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DEVELOPMENT OF AUGMENTED REALITY-BASED MATHEMATICS LEARNING MEDIA TO FACILITATE STUDENTS' MATHEMATICAL COMPUTATIONAL THINKING SKILLS

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Abstract:
The development of digital technology has positively impacted the world of education, especially in creating more interactive and innovative learning media. The integration of Augmented Reality (AR) in learning is one of the innovations that can provide new learning experiences for students by presenting visualizations of abstract concepts in real life. This research aims to develop AR-based mathematics learning media to facilitate students' mathematical computational thinking skills. The research method used is Research and Development (R&D) with the ADDIE development model (Analysis, Design, Development, Implementation, Evaluation). The research subjects involved 16 Insan Cendekia Sheikh Yusuf Gowa High School students. The research instruments used included product validation sheets, learner and teacher response questionnaires, and mathematical computational thinking ability tests. Analysis of research data focused on analyzing the validity, practicality, and effectiveness of Augmented Reality-based mathematics learning media. The results showed that the Augmented Reality-based mathematics learning media developed had met the criteria of validity, practicality, and effectiveness.

Keywords: Augmented Reality, Mathematical Computational Thinking Ability, Learning Media

PENGEMBANGAN MEDIA PEMBELAJARAN MATEMATIKA BERBASIS AUGMENTED REALITY UNTUK MEMFASILITASI KEMAMPUAN BERPIKIR KOMPUTASI MATEMATIS PESERTA DIDIK

Abstrak:
Perkembangan teknologi digital telah membawa dampak positif dalam dunia pendidikan, terutama dalam menciptakan media pembelajaran yang lebih interaktif dan inovatif. Integrasi Augmented Reality (AR) pada pembelajaran menjadi salah

satu inovasi yang dapat memberikan pengalaman belajar baru bagi peserta didik dengan menghadirkan visualisasi konsep-konsep abstrak secara nyata. Penelitian ini bertujuan untuk mengembangkan media pembelajaran matematika berbasis AR guna memfasilitasi kemampuan berpikir komputasi matematis peserta didik. Metode penelitian yang digunakan adalah Research and Development (R&D) dengan model pengembangan ADDIE (Analysis, Design, Development, Implementation, Evaluation). Subjek penelitian melibatkan 16 orang peserta didik SMA Insan Cendekia Syekh Yusuf Gowa. Instrumen penelitian yang digunakan meliputi lembar validasi produk, angket respons peserta didik dan guru, serta tes kemampuan berpikir komputasi matematis. Analisis data penelitian difokuskan pada analisis kevalidan, kepraktisan, dan keefektifan media pembelajaran matematika berbasis Augmented Reality. Hasil penelitian menunjukkan bahwa media pembelajaran matematika berbasis Augmented Reality yang dikembangkan telah memenuhi kriteria kevalidan, kepraktisan, dan keefektifan.

Kata Kunci: Augmented Reality, Kemampuan Berpikir Komputasi Matematis, Media Pembelajaran

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INTRODUCTION

Entering the 21st-century era, the world is facing increasingly complex and dynamic global challenges (Arifin, Pujiastuti, & Sudiana, 2020). Rapid technological developments and digital transformations that occur in various fields require an increase in competencies and relevant skills to face these challenges. Education is one of the sectors most affected by rapid technological developments (Rahmadani, Azmi Rifaldi, Athoullah, Wiyono, Umam, & Nafrijal, 2024; Indahsari & Sumirat, 2023; Setyawan, Hakim, & Aziz, 2023; Feby & Siregar, 2022). Therefore, there is an urgent need to develop a special skill in dealing with this problem. One of the skills needed in the 21st century is the ability to think in a computative way or Computational Thinking (CT) (Jamna, Hamid, & Bakar, 2022; Veronica, Siswono, & Wiryanto, 2022).

Computational thinking is a thinking process that involves problem-solving through decomposition, pattern recognition, abstraction, modeling/simulation, algorithms, and evaluation (Ihsan, Sutarmin, Arwadi, Zaki, & Naufal, 2021). Computational thinking is also defined as a thinking approach that involves the formulation of problems and solutions so that the solution can be represented in a form that can be processed by a person in processing information (Sitorus & Yahfizham, 2024). Not only do these skills have relevance in the realm of information technology, but they also play a very significant role in a variety of disciplines, including mathematics. In the context of mathematics learning, computational thinking skills are very crucial because they provide a framework that helps students analyze and compile complex and abstract mathematical concepts more systematically and logically. By computational thinking, students can solve mathematical problems with a more organized approach, so that they can formulate more effective and efficient solutions. These skills not only strengthen their conceptual understanding but also enhance their ability to apply mathematics in real-life situations and across disciplines.

However, the facts in the field show that many students face difficulties in developing this computational thinking ability. The results of the research by Kamil, Imami, & Abadi (2021) revealed that the average mathematical computing ability of students is still low. Another study by Aisy & Hakim (2023) also revealed that students have not been able to achieve the indicators of mathematical computational thinking skills optimally. Some of the difficulties faced by students in solving problems related to mathematical computational thinking skills include obstacles in understanding the problems presented, which then have an impact on difficulties in identifying appropriate patterns or formulas to solve them.

One solution that can be applied to overcome this problem is to integrate Augmented Reality (AR) technology into the learning process. AR technology can be an effective approach because it allows the incorporation of virtual objects, both two-dimensional and three-dimensional, into a three-dimensional real environment. AR projects these virtual objects in real time, thus providing a more interactive and immersive learning experience for learners (Sari, Batubara, Hazidar, & Basri, 2022; Rusnandi, Sujadi, Fibriyany, & Fauzyah, 2015). AR combines digital elements with the real world which allows students to interact with learning materials more visually and interactively With the help of this visualization, learners can see and manipulate abstract representations of elusive concepts so that their understanding of the material becomes deeper and more structured. AR integration can also enrich the learning experience through a combination of visual and audio elements, which overall increases the attractiveness and effectiveness of learning, especially in understanding complex mathematical concepts. Several previous studies have documented findings related to the positive impact of AR use in improving several important skills such as the ability to understand geometry concepts (Jumaena, Salmilah, & Munir, 2024), mathematical spatial skills (Yanuarto & Iqbal, 2022; Arifin, Pujiastuti, & Sudiana, 2020), mathematical learning outcomes (Hamzah, Alhusna, Ni'mah, Rahaju, & Wahyu, 2024; Elly Nafsiah & Tiur Malasari Siregar, 2023; Rizal & Yermiandhoko, 2018), digital numeracy literacy skills (Jannah & Oktaviani, 2022), dialogical skills in mathematics learning (Setyawan, Hakim, & Aziz, 2023), and mathematical literacy skills (Albar, Susilawati, & Fatmawati, 2022). However, this study provides a different focus than previous studies, namely facilitating mathematical computational thinking skills for students.

To support the achievement of this positive impact in mathematics learning, an effective bridge is needed, one of which is through the learning media used by educators. The importance of learning media followed by rapid technological developments has made the concept of learning media also change along with technological advances (Cahdriyana & Nurnugroho, 2023). By using AR in learning media, abstract mathematical concepts can be visualized in three-dimensional form, making it easier for students to understand. Several previous studies have developed Augmented Reality-based mathematics learning media, including Augmented Reality-based learning media on space building materials (Listiawan, Hayuningrat, & Anwar, 2022), Augmented Reality technology-based learning media on limas materials (Sungkono, Apiati, & Santika, 2022) mathematics learning media based on Augmented Reality (AR) on geometric transformation materials (Listiawan & Antoni, 2021) android-based mathematics learning media using Augmented Reality on curved side space building materials (Fahmi & Noviani, 2021) and Augmented Reality-based learning media on flat side space building materials (Wulandari, Samijo, & Darsono, 2022)

Although Augmented Reality (AR) has significant potential in learning, its application to improve mathematical computational thinking skills is still not widely done. This is reflected in the limitations of previous research that has not discussed in depth the development of AR-based learning media to support mathematical computational thinking skills. This is also in line with the needs analysis conducted by Cahdriyana & Nurnugroho (2023) in their research which revealed that most teachers have never used AR applications based on computational thinking skills. As a result, there are gaps in the literature that need to be filled in to optimize the use of AR in the context of mathematics learning. Therefore, this study aims to fill this gap by developing and evaluating Augmented Reality (AR)-based learning media that is specifically designed to improve students' mathematical computational thinking skills. This research makes an important contribution by not only developing innovative AR-based learning media but also providing practical guidance for educators in integrating this technology to encourage students' mathematical computational thinking skills. In addition, this research is expected to enrich the literature in the field of educational technology, especially related to the application of AR in mathematics learning.

METHODS

This research uses a type of research and development method also known as Research and Development (R&D). In this study, the ADDIE model is used, which as the name implies, consists of 5 main stages, namely Analysis, Design, Development, Implementation, and Evaluation.

In the analysis stage, the researcher conducted a pre-survey at SMA Insan Cendekia Sheikh Yusuf Gowa which aimed to collect information about needs in the learning process. In addition, this research involves an in-depth literature review to understand the concept of Augmented Reality (AR), computational thinking skills, and relevant learning media development approaches.

The design stage focuses on designing learning media that is developed by the results of the needs analysis. This includes designing learning media components, such as how mathematical content is integrated with an Augmented Reality technology. The design also includes learning scenarios and storyboards describing how AR will be used to convey mathematical concepts, an intuitive and engaging user interface to ensure learners can easily interact with AR-based learning media and activities that support students' mathematical computational thinking skills. The indicators of mathematical computational thinking involve several main components, namely: decomposition, which is breaking down a problem into small parts; pattern recognition, which is analyzing data to find patterns that help understand the data; abstraction, by eliminating unnecessary details and focusing on important elements; modeling or simulation, which is representing the process through a model or simulation; algorithm, which creates sequential steps to solve the problem; and evaluation, which assesses the effectiveness of the solution, generalize and applies it to new problems (Ihsan, Sutarmin, Arwadi, Zaki, & Naufal, 2021). On the other hand, the preparation of assessment instruments in the form of validation sheets that will be used to assess the products that have been developed, learning outcome tests, and student and teacher response questionnaires are also carried out to determine the practicality and effectiveness of the learning media that has been developed.

In the development stage, learning media is made that is ready to be tested and validated by experts. The development process includes the creation of learning media by the planned design. After the initial prototype was completed, the product was validated by three expert validators, consisting of two material experts, two media experts, and two technology experts. This validation produces quantitative data obtained from validation sheets and qualitative data derived from suggestions and inputs from expert validators. Quantitative data from validation test results will be analyzed using percentage analysis according to the following formula.

$$\text{Percentage} = \frac{\text{number of scores give}}{\text{maximum number of scores}} \times 100\% \quad (1)$$

The next step is to set the criteria for product validity before being tested on students. These validity criteria are listed in table 1.

Table 1. Criteria for the Validity of a Product

Valuation (%)	Category
80 < N ≤ 100	Very Valid
60 < N ≤ 80	Valid
40 < N ≤ 60	Quite Valid
20 < N ≤ 40	Invalid
0 < N ≤ 20	Very Invalid

Source: Yulianto, Ahmad, and Anwar (2022)

A product is considered valid if the average percentage exceeds 60% and can proceed to limited testing after revision based on input from experts.

In the implementation stage, the learning media that has been developed is applied to the test subjects. The test subjects in this study were 16 students of Insan Cendekia Syekh Yusuf Gowa High School. At the trial design stage, the implementation process of AR-based learning media is carried out in the classroom as part of geometric transformation learning. This activity begins with providing introductory material on the topic of geometric transformation to ensure students have an initial understanding of the material. Furthermore, students are directed to use the AR-based learning media that has been developed. In addition, the learning media was also given to mathematics teachers to assess the practicality of the media from the educator's side. Responses from students and teachers, as well as learning test results, were analyzed using percentage analysis with the following formula.

$$\text{Percentage} = \frac{\text{number of scores give}}{\text{maximum number of scores}} \times 100\% \qquad (2)$$

After analyzing the percentage of the results of the practicality test based on the responses of students and teachers, the product practicality criteria are determined according to table 2.

Table 2. Criteria for the Practicality of a Product

Valuation (%)	Category
80 < N ≤ 100	Very Practical
60 < N ≤ 80	Practical
40 < N ≤ 60	Quite Practical
20 < N ≤ 40	Impractical
0 < N ≤ 20	Very impractical

Source: Yulianto, Ahmad, and Anwar (2022)

The criteria for product practicality are considered practical if the average percentage exceeds 60%. Suggestions and inputs from students and teachers are also needed at this stage as materials for improving the learning media that has been developed. The effectiveness of the learning media developed is seen from the student learning outcome test. This ability is categorized as shown in table 3.

Table 3. Categories Mathematical Computational Thinking Skills

Valuation (%)	Category
86 – 100	Very High
71 – 85	High
56 – 70	Medium
0 – 55	Low

Source: Jamna, Hamid, and Bakar (2022)

The criteria for product effectiveness are considered effective if the average percentage of student learning outcome test scores exceeds 70.

The final stage in the ADDIE development model is the evaluation stage. At this stage, the researcher conducts an in-depth review to follow up on any deficiencies or problems identified in the previous stage. The purpose of the evaluation stage is to improve the learning media that will be used in the future. This evaluation includes an assessment of several key aspects, including the validity, practicality, and effectiveness of Augmented Reality-based learning media in supporting students' mathematical computational thinking skills. This evaluation is important to ensure that the learning media developed really meets the required standards and can be used optimally in the teaching and learning process. Researchers will analyze data from trials, feedback from users, and evaluation results to make necessary improvements and adjustments. Taking these factors into account, the evaluation stage aims to ensure that AR-based learning media is not only valid and practical but also effective in improving students' mathematical computational thinking skills, thus providing maximum benefits in the learning process.

RESULTS AND DISCUSSION

This research aims to develop Augmented Reality-based learning media to facilitate students' mathematical computational thinking skills in geometric transformation materials. The results of the study include the procedure for developing learning media by researchers, as well as an assessment of the validity, practicality, and effectiveness of learning media in facilitating students' mathematical computational thinking skills. Further details regarding the results are as follows.

1. Analysis

The analysis stage includes three steps that must be taken before researchers develop Augmented Reality-based mathematics learning media. These steps include problem analysis, analysis of student needs, and material analysis.

a. Problem analysis

Problem analysis is carried out to identify various challenges faced by educators and learners. The purpose of this analysis is to understand the types of learning media used by teachers in supporting the learning process in schools. Based on the results of observations in the classroom, the researcher identified several fundamental problems faced by class XI students at SMA Insan Cendekia Syekh Yusuf. The main problems found were that students found mathematics boring, had difficulty understanding the material, and did not have effective mathematics learning media to help improve their mathematical computational thinking skills, especially in geometry transformation materials. The absence of the right media hinders students' efforts to better process and apply mathematical concepts.

Furthermore, the results of an interview conducted by the researcher with one of the mathematics teachers in grade XI of SMA Insan Cendekia Syekh Yusuf showed that so far, learning activities at the school still depend on the mathematics package book provided by the government as the main handbook for teachers and students. The teacher revealed that there has been no variation in the active use of other learning media, and the package book is the only main source used. This indicates the lack of exploration and application of various additional learning media that can support the learning and teaching process more dynamically and interactively. These limitations can hinder the development of creativity in teaching methods as well as reduce students' opportunities to interact with different types of learning materials that may be more effective in improving their understanding and skills, especially in mathematics subjects.

Based on the results of observations and interviews conducted by the researcher, conclusions were obtained regarding the existence of several gaps or problems in class XI of SMA Insan Cendekia Sheikh Yusuf. The main findings include the low level of mathematical computational thinking ability among students and the lack of variation in the use of learning media by teachers in designing and implementing teaching methods. This limitation shows that the current methods are not effective enough in supporting the development of students' mathematical computational thinking skills. These problems encourage researchers to seek innovative solutions. Taking into account the existing limitations, the researcher took the initiative to develop Augmented Reality-based mathematics learning media. This media is specifically designed to facilitate the improvement of students' mathematical computational thinking skills, especially in geometry transformation materials. With the use of AR technology, it is hoped that students can have a more interactive and well-rounded learning experience, which in turn can help them better understand and apply mathematical concepts.

b. Student analysis

In a learning activity, the learning experience will be more interesting and the material will be easier for students to understand if the learning media used has an attraction and presents the material and the steps to work on the questions. This is important so that students can easily follow and understand the concepts of the material taught. To achieve this goal, researchers can apply technology as a tool in the learning process.

The findings from interviews with several students in grade XI of SMA Insan Cendekia Syekh Yusuf show that they prefer active learning methods and utilize technology, such as the use of interactive learning media. This information indicates that students feel more engaged and benefit more from learning that involves technology. Therefore, there is a need to provide learning media that is not only interesting but also effective and practical. Such media is expected to help students improve their mathematical computational thinking skills, as well as support the understanding and application of mathematical concepts in a more dynamic and fun way.

c. Material analysis

At this stage, the activities carried out involve the process of identifying, detailing, and preparing the main materials learned by students systematically. This process aims to structure the material in a structured and easy-to-understand way. In this study, the subject matter focused on geometric transformation. The scope of matter includes a variety of important concepts, including translation, reflection, rotation, and dilation. This material on geometric transformations is carefully structured to ensure that each concept is conveyed clearly and is well integrated. Translation includes an understanding of the shift in the position of an object in the coordinate plane, reflection involves an understanding of the object's reflection against a specific line, rotation relates to the rotation of an object around a central point, and dilation relates to a change in the size of an object through scale multiplication. By systematically compiling these materials, it is hoped that students can gain a deep and comprehensive understanding of the concepts of geometric transformation, and can apply this knowledge in a broader mathematical context.

2. Design

After completing the analysis stage, the next step is the design stage. At this stage, the researcher will design an Augmented Reality-based mathematics learning media to improve students' mathematical computational thinking skills. The design created at this stage is provisional and will undergo further development and improvement processes based on suggestions and feedback from a team of experts. During the design stage, all findings and study results from the analysis stage will be translated into a more concrete form. This includes creating initial prototypes of learning media designed to meet the needs of learners in understanding mathematical concepts more interactively and engagingly. This design process involves selecting and arranging AR elements to be used, such as 3D visualization, animation, and user interaction, to ensure that the learning media can support the learning process effectively. The resulting design will later be tested and evaluated to ensure that the learning media is following educational objectives and provides maximum benefits in learning activities. Therefore, this design stage is an important step in realizing the ideas that have been developed at the analysis stage into products that are ready to be used in the context of mathematics learning.

In making this mathematics learning media, the researcher uses the Canva and Assemblr Studio applications which will be used as support in conducting media development. In the summary material, LKPD, and learning videos are included in a QR code and included in the teaching module designed on the Canva application. The design of the structure of the designed learning media is as follows: (1) cover, (2) foreword, (3) table of contents, (4) module usage instructions, (5) concept map, (6) geometric transformation, (7) quiz time, (8) glossary, and (9) bibliography.

3. Development

After the design process is carried out, the next stage is development. The activities carried out at the development stage are the creation of learning media in the form of teaching modules, and product feasibility validation tests. The steps at the development stage are as follows.

a. Creation of teaching modules

This stage begins with the front page display of the teaching module, cover image and core competencies of the Canva application and its attachments with the help of the Assembler Studio application. The following are the results of the development of teaching modules developed by researchers, namely:

1) Cover

The cover is the initial appearance of the module as well as its face, which includes the design and name of the module. Here is the design created by the researcher.

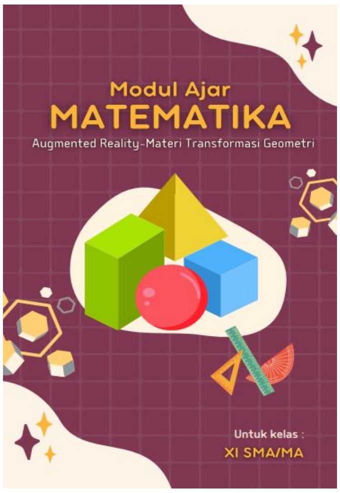
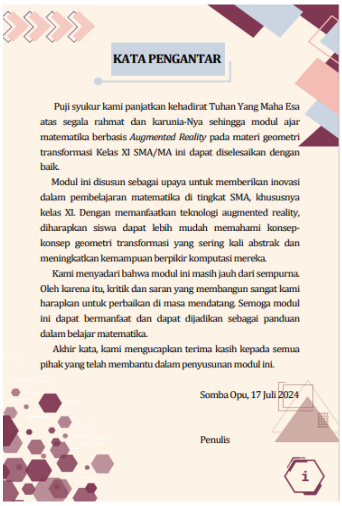


Figure 1. Cover Page

2) Foreword

This section contains gratitude to God for the smooth completion of the teaching module, and the purpose and benefits of making the teaching module.



KATA PENGANTAR

Puji syukur kami panjatkan kehadirat Tuhan Yang Maha Esa atas segala rahmat dan karunia-Nya sehingga modul ajar matematika berbasis *Augmented Reality* pada materi geometri transformasi Kelas XI SMA/MA ini dapat diselesaikan dengan baik.

Modul ini disusun sebagai upaya untuk memberikan inovasi dalam pembelajaran matematika di tingkat SMA, khususnya kelas XI. Dengan memanfaatkan teknologi augmented reality, diharapkan siswa dapat lebih mudah memahami konsep-konsep geometri transformasi yang sering kali abstrak dan meningkatkan kemampuan berpikir komputasi mereka.

Kami menyadari bahwa modul ini masih jauh dari sempurna. Oleh karena itu, kritik dan saran yang membangun sangat kami harapkan untuk perbaikan di masa mendatang. Semoga modul ini dapat bermanfaat dan dapat dijadikan sebagai panduan dalam belajar matematika.

Akhir kata, kami mengucapkan terima kasih kepada semua pihak yang telah membantu dalam penyusunan modul ini.

Somba Opu, 17 Juli 2024

Penulis

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Figure 2. Foreword

3) Table of contents

It contains a list of learning activity pages that aim to make it easier for teachers to find pages in this module.

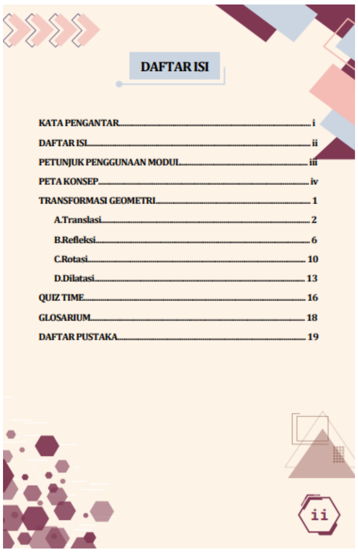
DAFTAR ISI

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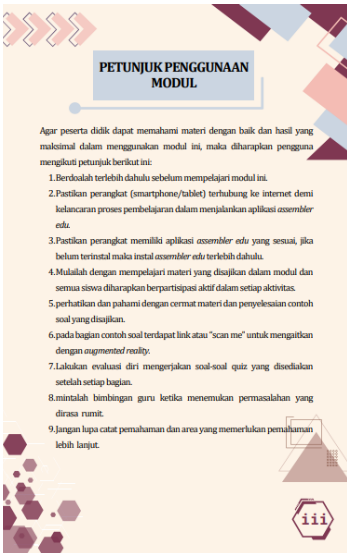
Figure 3. Table of Contents

4) Module usage instructions

This section contains how to use teaching modules that function to make it easier for teachers to use teaching modules.


PETUNJUK PENGGUNAAN MODUL

Agar peserta didik dapat memahami materi dengan baik dan hasil yang maksimal dalam menggunakan modul ini, maka diharapkan pengguna mengikuti petunjuk berikut ini:

1. Berdoalah terlebih dahulu sebelum mempelajari modul ini.
2. Pastikan perangkat (smartphone/tablet) terhubung ke internet demi kelancaran proses pembelajaran dalam menjalankan aplikasi *assembler edu*.
3. Pastikan perangkat memiliki aplikasi *assembler edu* yang sesuai, jika belum terinstal maka instal *assembler edu* terlebih dahulu.
4. Mulailah dengan mempelajari materi yang disajikan dalam modul dan semua siswa diharapkan berpartisipasi aktif dalam setiap aktivitas.
5. perhatikan dan pahami dengan cermat materi dan penyelesaian contoh soal yang disajikan.
6. pada bagian contoh soal terdapat link atau "scan me" untuk mengaitkan dengan *augmented reality*.
7. Lakukan evaluasi diri mengerjakan soal-soal quiz yang disediakan setelah setiap bagian.
8. mintalah bimbingan guru ketika menemukan permasalahan yang dirasa rumit.
9. Jangan lupa catat pemahaman dan area yang memerlukan pemahaman lebih lanjut.

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Figure 4. Module Usage Instructions

5) Concept map

The concept map section contains sub-material for geometric transformation.

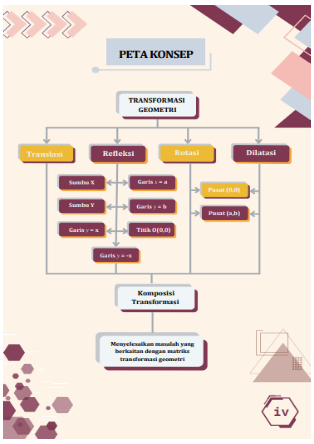

Figure 5. Concept Map

6) Material Description

In this section, it contains concise material about geometric transformations and their sub-sub-materials including translation, reflection, rotation, and dilatation. Each sub-material is equipped with summary materials, examples, practice questions, and learning videos available in the code that has been provided.

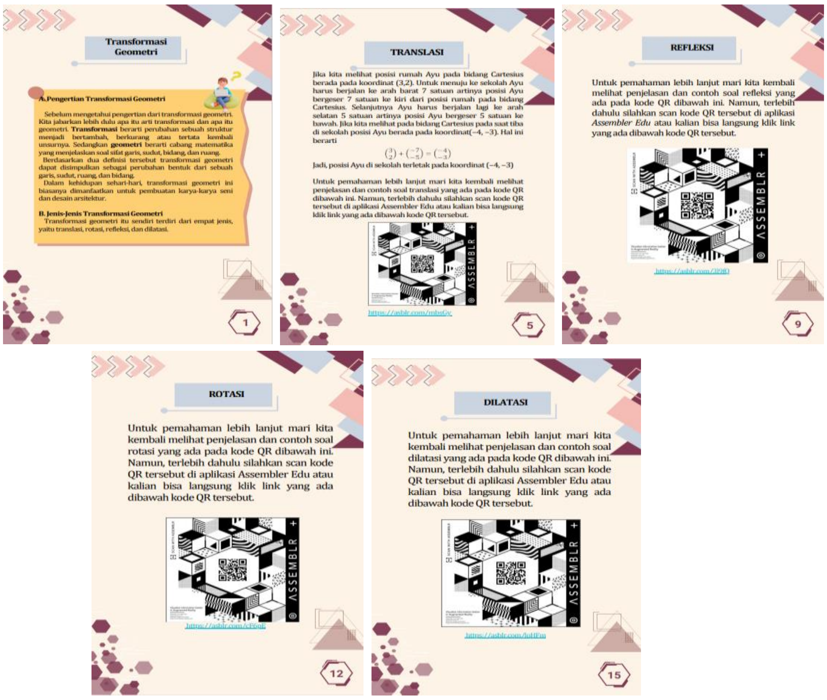

Figure 6. Material Description

7) Quiz Time

This section contains exercises to find out the extent of students' achievement in receiving material from the teacher.

Figure 7. Quiz Time

b. Integration of augmented reality in learning media

In the development of this Augmented Reality (AR)-based learning media, important materials such as translation, reflection, rotation, and dilatation are integrated into the AR application to enrich the learning experience of students. The development process begins with designing content that includes structured explanations of the material, visual examples, and reference videos from relevant YouTube to clarify these concepts. Each element in this material is adjusted so that it can be visualized interactively through AR so that students can understand the concepts of transformation geometry more easily and thoroughly.

This AR application is designed to be easily accessible by scanning the barcode listed on the teaching module that has been prepared. The barcode is directly connected to an AR display that projects visualizations of various geometric transformations. The developers also ensure that the AR app is compatible with a wide range of mobile devices commonly used in schools, as well as provide technical guidance for teachers and students so that the app can be operated easily. In addition, the developers also included a reference video feature taken from the YouTube platform to provide additional explanations about each material, which is accessed directly from within the AR application, so that students can gain a deeper understanding through various learning resources.

The display of Augmented Reality integration in the developed media can be seen in the following image.

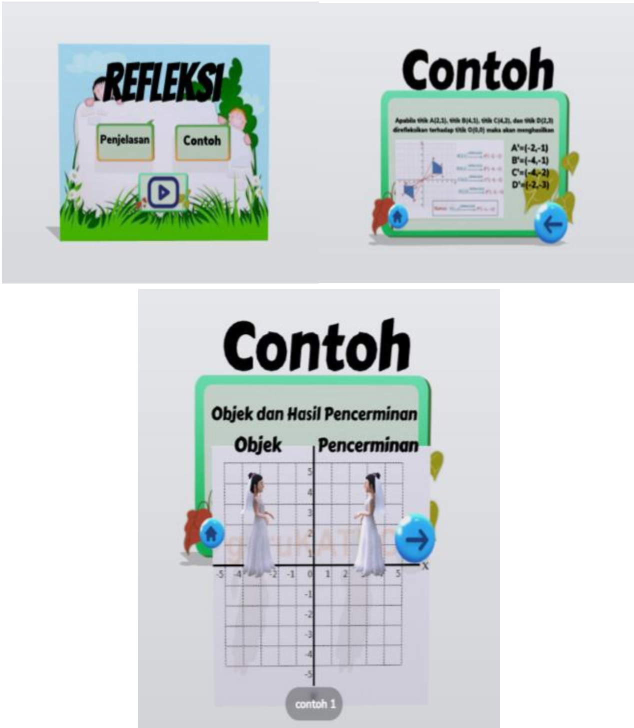

Figure 8. Augmented Reality Design

c. Product feasibility validation test

Product validation is carried out by validators consisting of material expert validators, media expert validators, and technology expert validators. The results of product validation are based on assessments from validators as shown in table 4.

Table 4. Product Validation Results

No	Validator	Assessment Percentage (%)	Information
1	Material Expert	98	Very Valid
2	Media Expert	98	Very Valid
3	Technologist	98	Very Valid

Based on the results of product validation in table 4, the percentage of validator assessments of material experts, media experts, and technology experts was obtained of 98% with a very valid category. Thus, Augmented Reality-based mathematics learning media has met the validity criteria.

4. Implementation

The deployment stage is the fourth step in the ADDIE development model. At this stage, researchers will apply Augmented Reality-based mathematics learning media that has been developed into the learning process. In addition, this stage also involves evaluating the media by collecting assessments from teachers and students. This implementation process aims to assess how practical and effective Augmented Reality-based learning media are in a real context. Evaluation by teachers will provide a perspective on how these media function in the teaching environment and whether they are appropriate for the curriculum needs and the teaching methods used. Meanwhile, feedback from students will provide insight into their experience in using this learning media, including the extent to which the media facilitates their understanding of mathematics material and increases their involvement in the learning process. By conducting this assessment, researchers can obtain valuable information about the success and potential improvement of the learning media that has been implemented. The results of the evaluation will be the basis for further revision and refinement, to ensure that Augmented Reality-based learning media can provide maximum benefits in improving the quality of mathematics learning.

The practicality analysis is based on the responses of students and teachers to Augmented Reality-based mathematics learning media. The results of the response analysis are described as shown in table 5.

Table 5. Analysis of Student and Teacher Responses

No.	Subject	Response Percentage (%)	Information
1	Students	75	Practical
2	Teacher	95	Very Practical

Based on the results of the analysis of student and teacher responses, it was found that Augmented Reality-based mathematics learning media received responses from students of 75% in the practical category and responses from teachers of 95% in the very practical category. Thus, the Augmented Reality-based mathematics learning media developed is considered to have met the standards of practicality.

Furthermore, the effectiveness analysis is based on a test of students' learning outcomes after using Augmented Reality-based mathematics learning media. The results of the test are described in table 6.

Table 6. Students' Computational Thinking Ability Level

Mastery Level	Frequency	Percentage of Grades (%)	Category	Average
86 – 100	6	37,50	Very High	74 (High)
71 – 85	5	31,25	High	
56 – 70	3	18,75	Medium	
0 – 50	2	12,50	Low	
Total	16	100		

5. Evaluation

The last stage in the ADDIE development model is the evaluation stage, which is the final step in the process of developing Augmented Reality-based mathematics learning media. At this stage, the researcher conducts a thorough evaluation of the media that has been developed to assess its various aspects. This evaluation involves an analysis of the validity, practicality, and effectiveness of the learning media. This evaluation process aims to ensure that Augmented Reality-based mathematics learning media meets the standards that have been set. The validity test refers to the extent to which the media is following the expected learning objectives and material, while the practicality test assesses how easy the media is to use in a real learning context. The effectiveness test evaluates the extent to which the media is successful in improving students' mathematical computational thinking skills.

After going through this evaluation, it was found that Augmented Reality-based mathematics learning media has met the set standards. This shows that the media is ready to be used in the learning process, and can be effective in facilitating students' mathematical computational thinking skills. Thus, this media is considered feasible and can be integrated into teaching and learning activities to support the improvement of students' mathematical understanding more interactively and interestingly.

The results of the research obtained are in line with several previous research studies that have developed Augmented Reality-based learning media and have met the criteria of validity, practicality, effectiveness, and feasibility of use in the learning process. Research by Feby and Siregar (2022) who developed a Google Sites Web-based learning media assisted by Augmented Reality. Research by Amrina, Sari, Alfino, and Mahdiansyah (2023) develops Augmented Reality (AR)-based mathematics learning media to improve student competence. Research by Rozi, Kurniawan, and Sukmana (2021) is an Augmented Reality-based learning medium for learning to recognize building spaces. Research by Wulandari, Samijo, and Darsono (2022) is an Augmented Reality-based mathematics learning medium on flat side space building materials. Finally, research by Listiawan, Hayuningrat, and Anwar (2022) which is an Augmented Reality-based learning media on space building materials. The difference between some previous studies and the research conducted lies in the specification of the objectives of the abilities to be achieved specifically, where the research carried out focuses on facilitating students' mathematical computational thinking skills.

The development of Augmented Reality (AR)-based mathematics learning media to improve students' mathematical computational thinking skills is an important breakthrough in the world of education. Augmented Reality (AR) technology has entered various sectors, from industry and marketing to education, where AR plays a role as one of the main innovations in the development of learning media (Yusup, Azizah, Rejeki, Silviani, Mujahidin, & Hartono 2023). This technology allows users to see and interact with the real world enhanced by virtual elements (Indahsari & Sumirat, 2023) Augmented Reality (AR) focuses on integration with real environments, allowing for more direct and real-time interaction with systems. AR technology is experiencing rapid development, so it can be applied in various fields, including in education. An example of its application is in the teaching of mathematics material (Sari, Batubara, Hazidar, & Basri, 2022).

Augmented Reality (AR)-based mathematics learning media has a close relationship with the development of students' mathematical computational thinking skills. This media is designed to provide an interactive and immersive learning experience by presenting a visualization of mathematical concepts in three-dimensional form. The use of AR technology allows students to observe and interact directly with abstract representations that were previously difficult to understand through conventional methods. Students will gain experience by combining their real environment with a designed virtual environment (Manikam & Maat, 2023). This can help students understand and solve mathematical problems more effectively.

The ability to think computationally itself is highly dependent on abstract thinking skills, where students must be able to choose the right representation for a problem, either in visual, numerical, or symbolic form (Sitorus & Yahfizham, 2024). This is in line with the characteristics of AR media, which gives students the freedom to interact with visual representations of mathematical concepts dynamically and intuitively. With the help of AR, learners can transform abstract concepts into more concrete visualizations, thus facilitating computational thinking processes that involve the selection and manipulation of the most relevant mathematical representations for problem-solving.

Overall, the development of this media contributes significantly to overcoming the obstacles that students often face in learning mathematics, especially in terms of improving mathematical computational thinking skills. In the future, this AR-based learning media is expected to be integrated into various learning strategies to maximize the potential of technology in improving the quality of mathematics learning.

CONCLUSION

Based on the results of the research and discussion, it can be concluded that the Augmented Reality (AR)-based mathematics learning media to facilitate students' mathematical computational thinking skills has met the criteria of validity, practicality, and effectiveness. This media has been proven to be valid through the assessment of experts, practical in its use by teachers and students, and effective in facilitating students' mathematical computational thinking skills.

However, this study has some limitations. Product trials are only conducted on a limited group of learners and in a controlled learning environment, so the results may not be fully representative of the wider population. In addition, the long-term impact of the use of AR media on improving mathematical computational thinking skills has not been explored in depth. The suggestion for further research is to conduct a trial on a wider scale involving different levels of education and characteristics of different learners to test the generalization of these findings. Further research can also explore the development of additional features in AR media, such as the integration of artificial intelligence (AI) to provide automated feedback to learners, as well as improve the collaborative aspect of solving mathematical problems computationally.

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