyhedron was successfully achieved using the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. The material validation results yielded an average score of 109, classified as "Good," while media experts rated it with an average of 48.16, also in the "Good" category. The practicality results from the student response questionnaire indicated an average score of 78.36 in the "Very Good" category. Additionally, several features in the 3D storybook supported the enhancement of students' spatial abilities. However, issues remain with the 3D storybook, particularly the lengthy loading time for 3D content, which makes it difficult for some students to access, indicating a need for further development.

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