INDONESIAN JOURNAL OF SCIENCE AND MATHEMATICS EDUCATION
https://ejournal.radenintan.ac.id/index.php/IJSME/index
08 (1) (2025) 66-81
E-ISSN: 2615-8639
DOI: 10.24042/ijsme.v8i1.25875
March 2025

E-module for geometric transformation visualization: A case study on generation Z mathematics education

David Pratama[1*], Latifah Darojat[2]
[1,2]Department of Mathematics Education, Faculty of Teacher Training and Education, Universitas Singaperbangsa Karawang, Jawa Barat, Indonesia

**Corresponding author:* david.pratama@fkip.unsika.ac.id

Article history:

Submitted: December 7, 2025
Accepted: March 1, 2025
Published: March 30, 2025

Keywords:

e-module, generation Z, geometric transformations, simple project, visualization, YouTube video

ABSTRACT

Teaching transformation geometry in schools requires visualization tools to enhance students' conceptual understanding. Therefore, mathematics education students need to be equipped with adequate visualization skills. This study aimed to develop an interactive e-module based on YouTube video tutorials and simple projects to help students, particularly Generation Z, visualize transformation geometry concepts. The development model employed was the ADDIE (Analysis, Design, Development, Implementation, Evaluation). The findings indicated that the developed interactive e-module was valid (88.2%, excellent category), practical (75%, good category), and effective (94.3%) in supporting students in visualizing transformation geometry concepts. Integrating YouTube tutorial videos and simple projects facilitates students in learning and understanding the visualization of transformation geometry effectively and comprehensively. This study has implications for integrating technology-based interactive tools in learning, which can significantly enhance student engagement and mastery of abstract mathematical concepts.

E-modul untuk visualisasi transformasi geometri: Studi kasus pada mahasiswa pendidikan matematika generasi Z

Kata Kunci:

e-modul, generasi Z, transformasi geometri, proyek sederhana, visualisasi, video YouTube

ABSTRAK

Pembelajaran geometri transformasi di sekolah memerlukan alat bantu visualisasi untuk meningkatkan pemahaman konsep siswa. Oleh karena itu, mahasiswa pendidikan matematika perlu dibekali keterampilan visualisasi yang memadai. Penelitian ini bertujuan untuk mengembangkan e-modul interaktif berbasis video YouTube dan proyek sederhana yang membantu mahasiswa, khususnya Generasi Z, dalam memvisualisasikan bentuk-bentuk transformasi geometri. Metode yang digunakan adalah ADDIE (Analysis, Design, Development, Implementation, Evaluation). Hasil penelitian menunjukkan bahwa e-modul interaktif yang dikembangkan valid (88,2%, kategori excellent), praktis (75%, kategori good), dan efektif (94,3%) dalam mendukung mahasiswa memvisualisasikan konsep transformasi geometri. Penggunaan video tutorial YouTube dan proyek sederhana memudahkan mahasiswa dalam mempelajari dan memahami visualisasi bentuk-bentuk transformasi geometri secara lebih efektif dan mendalam. Penelitian ini berimplikasi pada integrasi alat interaktif berbasis teknologi ke dalam pembelajaran dapat secara signifikan meningkatkan keterlibatan siswa dan penguasaan mereka terhadap konsep matematika yang abstrak.

Contribution to the literature

This research contributes to:

- Providing interactive e-modules as learning materials to assist education students, particularly Generation Z, in easily and simply visualizing geometric transformation shapes.
- High validation scores and positive student responses indicate that the e-module effectively supports students in visualizing geometric transformation shapes.
- Supporting educational practices that align with the learning needs of the digital era to enhance student engagement and understanding.

1. INTRODUCTION

Visualization is crucial in learning geometric transformations, significantly contributing to students' conceptual understanding and problem-solving abilities. Spatial visualization skills are essential in solving geometric problems, as students are not only required to calculate values but must also be able to mentally visualize geometric objects [1]. However, one of the primary causes of students' errors in solving geometric transformation problems is their inadequate mastery of fundamental concepts [2]. A strong conceptual understanding greatly supports students in addressing and resolving mathematical problems effectively [3]–[5]. Effective visualization strategies have been shown to enhance students' understanding of transformation principles, ultimately improving their performance in learning geometric transformations [6]. Therefore, integrating visualization tools and strategies into teaching geometric transformations is essential for fostering deeper understanding and better learning outcomes.

Technology has become indispensable in modern education, enhancing learning quality and fostering academic excellence [7]–[9]. Integration of visualization software into learning frameworks has been shown to significantly enhance students' skills and knowledge in various mathematical topics, including geometric transformations [10]. Applications that support visualization in learning geometric transformations substantially positively impact students' conceptual understanding of mathematics [11], [12]. Research indicates a significant difference in students' learning outcomes before and after utilizing visualization software [13]. Moreover, tools such as GeoGebra make learning more engaging and effective by focusing on conceptual understanding rather than rote memorization [14]. Thus, incorporating visualization software into geometric transformation lessons can provide students with a more interactive and meaningful learning experience.

The results of the 2022 PISA (Programme for International Student Assessment) indicate that Indonesia's mathematical literacy scores have reached their lowest point since 2006, continuing a declining trend observed since the early 2000s [15], [16]. This concerning performance highlights the need for improved mathematics education, including a stronger emphasis on visualization skills in learning geometric transformations. In mathematics education programs, it is essential to equip future teachers—most of whom are Generation Z with the skills to effectively use visualization tools such as GeoGebra. Generation Z, characterized by their familiarity with technology, multitasking abilities, and preference for hands-on activities, [17]–[21] are more responsive to learning approaches that integrate digital tools and interactive activities. With their natural inclination toward interactive and technology-driven learning, Generation Z students are well-positioned to master visualization tools such as GeoGebra. Therefore, integrating technology is crucial.

Many Generation Z students struggle with conceptual understanding despite their technological familiarity and exhibit low learning engagement, particularly in mathematics. This issue can be attributed to the lack of teaching materials tailored to their characteristics and preferences. Traditional teaching methods, which rely heavily on passive instruction, fail to capture their attention and effectively convey abstract mathematical concepts [22]. Additionally, students often struggle to identify given information and construct logical proofs in geometric transformations [23]. Surveys and studies indicate that the conceptual understanding of mathematics among Indonesian students remains relatively low [23], [24]. Furthermore, many students encounter challenges in visualizing abstract geometric objects and require assistance from visualization tools like GeoGebra to bridge this gap [25]. Observations among mathematics education students at Universitas Singaperbangsa Karawang have revealed that traditional teaching methods often fail to stimulate active participation and engagement, highlighting the urgent need for innovative teaching materials aligned with the learning styles of Generation Z students.

An effective solution to address these challenges is the development of an interactive e-module tailored for use on mobile devices. This interactive e-module, based on GeoGebra and supported by simple projects and video tutorials uploaded on YouTube, offers students flexible access to learning materials anytime and anywhere [26]–[29]. Interactive e-modules aligned with technological advancements have enhanced students' motivation and achievement and improved their critical mathematical thinking skills [30]–[33]. Furthermore, video tutorials provide a flexible medium for self-paced learning, allowing students to revisit lessons as needed [34], [35]. Project-based learning embedded in these e-modules encourages students to actively engage in problem-solving, fostering curiosity, creativity, and critical thinking [36]–[38]. Additionally, GeoGebra applications are proven effective in enhancing students' conceptual understanding and mathematical skills [6], [11]. By integrating these tools into a cohesive e-module, educators can offer an innovative, engaging, and effective approach to teaching geometric transformations to Generation Z students.

A few researchers focused on the integration of visualization tools such as GeoGebra to enhance students' understanding of geometric transformations [6], [10], [11], [13], [14], [39]. Limited studies have concerned the development and evaluation of interactive e-modules specifically designed for Generation Z students, addressing their learning preferences and technological inclinations. Therefore, this research intends to develop and systematically evaluate an interactive e-module featuring GeoGebra, YouTube tutorials, and project-based learning to enhance mathematics education students' visualization skills and conceptual understanding.

This research aims to develop an interactive e-module specifically designed to support mathematics education students, particularly those belonging to Generation Z, in enhancing their visualization skills related to geometric transformations. As digital natives, Generation Z students are inherently familiar with technology and interactive digital tools, making integrating an interactive e-module highly relevant and effective for their learning experiences. This e-module aims to bridge the gap between abstract geometric concepts and students' ability to visualize these transformations dynamically. The study focuses on developing and evaluating the e-module's quality, emphasizing three critical aspects: validity, practicality, and effectiveness. Validity ensures that the content and structure of the e-module align with established mathematical principles and learning objectives. Practicality assesses whether the module is user-friendly, accessible, and feasible for implementation in classroom environments. Conversely, effectiveness is evaluated based on its ability to improve students' visualization skills in geometric transformations, enabling them to better understand and interpret abstract mathematical concepts through interactive and visual learning experiences.

2. METHOD

This research employed a developmental research approach, commonly referred to as Research and Development (R&D). The development model utilized in this study is the ADDIE model, which comprises five key stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model is widely recognized as an instructional design framework that outlines fundamental and systematic stages for designing and developing educational materials, offering a structured yet flexible guideline for researchers and educators [40]. The mnemonic ADDIE represents a series of interconnected procedures that cannot be separated, forming an integrated process essential in executing developmental research [41]. Each stage in the ADDIE model plays a critical role in ensuring the developed instructional materials' effectiveness, efficiency, and quality. After receiving athics approval, the research was conducted. The following are the stages of the ADDIE model developed in this study, as presented in Figure 1.

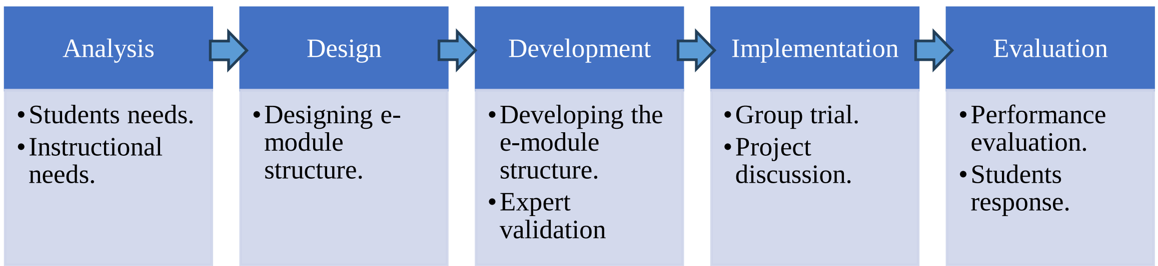


Figure 1. ADDIE Development Model

2.1 Participants

This study was conducted at Universitas Singaperbangsa Karawang, involving 32 fifth-semester students from the Mathematics Education Study Program enrolled in the Transformation Geometry course for the 2024/2025 academic year. After receiving consent from students, the research was conducted. The e-module was implemented by dividing the students into eight groups, each consisting of four members. Each group was assigned a project task integrated into the module. Furthermore, the module was evaluated by four expert validators, comprising two mathematics material experts and two media specialists. The involvement of student groups and expert validators ensured a systematic and comprehensive assessment of the module's design, content, and effectiveness in enhancing students' ability to visualize geometric transformations.

2.2 Instruments

This study employs several instruments to collect the necessary data, including validation sheets, student response questionnaires, and project assessment rubrics, as follows:

1. A validation sheet is utilized to assess the quality of the e-module from both material and media perspectives, ensuring its alignment with educational standards and learning objectives. This instrument is a structured evaluation tool provided to four expert validators, consisting of two material experts and two media experts. The material experts evaluate the relevancy, accuracy, convenience, attractiveness, and comprehensiveness of the content of the curriculum. In contrast, the media experts

assess the module's presentation, functionality, and significance as a digital learning resource. Through this validation process, feedback and recommendations are gathered to refine and enhance the quality of the e-module before its implementation in the classroom.

2. A student response questionnaire is used to assess the practicality of the e-module from the learners' perspective. This instrument collects feedback on two aspects of the module: functionality and accessibility throughout the learning process. It also explores whether the e-module effectively supports students in achieving the learning objectives and whether its interactive features contribute to enhanced engagement and ability to visualize geometric transformations.
3. Project assessment rubrics evaluate the outcomes of students' projects. This assessment provides insights into whether the e-module effectively aids students in visualizing geometry's various shapes and transformations.

2.3 Data Analysis

Several analyses are conducted during the development process using the ADDIE method, focusing on various stages to ensure the effectiveness and quality of the e-module.

2.3.1 Validity Analysis

The e-module will be thoroughly evaluated by validators, with two experts assigned to assess each component: material and media. For both the material and media components, various evaluation aspects will be rated on a scale from 1 to 5, where 1 represents "highly invalid," 2 indicates "invalid," 3 signifies "somewhat valid," 4 stands for "valid," and five denotes "highly valid." The validity score from the two validators will be calculated using the following formula:

$$v = \frac{val_1 + val_2}{2} \qquad (1)$$

v = Combined validity score
val_1 = Validity score of the validator 1
val_2 = Validity score of the validator 2
Subsequently, the combined validity score (v) will be converted into a percentage, with the validity categorized as follows:

Table 1. Product criteria [42]

No	Interval Percentage	Criteria
1	81 – 100	Excellent
2	61 – 80	Good
3	41 – 60	Fairly Good
4	21 – 40	Poor
5	0 – 20	Very Poor

2.3.2 Practicality Analysis

To assess the practicality of the e-module, students will complete a response questionnaire on a scale of 1 to 5, with each score representing categories used in the validity analysis. The average score will then be calculated using the following formula:

$$\bar{P} = \frac{\sum P_i}{n} \qquad (2)$$

$\bar{P}$ = Average of practicality score
$\sum P_i$ = Sum of practicality score from $i = 1$ to n
n = Number of participants
Subsequently, the average practicality score $(\bar{P})$ will be converted into a percentage and compared with Table 1 to determine the corresponding practicality criteria.

2.3.3 Effectiveness Analysis

To measure the effectiveness of the e-module, a scoring process is conducted on the project outcomes completed by student groups using a provided rubric. The average score of the eight groups is then calculated using the following formula:

$$\bar{E} = \frac{E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7 + E_8}{8} \quad (3)$$

$\bar{E}$ = Average of effectiveness score
E_i = Effectiveness score of the group $i = 1$ to 8.
Subsequently, the average effectiveness score $(\bar{E})$ will be converted into a percentage and referenced against Table 1 to assess the corresponding effectiveness criteria.

3. RESULTS AND DISCUSSION

The development of the interactive e-module for enhancing geometric transformation visualization skills utilized the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model. This systematic approach ensured each phase contributed to the module's quality. The Analysis phase identified student needs and instructional needs; the Design phase outlined the module structure; the Development phase involved expert validation; the Implementation phase tested it in classrooms; and the Evaluation phase assessed practicality and effectiveness. The following sections detail the outcomes of each phase.

3.1 Analysis

The analysis phase aimed to systematically identify and evaluate the challenges and instructional needs in the teaching and learning of geometric transformation among mathematics education students. Data was collected through structured interviews and classroom observations across four instructional sessions. The findings revealed that geometric transformation courses remain predominantly theoretical despite the essential role of visualization skills in effectively teaching these concepts at the school level. Prospective teachers require hands-on visualization proficiency to bridge the theoretical understanding and practical application gap. Moreover, as digital natives, Generation Z students demonstrate a heightened preference for technology-integrated instructional strategies. The traditional lecture-based approach was observed to induce disengagement. It was perceived as pedagogically ineffective, emphasizing the urgent need for instructional materials that align with their cognitive and behavioral characteristics. These insights underscore the necessity of developing instructional materials tailored to Generation Z learners' distinctive learning preferences and technological inclinations.

3.2 Design

The design phase focuses on developing an interactive e-module for geometric transformation visualization, utilizing GeoGebra as the primary software, complemented by simple project-based tasks and tutorial videos hosted on YouTube. The structure of the e-module begins with an introduction to GeoGebra as a visualization tool specifically tailored for geometric transformation learning. Subsequent sections focus on foundational concepts, including visualizing basic geometric objects, functions, and graphs and the relationships between parallel and perpendicular lines. The instructional design then progresses to more advanced topics, guiding users through the conceptual understanding and visualization techniques of core geometric transformations, including reflection, rotation, translation, and dilation. Each instructional segment is systematically reinforced with interactive activities and video tutorials to ensure clarity, engagement, and the practical application of learned concepts. The simplified design of the module structure is presented in Figure 2.

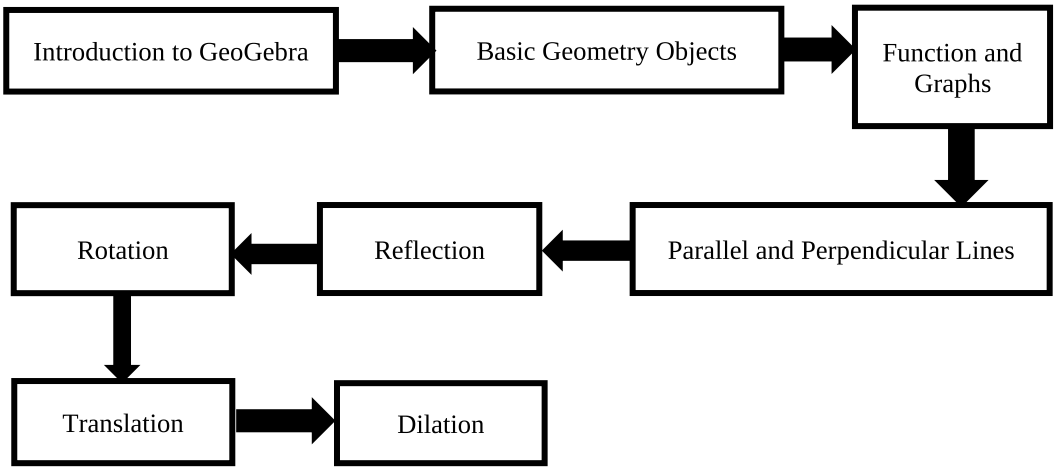


Figure 2. The Module Structure

3.3 Development

The e-module is developed in Indonesian and consists of four sub-sections within each chapter: Objectives, Basic Concepts, Visual Demonstration, and Project. These four components are systematically designed to guide students in independently learning the visualization of geometric transformations.

1. Objectives: The Objectives section clearly outlines the expected learning outcomes that students should achieve after completing the chapter. Each chapter's objectives are carefully crafted and structured into two primary achievements. The first achievement emphasizes explaining and understanding the fundamental concepts and principles related to the discussed topic. Meanwhile, the second achievement highlights the development of visualization skills using GeoGebra as an interactive learning tool. This dual focus ensures a balanced approach, combining theoretical knowledge with practical application.
2. Basic Concepts: Students will encounter the Basic Concepts section after defining the objectives. This section is presented through concise narratives; where possible, explanations are supported by illustrations or tables. This approach aligns with the characteristics of Generation Z, who generally prefer visually engaging content over traditional reading activities.
3. Visual Demonstration: Students will proceed to the Visual Demonstration section after studying basic concepts. This subsection is divided into Case, Visualization Procedure, and Visualization Results. The case was presented descriptively, and this component included problems requiring students to visualize specific geometric transformations. Solutions are provided through videos demonstrating step-by-step visualization processes and visualization Procedures. The videos included in the e-module are

designed to enhance the learning experience while maintaining efficiency and clarity. Each video must have a duration of under five minutes; if the content requires more time, it should be divided into two or more parts to ensure accessibility and focus. The videos must directly address the intended substance, ensuring the content is efficient and effective. Every step in the demonstration must be clearly shown, with problem-solving steps presented legibly and organized to support students' understanding. Additionally, background music is incorporated to create an engaging and conducive learning atmosphere, making the videos more enjoyable and motivating for students.

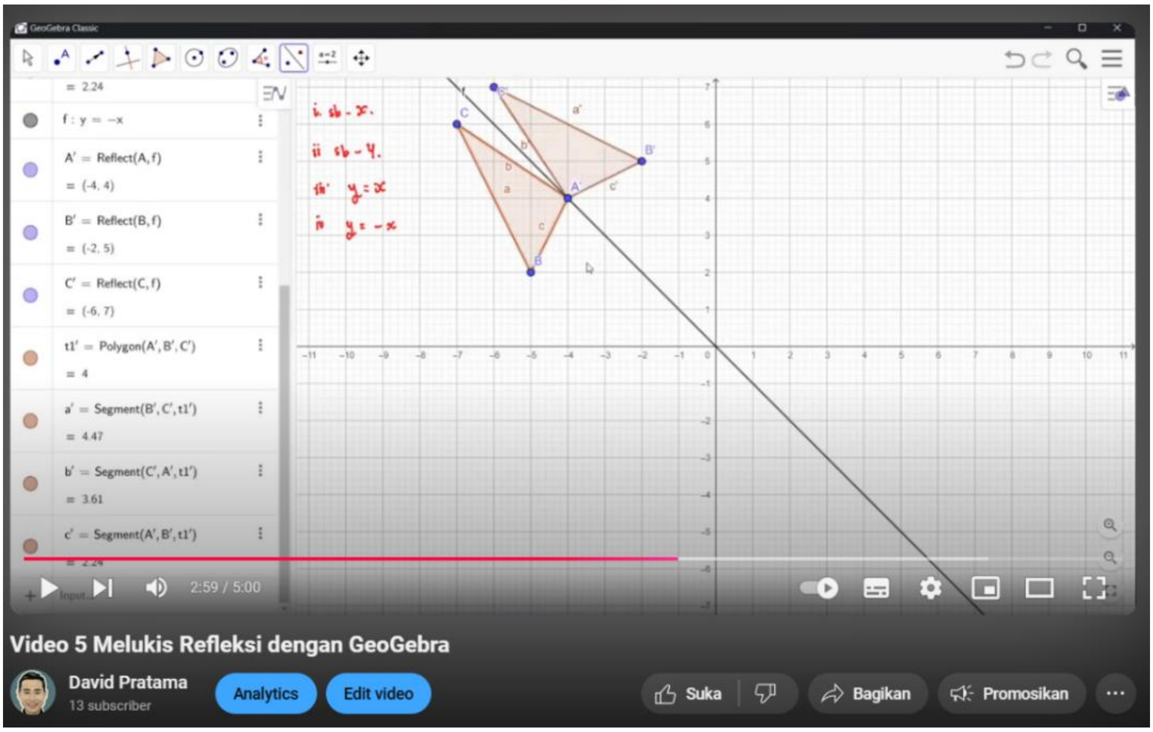


Figure 3. The Video of Visualization Processes Hosted on YouTube

4. Project: The final sub-section is the Project. This section provides group project tasks that are simple yet meaningful, requiring students to collaborate and work together effectively. These tasks are meticulously designed with several criteria to support students' learning and engagement. Firstly, the project tasks are intentionally modeled after the case problems presented in the Visual Demonstration subsection. This alignment allows students to apply theoretical knowledge to practical scenarios, bridging the gap between abstract concepts and their real-world applications. Secondly, each project consists of three distinct tasks, divided into two difficulty levels: easy and moderate. Every project includes an additional exploration task to further challenge students, encouraging them to deepen their conceptual understanding and critical thinking skills. Lastly, the time allocation for completing each project is planned so that it can be accomplished within a single day.

The final outcomes are displayed in images derived from the visual demonstrations. They illustrate the final product of the visualization, providing students with a clear representation of the expected outcomes. Below is an example of a visualization result using GeoGebra included in the e-module, complete with a sample project. These images serve as a visual guide for students to understand the intended learning objectives. Furthermore, they allow students to compare their own work to the expected standards.

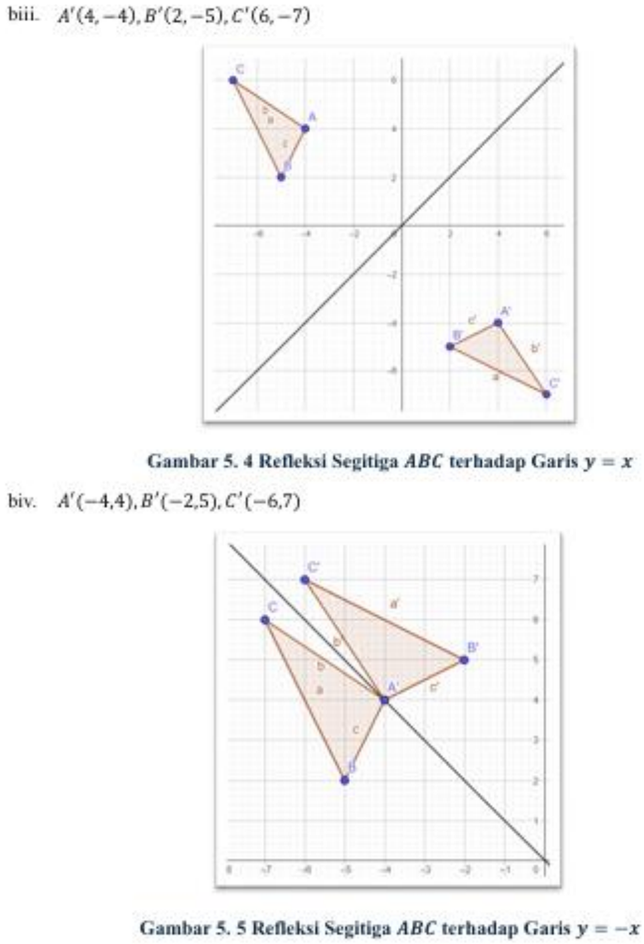


Figure 4. The Final Product of Visualization

The validation process was carried out to evaluate the quality of content and instructional materials and the design and presentation aspects of the developed module. This process involved four experts: two subject-matter experts specializing in geometric transformations and two experts in instructional media. The results of their assessment are systematically presented in Tables 2 and 3. Thus, the e-module could be tested after revisions based on the validator's feedback. The data presents the results of expert or validator feedback in Table 4.

Table 2. Validation Results of Material

Aspects	Percentage (%)
Relevancy	93.3
Accuracy	92.5
Convenience	95.
Attractiveness	80
Comprehensiveness	87.5
Average Score	89.7
Criteria	Excellent

Table 3. Validation Results of Media

Aspects	Percentage (%)
Presentation	80
Functionality	90
Significances	90
Average score	86.7
Criteria	Excellent

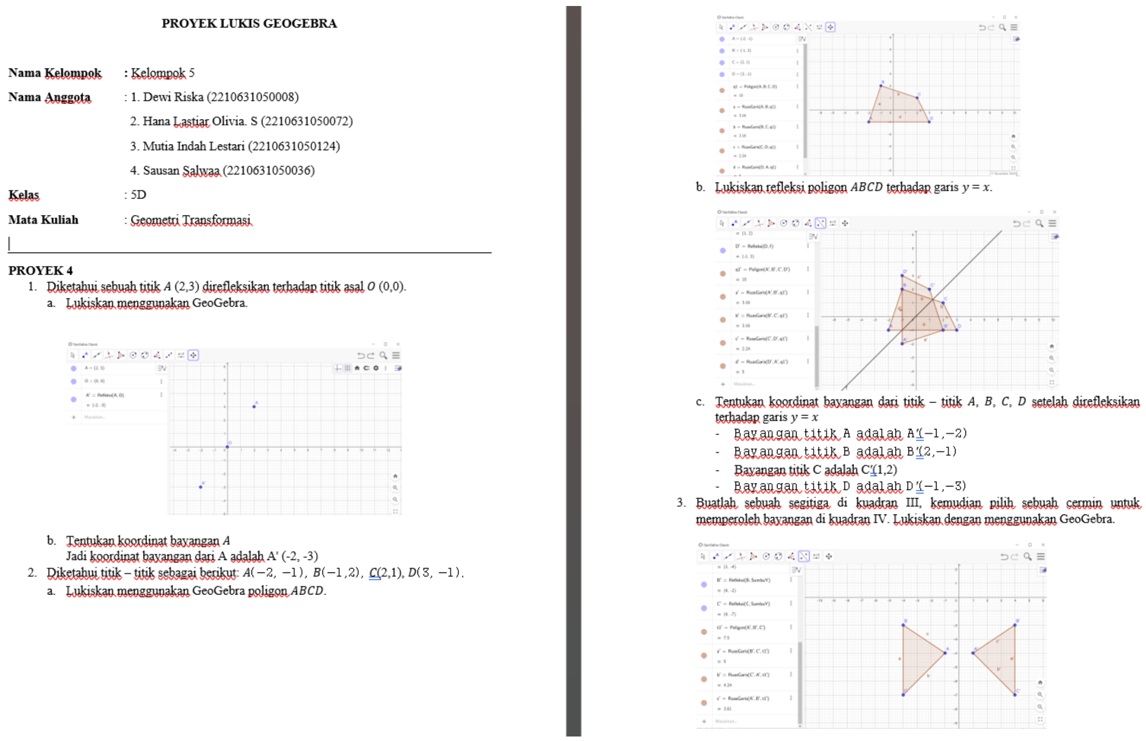
Table 4. Expert's Feedback

Aspects	Feedback
Content and Material	Add a brief explanation on renaming or relabeling points, lines, or objects that will be transformed.
Display and Presentation	In Chapter 1, it is necessary to add images and explanations regarding the functions of each toolbar, at least for the toolbar related to lines, polygons, and geometric transformations.

The revision incorporates detailed explanations of each toolbar in Chapter 1 through video tutorials. Furthermore, additional clarification is provided regarding the naming or labeling points, lines, or other objects involved in geometric transformations.

3.4 Implementation

The Implementation phase of this study involved a comprehensive testing process of the developed module to evaluate its effectiveness in enhancing students' visualization of geometric transformations. The process was conducted with 32 mathematics education students from Universitas Singaperbangsa Karawang. To ensure systematic collaboration and equitable participation, the participants were divided into eight groups, each with four members. This group structure was designed to promote cooperative learning and active engagement among students. Each group was tasked with independently completing four primary projects, each focusing on a specific topic in geometric transformations: reflection, rotation, translation, and dilation. These topics were selected to provide a well-rounded exploration of key concepts in the subject matter.


PROYEK LUKIS GEOGEBRA

Nama Kelompok : Kelompok 5
Nama Anggota : 1. Dewi Riska (2210631050008)
2. Hana Lastiar Olivia. S (2210631050072)
3. Mutia Indah Lestari (2210631050124)
4. Sausan Salwaa (2210631050036)
Kelas : 5D
Mata Kuliah : Geometri Transformasi

PROYEK 4
1. Diketahui sebuah titik A (2,3) direfleksikan terhadap titik asal O (0,0).
a. Lukiskan menggunakan GeoGebra.
b. Tentukan koordinat bayangan A
Jadi koordinat bayangan dari A adalah A' (-2, -3)
2. Diketahui titik – titik sebagai berikut: $A(-2,-1)$, $B(-1,2)$, $C(2,1)$, $D(3,-1)$.
a. Lukiskan menggunakan GeoGebra poligon $ABCD$.
b. Lukiskan refleksi poligon $ABCD$ terhadap garis $y = x$.
c. Tentukan koordinat bayangan dari titik – titik A, B, C, D setelah direfleksikan terhadap garis $y = x$
- Bayangan titik A adalah A'(−1,−2)
- Bayangan titik B adalah B'(2,−1)
- Bayangan titik C adalah C'(1,2)
- Bayangan titik D adalah D'(−1,−3)
3. Buatlah sebuah segitiga di kuadran III, kemudian pilih sebuah cermin untuk memperoleh bayangan di kuadran IV. Lukiskan dengan menggunakan GeoGebra.

Figure 5. Example of the Project Outcomes

The allocated time frame for completing the projects was one week, which allowed students to manage their time effectively while delving into the theoretical and practical aspects of the module. During this period, students worked collaboratively within their groups, applying the knowledge and skills presented in the module to address the assigned tasks. This approach reinforced their conceptual understanding and encouraged the development of teamwork and problem-solving skills. At the end of the project period, each group submitted a detailed project report outlining their methods, findings, and reflections on the learning process.

In addition to the project submissions, all students must complete a performance response questionnaire. This instrument was designed to capture their perceptions of the module's functionality and accessibility in facilitating learning. The feedback provided by students offered valuable insights into their experiences, highlighting both the module's strengths and potential areas for refinement. This evaluation was crucial in determining the module's impact and guiding future improvements. The following section provides examples of project outcomes produced by the students during this phase.

3.5 Evaluation

The Evaluation phase was systematically conducted to measure the developed module's practicality and effectiveness. The practicality assessment was derived from student response questionnaires, the results of which are presented in Table 5.

Table 5. Assessment of Practicality

Aspects	Percentage (%)
Functionality	96,9
Accessibility	59,4
Average score	78.15
Criteria	Good

Besides aspects of functionality and accessibility, the student response survey also revealed that students assigned each group member to work on an individual project, with the majority (43.8%) working on the project alone, 84.4% repeatedly using video tutorials, 81.3% seeking additional learning resources from YouTube, and 84.4% completing the project within the same day.

The effectiveness of the module was evaluated through an in-depth assessment of each group's project outcomes. These outcomes were rigorously analyzed against predefined evaluation criteria to ensure consistency, objectivity, and reliability in measuring students' comprehension and skill acquisition. Table 6 systematically presents a comprehensive overview of the assessment results for each group's project outcomes.

Table 6. Performance Evaluation

Group	Performance (%)	Criteria
1	90	Excellent
2	100	Excellent
3	95	Excellent
4	100	Excellent
5	95	Excellent
6	100	Excellent
7	85	Excellent
8	90	Excellent
Average	94.3	Excellent

Based on Table 6, each group successfully completed their project tasks with excellent results, as all outcomes met the 'Excellent' criteria. With an average score of 94.3%, the module's effectiveness falls within the 'Excellent' category. The e-module has proven effective in helping students visualize geometric transformation concepts.

The results of this study demonstrate the successful development and implementation of an interactive e-module for enhancing students' visualization skills in geometric transformations, specifically designed to cater to the learning preferences of

Generation Z. The evaluation of the e-module's validity, practicality, and effectiveness yielded highly positive outcomes, indicating its potential as an effective instructional tool.

The validation phase revealed an overall validity score of 88.2%, categorizing the module as "Excellent." Both content and media experts praised the material's clarity, relevance, and accuracy. Minor revisions, such as adding more detailed explanations for toolbar functionalities and labeling geometric objects, were implemented to enhance clarity. These findings align with Asare and Atteh [6] and Mthethwa *et al.* [14], who emphasized that effective instructional tools must prioritize conceptual clarity and alignment with learning objectives to optimize student outcomes.

Based on student responses, the practicality assessment yielded an average score of 75%, categorized as "Good." While functionality scored exceptionally high (96.9%), accessibility scored relatively lower (59.4%). The findings suggest that while students found the module highly functional and effective in supporting their visualization tasks, accessibility issues—likely related to device compatibility or connectivity—may need further attention in future iterations. These results resonate with Rohmatulloh et al. [30], who argued that while digital instructional tools significantly enhance student engagement, accessibility, and technical barriers remain critical factors that educators must address.

The effectiveness evaluation, measured through group project performance, yielded an impressive average score of 94.3%, categorized as "Excellent." Each group successfully demonstrated their understanding and application of geometric transformation concepts through project-based tasks. This finding supports the claims of Maf'ulah *et al.* [13] and Afhami [11], who noted significant improvements in student outcomes after integrating visualization software into mathematical instruction. Additionally, the project-based learning approach embedded within the e-module aligns with Zakiah *et al.* [37], highlighting its role in fostering creativity, problem-solving, and deeper conceptual understanding. Integrating GeoGebra as a core tool within the e-module proved highly effective in facilitating dynamic and interactive visualization. Moreover, including short, focused YouTube video tutorials allowed students to revisit lessons at their own pace, further reinforcing their understanding. This approach aligns with the observations of Parida *et al.* [34] and Tamu *et al.* [35], who highlighted the flexibility of video-based instructional tools in supporting personalized and self-paced learning experiences.

The student response data revealed interesting insights into learning behaviors. Most students reported working independently on their projects while frequently revisiting video tutorials for clarity. This independent learning behavior underscores the module's flexibility and alignment with the self-directed learning preferences commonly associated with Generation Z, as described by Kinanti and Erza [17] and Mardianto [19]. The results also reflect the challenges identified by Rastati [22], who noted that traditional lecture-based methods often fail to capture the attention and engagement of tech-savvy learners.

Despite the overwhelmingly positive results, challenges related to accessibility highlight the need to ensure that future versions of the module are optimized for various devices and internet conditions. Additionally, while video tutorials were highly effective, ensuring consistency in video quality and clarity remains an ongoing priority. These findings are consistent with Hendriyani *et al.* [26], who emphasized the importance of balancing instructional design with technical feasibility in digital learning environments.

4. CONCLUSION

The interactive e-module developed in this study has proven valid, practical, and effective for enhancing students' visualization skills in geometric transformations. Its integration of GeoGebra, project-based tasks, and YouTube video tutorials align well with the learning preferences of Generation Z. Furthermore, the results reinforce existing findings from previous research, highlighting the importance of combining visualization tools, interactive learning strategies, and digital media in mathematics education. Future research may explore broader implementation across diverse educational settings and investigate long-term impacts on students' conceptual understanding and engagement. This research implies that integrating interactive and technology-driven tools into the curriculum can significantly enhance students' engagement and mastery of abstract mathematical concepts.

AUTHOR CONTRIBUTION STATEMENT

DP contributed to designing the study, conducting research, analyzing the data, and drafting the manuscript. LD contributed to reviewing and editing, conducting formal analysis, and refining the methodology.

REFERENCES

[1] K. D. Octaviani, N. Indrawatiningsih, and A. Afifah, “Kemampuan visualisasi spasial siswa dalam memecahkan masalah geometri bangun ruang sisi datar,” *Int. J. Progress. Math. Educ.*, vol. 1, no. 1, pp. 27–40, 2021, doi: 10.22236/ijopme.v1i1.6583.

[2] F. I. Maulani and L. S. Zanthy, “Analisis kesulitan siswa dalam menyelesaikan soal materi transformasi geometri,” *J. Gammath*, vol. 5, no. 1, pp. 16–25, 2020, doi: 10.32528/gammath.v5i1.3189.

[3] F. A. Salma and T. S. Sumartini, “Kemampuan representasi matematis siswa antara yang mendapatkan pembelajaran contextual teaching and learning dan discovery learning,” *Plusminus J. Pendidik. Mat.*, vol. 2, no. 2, pp. 265–274, 2022, doi: 10.31980/plusminus.v2i2.1103.

[4] A. Arcat, “Pengaruh model pembelajaran kooperatif teknik write-pair-squar terhadap kemampuan pemahaman konsep matematis siswa SMA Negeri 2 Bangkinang,” *SJME (Supremum J. Math. Educ.*, vol. 1, no. 1, pp. 1–6, 2017, doi: 10.35706/sjme.v1i1.547.

[5] M. Sari, M. Habibi, and R. Putri, “Pengaruh model pembelajaran kooperatif tipe think-pairs-share dalam pembelajaran matematika terhadap kemampuan pemahaman konsep matematis dan pengembangan karakter siswa sma kota sungai penuh,” *Edumatika J. Ris. Pendidik. Mat.*, vol. 1, no. 1, pp. 7–21, 2018, doi: 10.32939/ejrpm.v1i1.221.

[6] J. T. Asare and E. Atteh, “The impact of using GeoGebra software in teaching and learning transformation (rigid motion) on senior high school students’ achievement,” *Asian J. Educ. Soc. Stud.*, vol. 33, no. 1, pp. 36–46, 2022, doi: 10.9734/ajess/2022/v33i130784.

[7] D. H. Syah, I. Muda, and E. A. Bakar, “Development of learning media for android-based budget accounting,” in *Journal of Physics: Conference Series*, 2021, vol. 1779, no. 1, pp. 1-9, doi: 10.1088/1742-6596/1779/1/012017.

[8] N. A. Handoyono, “Development of android-based learning application in EFI materials for vocational schools,” in *Journal of Physics: Conference Series*, 2020, vol. 1456, no. 1, pp. 1-8, doi: 10.1088/1742-6596/1456/1/012050.

[9] M. Bani and M. Masruddin, “Development of an android-based harmonic oscillation pocket book for senior high school students,” *J. Technol. Sci. Educ.*, vol. 4, no. 4, pp. 215–227, 2022, doi: 10.3926/jotse.1051.

[10] R. Ziatdinov and J. R. Valles Jr, “Synthesis of modeling, visualization, and

programming in GeoGebra as an effective approach for teaching and learning STEM topics," *Mathematics*, vol. 10, no. 3, pp. 1-16, 2022, doi: 10.3390/math10030398.

[11] A. H. Afhami, "Aplikasi GeoGebra classic terhadap pemahaman konsep matematika siswa pada materi transformasi geometri," *Plusminus J. Pendidik. Mat.*, vol. 2, no. 3, pp. 449–460, 2022, doi: 10.31980/plusminus.v2i3.1119.

[12] I. P. Luritawaty, "Pembelajaran take and give dalam upaya mengembangkan kemampuan pemahaman konsep matematis," *Mosharafa J. Pendidik. Mat.*, vol. 7, no. 2, pp. 179–188, 2018, doi: 10.31980/mosharafa.v7i2.27.

[13] S. Maf'ulah, S. Wulandari, and L. Jauhariyah, "Pembelajaran matematika dengan media software GeoGebra materi dimensi tiga," *Mosharafa J. Pendidik. Mat.*, vol. 10, no. 3, pp. 449–460, 2021, doi: 10.31980/mosharafa.v10i3.1021.

[14] M. Mthethwa, A. Bayaga, M. J. Bossé, and D. Williams, "GeoGebra for learning and teaching: A parallel investigation," *South African J. Educ.*, vol. 40, no. 2, pp. 1-12, 2020.

[15] H. F. Atikah, I. Sarifah, and C. B. Yudha, "Analisis kemampuan literasi matematika dalam pandangan PISA 2022," *Literasi J. Ilmu Pendidik.*, vol. 15, no. 2, pp. 152–161, 2024, doi: 10.21927/literasi.2024.15(2).152-161.

[16] S. Putrawangsa and U. Hasanah, "Analisis capaian siswa Indonesia pada PISA dan urgensi kurikulum berorientasi literasi dan numerasi," *EDUPEDIKA J. Stud. Pendidik. Dan Pembelajaran*, vol. 1, no. 1, pp. 1–12, 2022.

[17] Di. N. Kinanti and E. K. Erza, "Analisis kebutuhan informasi generasi Z dalam akses informasi di media," *Shaut Al-Maktabah J. Perpustakaan, Arsip dan Dokumentasi*, vol. 12, no. 1, pp. 72–84, 2020, doi: 10.37108/shaut.v12i1.303.

[18] K. Laturette, L. P. Widianingsih, and L. Subandi, "literasi keuangan pada generasi Z," *J. Pendidik. Akunt.*, vol. 9, no. 1, pp. 131–139, 2021, doi: 10.26740/jpak.v9n1.p131-139.

[19] Mardianto, "Peran guru di era digital dalam mengembangkan self regulated learning siswa generasi Z untuk pencapaian hasil pembelajaran optimal," *Pros. Semin. Nas. Call Pap.* , vol. 1, no. 1, pp. 150–158, 2019, doi: 10.31227/osf.io/wah3r.

[20] C. Marisa, "Gambaran motivasi belajar pada siswa generasi Z dan implikasinya dalam pelayanan bimbingan dan konseling di sekolah," *Guid. J. Bimbing. Dan Konseling Vol.*, vol. 17, no. 12, pp. 21–32, 2020, doi: 10.34005/guidance.v17i02.1117.

[21] F. Rachmawati and J. P. Purwaningrum, "Model discovery learning berbasis etnomatematika pada bangun ruang untuk menumbuhkan kemampuan literasi dan karakter nasionalisme pada generasi Z 4.0," *AKSIOMA J. Mat. dan Pendidik. Mat.*, vol. 10, no. 2, pp. 254–260, 2019, doi: 10.26877/aks.v10i2.4837.

[22] R. Rastati, "Media literasi bagi digital natives: perspektif generasi Z di Jakarta," *Kwangsan J. Teknol. Pendidik.*, vol. 6, no. 1, pp. 60–73, 2018, doi: 10.31800/jtp.kw.v6n1.p60--73.

[23] A. Karim and A. Nurrahmah, "Analisis kemampuan pemahaman matematis mahasiswa pada mata kuliah teori bilangan," *J. Anal.*, vol. 4, no. 1, pp. 24–32, 2018, doi: 10.15575/ja.v4i1.2101.

[24] D. Hoiriyah, "Analisis kemampuan pemahaman konsep matematis mahasiswa program studi PGSD," *Logaritma J. Ilmu-ilmu Pendidik. dan Sains*, vol. 8, no. 2, pp. 199–212, 2020, doi: 10.24952/logaritma.v8i02.2773.

[25] K. B. Dinata, "Problematika membangun pemahaman konsep geometri transformasi mahasiswa pendidikan matematika di Universitas Muhammadiyah

Kotabumi tahun akademik 2019/2020," *Kaos GL Derg.*, vol. 8, no. 75, pp. 147–154, 2020, doi: 10.47637/eksponen.v9i2.54.

[26] Y. Hendriyani, V. I. Delianti, and L. Mursyida, "Analisis kebutuhan pengembangan media pembelajaran berbasis video tutorial," *J. Teknol. Inf. Dan Pendidik.*, vol. 11, no. 2, pp. 85–88, 2018, doi: 10.24036/tip.v11i2.147.

[27] A. Septian, M. L. Fahrisyal, and N. Jusniani, "Pengembangan GeoGebra classroom pada materi transformasi geometri," *Prisma*, vol. 11, no. 2, pp. 504–514, 2022, doi: 10.35194/jp.v11i2.2483.

[28] D. Setiyadi, D. Fortuna, and A. B. Ramadhan, "Pemanfaatan video kreatif dan media sosial youtube sebagai media pembelajaran matematika kelas tinggi," *Dawuh Guru J. Pendidik. MI/SD*, vol. 2, no. 1, pp. 31–42, 2022, doi: 10.35878/guru.v2i1.344.

[29] H. Humaidi, A. Qohar, and S. Rahardjo, "Respon siswa terhadap penggunaan video youtube sebagai media pembelajaran daring matematika," *JIPM (Jurnal Ilm. Pendidik. Mat.*, vol. 10, no. 2, pp. 153–162, 2022, doi: 10.25273/jipm.v10i2.9108.

[30] R. Rohmatulloh, H. Nindiasari, and A. Fatah, "Pengembangan e-modul interaktif berbasis problem based learning (PBL) untuk meningkatkan kemampuan berpikir kritis matematis," *AKSIOMA J. Progr. Stud. Pendidik. Mat.*, vol. 12, no. 4, pp. 3599–3612, 2023, doi: 10.24127/ajpm.v12i4.8172.

[31] R. Aspriyani and A. Suzana, "Pengembangan e-modul interaktif materi persamaan lingkaran berbasis realistic mathematics education berbantuan GeoGebra," *AKSIOMA J. Progr. Stud. Pendidik. Mat.*, vol. 9, no. 4, pp. 1099–1111, 2020, doi: 10.24127/ajpm.v9i4.3123.

[32] B. W. A. Pramana, A. Suwito, N. D. S. Lestari, and R. P. Murtikusuma, "Pengembangan e-modul berbantuan Geogebra pada materi transformasi geometri SMA," *GAUSS J. Pendidik. Mat.*, vol. 5, no. 2, pp. 1–14, 2022, doi: 10.30656/gauss.v5i2.5694.

[33] S. Winarni, R. P. Simanjuntak, M. Marlina, R. Rohati, and A. Kumalasari, "Pengembangan e-modul interaktif untuk mendukung algebraic thinking pada materi turunan fungsi aljabar," *AKSIOMA J. Progr. Stud. Pendidik. Mat.*, vol. 13, no. 3, pp. 791–803, 2024, doi: 10.24127/ajpm.v13i3.8540.

[34] L. Parida, B. Sahono, and J. Sapri, "Pengaruh pembelajaran video tutorial terhadap prestasi belajar," *J. Pendidikan, Teknol.*, vol. 8, no. 1, pp. 12–21, 2019.

[35] S. D. Tamu, E. Hulukati, and I. Djakaria, "Pengembangan modul dan video pembelajaran matematika persiapan ujian nasional pada materi dimensi tiga," *Jambura J. Math. Educ.*, vol. 1, no. 1, pp. 21–31, 2020, doi: 10.34312/jmathedu.v1i1.4558.

[36] Z. Gusmanely and S. Yurinanda, "Implementasi model pembelajaran berbasis proyek untuk mengidentifikasi kemampuan berpikir kreatif mahasiswa matematika," *Prism. J. Pendidik. dan Ris. Mat.*, vol. 6, no. 2, pp. 433–442, 2024, doi: 10.33503/prismatika.v6i2.4106.

[37] N. E. Zakiah, A. T. Fatimah, and Y. Sunaryo, "Implementasi project-based learning untuk mengeksplorasi kreativitas dan kemampuan berpikir kreatif matematis mahasiswa," *Teorema Teor. dan Ris. Mat.*, vol. 5, no. 2, pp. 285–293, 2020, doi: 10.25157/teorema.v5i2.4194.

[38] D. Mardhiyana, "Kuliah evaluasi proses dan hasil pembelajaran," *J. Ilm. Pendidik. Mat.*, vol. 5, no. 1, pp. 1–8, 2017, doi: 10.31941/delta.v5i1.389.

[39] D. Desniarti and R. Ramadhani, "Pengaruh GeoGebra terhadap kemampuan pemahaman konsep pada matakuliah geometri analitik bidang," *J. Penelit. Pendidik.*

Mipa, vol. 4, no. 1, pp. 237–246, 2019, doi: 10.32696/jp2mipa.v4i1.276.

[40] R. A. H. Cahyadi, "Pengembangan bahan ajar berbasis ADDIE model," *Halaqa Islam. Educ. J.*, vol. 3, no. 1, pp. 35–42, 2019, doi: 10.21070/halaqa.v3i1.2124.

[41] Y. H. Rayanto, *Penelitian Pengembangan Model Addie Dan R2d2: Teori & Praktek*. Lembaga Academic & Research Institute, 2020.

[42] Riduwan, *Skala Pengukuran Variabel - Variabel Penelitian*, vol. 10, no. 1. Bandung: Alfabeta, 2015.