



## Development and evaluation of an animation-assisted e-module to enhance students' mathematical understanding in three-dimensional geometry learning

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### Abstract

**Background:** Rapid advancements in science and technology have significantly influenced various sectors, including education. In mathematics learning, the integration of technology through animation-assisted e-modules offers a promising approach to enhance interactivity and facilitate students' understanding of abstract concepts.

**Aims:** This study aims to develop and evaluate an animation-assisted e-module for teaching three-dimensional geometry to eighth-grade students.

**Method:** This research employed a Research and Development (R&D) approach using the 4D model (Define, Design, Develop, Disseminate). The study was conducted at SMP Negeri 3 Purbalingga during the 2024/2025 academic year, involving experimental and control groups. Data were collected through interviews, questionnaires, and documentation. Quantitative analysis was used to assess the validity, practicality, and effectiveness of the developed e-module, including an independent samples t-test after meeting normality and homogeneity assumptions.

**Results:** The findings revealed that the e-module achieved a high level of validity based on expert evaluations. The practicality test showed an average score of 3.43 (out of 4.00), indicating a very practical category based on responses from teachers and students. Furthermore, the effectiveness test demonstrated a significant difference between the experimental and control groups (Sig. 2-tailed = 0.000 < 0.05), confirming the positive impact of the e-module on students' learning outcomes.

**Conclusion:** The animation-assisted e-module is valid, highly practical, and effective, making it a feasible instructional medium for improving students' understanding of three-dimensional geometry.

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## INTRODUCTION

The current learning environment has undergone significant transformation due to the rapid advancement of science and technology. The integration of technology into education has become an essential strategy to support effective teaching and learning processes (Akram et al., 2022; Alenezi et al., 2023; Asad et al., 2021; Peng et al., 2023). Technology enables educators to design more adaptive, interactive, and engaging learning experiences that align with the demands of the modern era (Rahimi & Oh, 2024). In mathematics education, the use of technology is particularly important because it helps students understand abstract concepts through visual and dynamic representations (Cirneanu & Moldoveanu, 2024; Drijvers & Sinclair, 2024; Engelbrecht & Borba, 2024; Žakelj & Klančar, 2022). Digital literacy has also become a fundamental competency that students must possess to actively participate in the digital society (Falloon, 2020; Milenkova & Lendzhova, 2021;

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Nuryadi & Widiatmaka, 2023; Setiadi et al., 2023). Therefore, educators are required to adopt innovative approaches that integrate technology into classroom practices. Technology-based learning not only enhances students' academic performance but also supports the development of critical thinking and problem-solving skills (Asad & Qureshi, 2025; Cong & Ironsi, 2025; Kravchenko et al., 2023). The use of digital tools can provide opportunities for students to learn independently and explore learning materials more deeply. In addition, technology facilitates access to diverse learning resources that can enrich students' learning experiences. Consequently, the integration of technology in education is no longer optional but has become a necessity in contemporary learning environments.

Despite the potential benefits of technology integration, its implementation in classroom practice is still not fully optimal. In many cases, mathematics instruction at the junior high school level continues to rely on conventional teaching methods (Chirinda et al., 2021; Hackenberg et al., 2021; Lo & Hew, 2020; Nkundabakura et al., 2023). Teachers often dominate the learning process, while students tend to take a passive role in receiving information (Carless, 2022). This teacher-centered approach limits opportunities for students to actively engage in constructing their own understanding. As a result, the learning process becomes less interactive and less meaningful for students. Furthermore, the limited use of appropriate learning media makes it difficult for students to visualize abstract mathematical concepts. Topics such as three-dimensional geometry require strong spatial visualization skills, which are difficult to develop through traditional teaching methods alone (Ibili et al., 2020; Mjenda et al., 2023; Ziatdinov & James R. Valles, 2022). The reliance on lecture-based instruction and static materials reduces students' interest and motivation in learning mathematics. These conditions indicate that there is a gap between the potential of technology and its actual implementation in classrooms. Therefore, there is a need for innovative learning strategies that can transform traditional teaching practices into more interactive and student-centered approaches.

The problem is further exacerbated by the continued use of printed modules as the primary learning resource in mathematics instruction. Printed modules generally present information in the form of text and two-dimensional images, which are insufficient for explaining complex and abstract concepts (Trujillo-Cayado et al., 2024; Wang et al., 2020). Such materials often fail to capture students' attention and do not provide interactive learning experiences. As a result, students may experience boredom and difficulty in understanding the material. To overcome these limitations, the development of digital learning media that incorporate multimedia elements is essential. One promising solution is the use of animation-assisted e-modules, which combine digital content with visual and dynamic representations. E-modules offer flexibility, accessibility, and interactivity, allowing students to learn anytime and anywhere according to their own pace. The integration of animation can help transform abstract mathematical concepts into more concrete and understandable forms (Mou, 2023). Moreover, animation-based learning can increase students' motivation by presenting content in a more engaging and enjoyable manner (Laksmi et al., n.d.; Utaminingsih et al., 2024; Zhang & Lin, 2026). In addition, e-modules support student-centered learning by enabling students to explore learning materials independently. Therefore, the development of animation-assisted e-modules is considered an appropriate approach to improving the quality of mathematics learning.

Despite the growing body of research highlighting the effectiveness of technology integration in mathematics education, particularly in enhancing conceptual understanding and student engagement, several limitations remain evident in the existing literature. Previous studies have demonstrated the potential of digital learning tools such as e-modules, realistic mathematics education approaches, and multimedia-based instruction in improving students' learning outcomes (Palinussa et al., 2025), while other research has emphasized the role of advanced visualization

technologies such as augmented reality and mobile-based applications in supporting students' three-dimensional geometry thinking skills (İbili et al., 2020; Rohendi & Wihardi, 2020). Additionally, studies on simulations, STEAM approaches, and visual representations have shown their effectiveness in fostering conceptual understanding across disciplines, including mathematics and physics (Banda & Nzabahimana, 2021; Ozkan & Umdü Topsakal, 2021; Žakelj & Klančar, 2022). However, these studies largely focus on either standalone visualization tools or general digital learning environments, without integrating animation into structured instructional materials such as e-modules. Moreover, existing research on geometry learning often addresses students' difficulties or emphasizes specific technological tools rather than developing comprehensive, curriculum-aligned digital modules that combine interactivity, animation, and systematic content delivery. Importantly, there is still limited research that simultaneously evaluates the validity, practicality, and effectiveness of animation-assisted e-modules, particularly in the context of three-dimensional geometry learning at the junior high school level. Therefore, this study aims to address this gap by developing and evaluating an animation-assisted e-module that integrates interactive visualization with structured mathematical content to enhance students' conceptual understanding.

Based on the problems identified, this study aims to develop and evaluate an animation-assisted e-module for mathematics learning at the junior high school level. The study focuses on designing a digital learning medium that integrates animation to support students' understanding of three-dimensional geometry concepts. The developed e-module is expected to provide an interactive and engaging learning experience for students. In addition, this research aims to assess the validity of the e-module through expert evaluation. The practicality of the e-module will also be examined based on responses from both teachers and students. Furthermore, the effectiveness of the e-module will be evaluated by comparing students' learning outcomes between experimental and control groups. This study also aims to determine whether the use of animation can enhance students' conceptual understanding of abstract mathematical concepts. The research is expected to contribute to the development of innovative and technology-based learning media in mathematics education. Moreover, the findings of this study are intended to provide practical insights for educators in implementing digital learning tools in the classroom. Ultimately, this study aims to support the creation of more interactive, meaningful, and student-centered mathematics learning environments.

## LITERATURE REVIEW

The integration of technology in mathematics education has become a critical focus in improving the quality of teaching and learning. Technology-enhanced learning environments provide opportunities for students to engage more actively with mathematical concepts (Demir & Önal, 2021; Georgiou & Ioannou, 2021; Shé et al., 2023; Weinhandl et al., 2023). The use of digital learning media has been shown to support students in developing deeper conceptual understanding. In particular, digital tools enable the visualization of abstract mathematical ideas that are otherwise difficult to comprehend (Engelbrecht & Borba, 2024; Jacinto & Carreira, 2023; Medina Herrera et al., 2024; Ziatdinov & James R. Valles, 2022). Mathematics learning often involves complex and symbolic representations that require effective instructional strategies (Mutodi & Mosimege, 2021). Therefore, technology plays an essential role in bridging the gap between abstract concepts and students' understanding. The incorporation of multimedia elements such as text, images, audio, and animation can enrich the learning experience. Interactive digital media also encourages students to explore concepts independently and collaboratively (Blau et al., 2020; Gopinathan et al., 2022; Selfa-Sastre et al., 2022). Furthermore, the flexibility of digital learning allows students to access materials at their own pace. As a result, technology integration has become a key component in modern mathematics education.

E-modules are one of the most widely used forms of digital learning media in contemporary education. An e-module is a structured digital learning resource that presents instructional content in an organized and systematic manner (Delita et al., 2022). Unlike traditional printed modules, e-modules provide interactive features that enhance students' engagement. E-modules can incorporate multimedia elements that make learning more dynamic and meaningful (Alyusfitri et al., 2024). In mathematics education, e-modules have been used to facilitate self-directed learning and improve learning outcomes (Palinussa et al., 2025). The flexibility of e-modules allows students to revisit materials multiple times, which supports mastery learning. In addition, e-modules enable teachers to present content in a more innovative and engaging format. The use of e-modules also aligns with the principles of student-centered learning. Students can control their learning pace and adapt the content to their individual needs. Therefore, e-modules are considered an effective instructional medium for improving mathematics learning.

Animation is an important component in digital learning that enhances the visualization of abstract concepts. In mathematics, animation can be used to illustrate dynamic processes and relationships between variables (Bos & Wigmans, 2025; Ploetzner et al., 2020). The use of animation helps students to understand concepts that involve movement, transformation, and spatial relationships (Farrokhnia et al., 2020; Shapiro & Silvis, 2025). Animation can also reduce cognitive load by presenting information in a more intuitive and engaging way. Furthermore, animated representations allow students to observe step-by-step processes that are difficult to demonstrate using static images. This is particularly relevant in learning geometry, where spatial reasoning is required. Animation-based learning has been shown to increase students' motivation and interest in learning (Utaminingsih et al., 2024; Zhang & Lin, 2026). The visual and dynamic nature of animation can make learning more enjoyable and less intimidating. In addition, animation supports the development of higher-order thinking skills by enabling students to analyze and interpret visual information. Consequently, animation is a powerful tool in enhancing mathematics learning.

Three-dimensional geometry is one of the most challenging topics in mathematics learning at the junior high school level. This topic requires students to understand spatial relationships and visualize objects in three dimensions. Many students experience difficulties in comprehending concepts such as volume, surface area, and geometric transformations (İbili et al., 2020; Machaba et al., 2024; Žakelj & Klančar, 2022). The abstract nature of three-dimensional geometry makes it difficult to teach using traditional methods. Students often rely on memorization rather than conceptual understanding (Heber et al., 2023; Hurrell, 2021). The lack of effective visualization tools further limits students' ability to grasp these concepts (Chang et al., 2024; Medina Herrera et al., 2024; Ziatdinov & James R. Valles, 2022). Therefore, innovative instructional approaches are needed to support students' spatial reasoning skills. The use of digital learning media can provide more effective representations of three-dimensional objects. In particular, animation can help students visualize geometric structures more clearly. As a result, integrating animation into mathematics learning is expected to improve students' understanding of three-dimensional geometry.

Despite the increasing use of digital learning media and animation in education, several limitations remain in the existing literature. Many studies focus on the use of e-modules without integrating animation as a core component of the instructional design. Other studies emphasize animation as a standalone tool without embedding it within a structured learning module. In addition, research on geometry learning often highlights students' difficulties without providing comprehensive instructional solutions. There is also a lack of studies that evaluate learning media based on multiple criteria such as validity, practicality, and effectiveness. Furthermore, limited research specifically addresses the integration of animation-assisted e-modules in three-dimensional geometry learning. The majority of existing studies examine general mathematics learning without focusing on specific topics. This indicates a gap in the development of targeted instructional media

for geometry learning. Therefore, there is a need for research that combines animation, e-modules, and structured instructional design. This study seeks to address this gap by developing and evaluating an animation-assisted e-module for mathematics learning.

## METHOD

### Research Design

This study employed a Research and Development (R&D) approach aimed at producing an animation-assisted e-module and evaluating its feasibility and practicality. The development process followed the 4D model, which consists of Define, Design, Develop, and Disseminate stages. The Define stage focused on identifying learning problems, analyzing students' characteristics, and determining learning objectives. The Design stage involved developing the initial prototype, including content organization, media selection, and instructional design. The Develop stage included expert validation, revision, and product trials to ensure the quality of the e-module. The Disseminate stage involved the implementation and broader distribution of the developed product. This design enabled a systematic and iterative development process. The study also applied quantitative evaluation methods to assess product quality. The evaluation emphasized validity and practicality aspects. Therefore, the R&D design was appropriate for developing and assessing instructional media.

### Participant

The participants in this study consisted of eighth-grade students from a junior high school. The participants were involved during the product trial stage to evaluate the practicality of the developed e-module. A mathematics teacher also participated in assessing the usability of the product in classroom practice. In addition, expert validators were involved in evaluating the validity of the e-module. The validators consisted of subject matter experts and media experts. The selection of participants was based on their roles in the development process. Students represented the primary users of the product. Teachers provided insights related to instructional implementation. Experts ensured the academic and technical quality of the product. The involvement of multiple participants strengthened the reliability of the evaluation results.

### Instrument

Data were collected using several instruments, including interview guidelines, validation sheets, questionnaires, and documentation. Interviews were conducted during the initial stage to identify problems in mathematics learning and determine students' needs. Validation sheets were used to assess the validity of the e-module based on expert judgment. Questionnaires were distributed to teachers and students to evaluate the practicality of the e-module. Documentation was used to record the development process and support data collection. All instruments were designed based on research objectives and evaluation criteria. Data collection was conducted systematically at each stage of the research. The use of multiple instruments allowed for comprehensive evaluation. This approach ensured data accuracy and consistency. The collected data were then analyzed quantitatively.

### Data Analysis

The data obtained were analyzed using quantitative descriptive analysis. The validity and practicality of the e-module were determined using the average score formula:

$$R = \frac{\sum x}{n}$$

where R represents the average score,  $\sum x$  is the total score, and n is the number of items. The results were interpreted based on predetermined criteria for validity and practicality. A score of 2.50 or higher indicated that the product met the acceptable criteria. The analysis provided clear classification of the product quality. The use of descriptive statistics enabled systematic

interpretation. The results were then used as a basis for product revision. This approach ensured that the developed e-module met quality standards. Therefore, the data analysis process supported objective evaluation of the product.

**Procedure**

The research procedure followed the stages of the 4D development model. In the Define stage, observations and interviews were conducted to identify learning problems and analyze students' needs. In the Design stage, the initial prototype of the animation-assisted e-module was developed. This stage included content preparation, media selection, and layout design. In the Develop stage, the prototype was validated by experts and revised based on their feedback. After validation, the product was tested in a limited trial to evaluate its practicality. Questionnaires were distributed to teachers and students to collect responses. In the Disseminate stage, the final product was introduced for broader implementation. Each stage was conducted systematically to ensure product quality. The iterative process allowed continuous improvement of the e-module. Overall, the procedure ensured that the product was valid and practical.

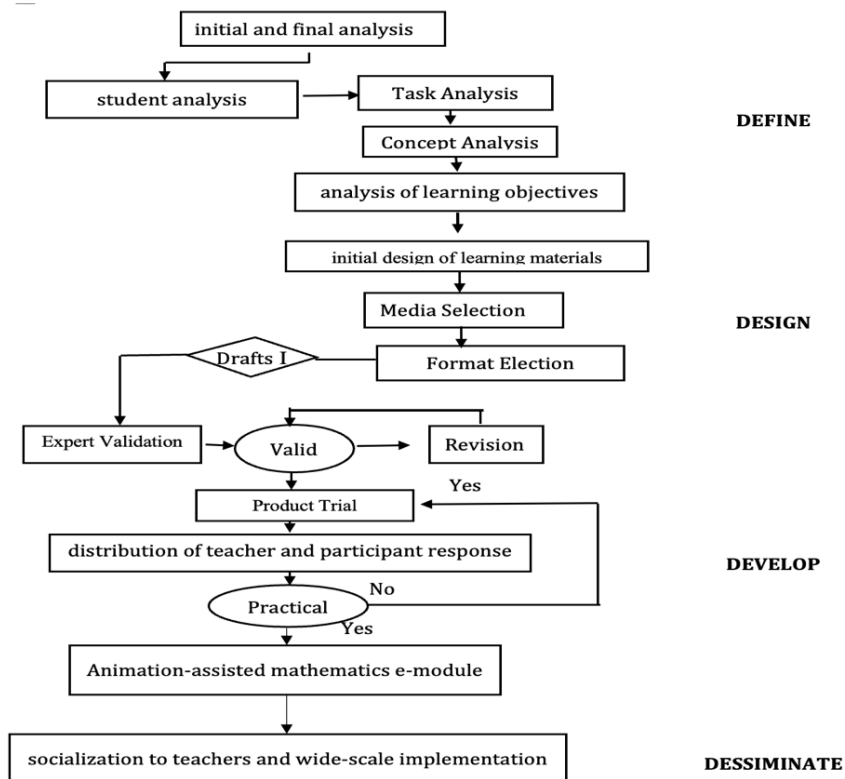
**Table 1.** Validity criteria

Score Range	Category
$3.25 \leq R \leq 4.00$	Very Valid
$2.50 \leq R < 3.25$	Valid
$1.75 \leq R < 2.50$	Not Valid
$1.00 \leq R < 1.75$	Very Not Valid

**Note:** The product is considered valid if  $R \geq 2.50$ .

**Table 2.** Practicality Criteria

Score Range	Category
$3.25 \leq R \leq 4.00$	Very Practical
$2.50 \leq R < 3.25$	Practical
$1.75 \leq R < 2.50$	Not Practical
$1.00 \leq R < 1.75$	Very Not Practical



**Figure 1.** Research Method Flow

## RESULTS AND DISCUSSION

### Results


#### *Define stage (Needs analysis)*

The initial stage focused on identifying problems and learning needs in mathematics instruction. The findings from classroom observations and teacher interviews revealed that the current instructional practices were still dominated by conventional lecture-based approaches. Learning media used in the classroom were limited and did not adequately support the visualization of abstract mathematical concepts, particularly in three-dimensional geometry. As a result, students experienced difficulties in understanding spatial concepts and relationships. These findings indicate a mismatch between instructional needs and the available learning media. Furthermore, the lack of interactive learning resources contributed to low student engagement during the learning process. Therefore, there was a need to develop an instructional medium that integrates visualization and interactivity. Based on this analysis, an animation-assisted e-module was proposed as a solution to address these issues. This stage provided the foundation for the design and development of the learning product. The results of this stage emphasize the urgency of integrating technology into mathematics learning.

#### *Design stage (prototype development)*

At the design stage, the initial prototype of the animation-assisted e-module was developed. The module was structured systematically to support students' learning processes. The content focused on three-dimensional geometry topics, including cubes, cuboids, prisms, and pyramids. The e-module consisted of several key components such as cover, introduction, table of contents, user instructions, concept maps, learning objectives, learning materials, evaluation, summary, answer key, references, and author profile. The learning materials were divided into two main sections to facilitate progressive understanding. The integration of animation was designed to enhance the visualization of abstract mathematical concepts. The interface of the e-module was designed to be visually appealing and user-friendly. Each component was arranged to support both independent and guided learning. The design also emphasized clarity of content and instructional coherence. Overall, the prototype aimed to provide an engaging and interactive learning experience.

**Table 1.** Components of the developed E-module

Component	Description	Image of module components
Cover	Designed with visual elements, title, and author identity	

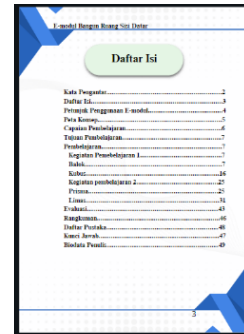
Introduction

Provides background and purpose of the module



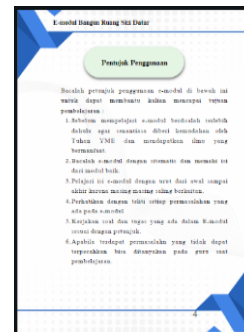
Table of Contents

Facilitates navigation



User Instructions

Guides students in using the module



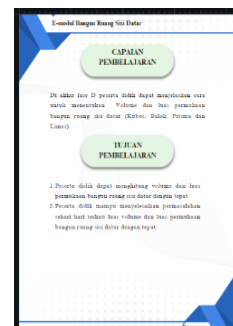
Concept Map


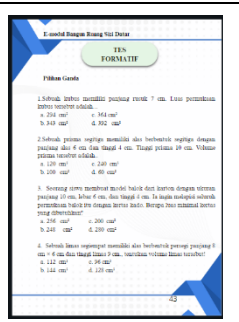
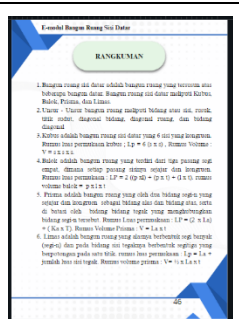
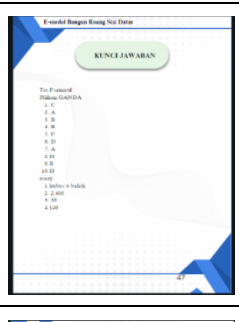
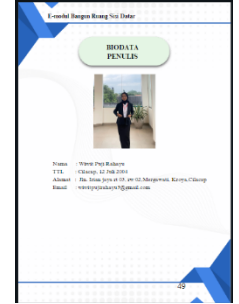
Presents structured overview of topics



Learning Objectives

Defines expected competencies



<p>Learning Materials</p>	<p>Covers geometry concepts (cube, prism, pyramid)</p>	
<p>Evaluation</p>	<p>Measures students' understanding</p>	
<p>Summary</p>	<p>Highlights key concepts</p>	
<p>Answer Key</p>	<p>Supports self-assessment</p>	
<p>References</p>	<p>Lists supporting sources</p>	
<p>Author Profile</p>	<p>Provides author information</p>	

***Develop stage (validation and practicality testing)******Expert validation***

The developed e-module was evaluated by subject matter experts and media experts. The results indicated that the e-module achieved a high level of validity across all evaluated aspects. Content validity reached an average score of 3.58, indicating that the material was highly aligned with learning objectives. Language and presentation aspects also achieved high scores, demonstrating clarity and appropriateness. Similarly, media validation results showed high scores in presentation, layout, and usability. These findings indicate that the developed e-module met both academic and technical standards.

**Table 3.** Expert validation results

Aspect	Mean Score	Category
Content Feasibility	3.58	Very Valid
Language	3.25	Very Valid
Presentation	3.42	Very Valid
Layout	3.40	Very Valid
Usability	3.67	Very Valid

***Practicality testing***

Practicality testing was conducted through teacher and student responses. The teacher's evaluation showed that the e-module was easy to use and effectively supported learning activities. Students also reported positive responses, indicating that the e-module was engaging and easy to understand. The average practicality score from teachers was 3.43, while students' responses yielded an average score of 3.45. These results indicate that the e-module falls into the "very practical" category. The findings suggest that the developed product is suitable for classroom implementation. The integration of animation contributed significantly to ease of understanding. Overall, the practicality test confirmed the usability of the e-module.

**Table 4.** Practicality test results

Respondent	Mean Score	Category
Teacher	3.43	Very Practical
Students	3.45	Very Practical
<b>Overall</b>	<b>3.44</b>	<b>Very Practical</b>

***Effectiveness testing***

Prior to hypothesis testing, normality and homogeneity tests were conducted. The Shapiro-Wilk test indicated that both experimental and control groups were normally distributed. The Levene test showed that the data were homogeneous. These results confirmed that the assumptions for parametric testing were met. Subsequently, an independent samples t-test was conducted to examine the effectiveness of the e-module. The results showed a significance value of 0.000 ( $p < 0.05$ ), indicating a statistically significant difference between the experimental and control groups. This suggests that the use of the animation-assisted e-module had a positive effect on students' learning outcomes. The mean difference further supports the effectiveness of the intervention. The results confirm that the e-module significantly improved students' understanding of three-dimensional geometry. Therefore, the developed e-module can be considered effective as a learning medium.

**Table 5.** Hypothesis testing results

Test	Value
t-value	-3.804
df	62
Sig. (2-tailed)	0.000
Mean Difference	-9.324

## Discussion

The findings of this study indicate that the developed animation-assisted e-module achieved a high level of validity, demonstrating its alignment with instructional objectives and learning needs. The validation results from subject matter experts and media experts confirm that the content, language, and presentation of the e-module were appropriate for junior high school students. The high validity scores suggest that the integration of structured instructional design and animation features contributed significantly to the quality of the learning material. This result reflects the importance of systematic development models in producing effective instructional media. The use of the 4D development model ensured that each stage of development was carried out thoroughly and systematically. The modification of the model into a more practical form did not reduce the quality of the final product. Instead, it allowed for more efficient development without compromising instructional value. The involvement of experts from different fields also strengthened the credibility of the validation process. Compared to conventional learning materials, the developed e-module provides a more comprehensive and structured learning experience. Therefore, the validity results indicate that the e-module is highly suitable for implementation in mathematics learning.

The practicality results further support the feasibility of the developed e-module as an instructional medium. The high practicality score obtained from both teachers and students indicates that the e-module is easy to use and effectively supports the learning process. The clarity of instructions, organization of content, and interactive features contributed to the usability of the module (Al-Amri et al., 2023; Almusharraf, 2024; Awang et al., 2024). Students were able to navigate the e-module independently and engage with the learning materials more actively (Delita et al., 2022). Teachers also found the e-module helpful in delivering instructional content in a more efficient and structured manner. This finding is consistent with the idea that well-designed digital learning media can enhance classroom implementation. The integration of animation played a key role in improving students' comprehension of abstract concepts. Compared to traditional printed modules, the e-module offers greater flexibility and accessibility. The positive responses from users indicate that the module successfully addressed the limitations of conventional learning resources. Therefore, the practicality results confirm that the developed e-module is highly usable in real classroom settings.

The effectiveness analysis demonstrates that the animation-assisted e-module significantly improved students' learning outcomes. The results of the statistical test indicate a clear difference between students who used the e-module and those who received conventional instruction. This suggests that the integration of animation and interactive elements enhances students' understanding of mathematical concepts. The use of visual representations helped students grasp abstract ideas more effectively. This finding aligns with theoretical perspectives that emphasize the importance of visualization in learning complex subjects (Bozkurt, 2022; Marougkas et al., 2023; Shapiro et al., 2025; Shreiner & Dykes, 2021). Compared to traditional teaching methods, the e-module provided a more engaging and meaningful learning experience. Students were not only able to understand the material but also to apply it in problem-solving contexts (Ahdhianto et al., 2020; Pozas et al., 2020). The improvement in learning outcomes indicates that the e-module supports deeper conceptual understanding rather than surface-level learning. This highlights the effectiveness of combining instructional design with multimedia elements. Therefore, the effectiveness results confirm that the e-module is a valuable tool for improving mathematics learning.

Furthermore, the integration of animation in the e-module played a significant role in facilitating students' understanding of three-dimensional geometry. Geometry learning requires the ability to visualize spatial relationships, which is often difficult to achieve through static images (Hsu & Hsu, 2025; Xiao et al., 2020). The use of animation enabled students to observe dynamic representations of geometric objects, making abstract concepts more concrete (Bos & Wigman,

2025; Dintarini et al., 2024). This approach reduced students' cognitive difficulties and improved their ability to interpret geometric structures. Compared to conventional instructional methods, the animation-assisted e-module provided a more intuitive learning experience. Students were able to explore concepts interactively and at their own pace. This aligns with the principles of student-centered learning, where learners actively construct their own knowledge. The engaging nature of animation also increased students' motivation and interest in learning. As a result, students became more involved in the learning process and showed better performance. Therefore, the integration of animation is a key factor contributing to the effectiveness of the e-module.

Despite the positive outcomes, several challenges were identified during the implementation of the e-module. Some students encountered difficulties in adapting to the use of technology in learning. In addition, there were instances where students were distracted by non-learning activities when using digital devices. These challenges highlight the importance of proper guidance and supervision during technology-based learning. Teachers need to provide clear instructions and monitor students' activities to ensure effective use of the e-module. Training and orientation for students may also be necessary to improve their digital literacy skills. Despite these challenges, the overall responses from teachers and students were highly positive. The e-module was perceived as an engaging and useful learning resource. The positive reception indicates that the benefits of the e-module outweigh its limitations. Furthermore, the challenges identified in this study provide valuable insights for future improvements. Therefore, while the e-module is effective, continuous refinement and support are necessary to optimize its implementation.

### **Implications**

The findings of this study provide important implications for the development and implementation of technology-based learning media in mathematics education. The high validity, practicality, and effectiveness of the animation-assisted e-module indicate that such digital learning tools can serve as a viable alternative to conventional instructional materials. The integration of animation into structured learning modules enhances students' ability to understand abstract mathematical concepts, particularly in three-dimensional geometry. This suggests that educators should consider incorporating multimedia elements into their teaching practices to improve conceptual understanding. In addition, the use of e-modules supports student-centered learning by allowing learners to access materials flexibly and independently. The positive responses from both teachers and students highlight the potential of digital learning media to increase engagement and motivation. From a pedagogical perspective, this study reinforces the importance of aligning instructional design with learners' needs and cognitive characteristics. Furthermore, the results suggest that the use of animation can reduce cognitive barriers associated with complex mathematical topics. For educational institutions, the implementation of such e-modules can contribute to improving the quality of teaching and learning processes. However, the challenges identified in this study also imply the need for proper guidance and monitoring when integrating technology into classrooms. Teachers play a crucial role in ensuring that digital tools are used effectively and responsibly by students. Therefore, this study underscores the need for continuous innovation, training, and support in the integration of educational technology to achieve meaningful and effective learning outcomes.

### **Limitations and Suggestions for Future Research**

This study has several limitations that should be acknowledged when interpreting the findings. First, the research was conducted in a single school context with a relatively limited sample size, which may restrict the generalizability of the results. The participants were limited to eighth-grade students, so the applicability of the findings to other educational levels remains uncertain. In addition, the study focused only on a specific topic in mathematics, namely three-dimensional

geometry, which may not represent the effectiveness of the e-module across other mathematical topics. The duration of the implementation was relatively short, which limits the ability to assess long-term learning retention and conceptual understanding. Furthermore, the study primarily relied on quantitative measures, which may not fully capture students' learning experiences and perceptions. Another limitation is related to the use of technology in the classroom, where some students experienced difficulties in adapting to digital learning environments. Distractions caused by access to non-learning content during the use of digital devices also affected the learning process. In addition, the study did not compare the developed e-module with other types of advanced digital learning tools. Based on these limitations, future research is recommended to involve larger and more diverse samples to improve generalizability. Further studies should also explore the application of animation-assisted e-modules in different mathematical topics and educational levels. Moreover, future research is encouraged to incorporate mixed-method approaches and investigate long-term learning outcomes to provide a more comprehensive understanding of the effectiveness of digital learning media.

## CONCLUSION

This study aimed to develop and evaluate an animation-assisted e-module for mathematics learning, particularly in three-dimensional geometry at the junior high school level. The development process followed a systematic Research and Development approach using the 4D model, ensuring that the product was designed based on identified learning needs. The findings demonstrated that the developed e-module achieved a high level of validity based on expert evaluations in terms of content, language, and media design. The practicality results indicated that the e-module was easy to use and well-received by both teachers and students in classroom implementation. Furthermore, the effectiveness analysis revealed a significant improvement in students' learning outcomes compared to conventional teaching methods. These results confirm that the integration of animation into digital learning modules enhances students' conceptual understanding of abstract mathematical concepts. The e-module also supports student-centered learning by providing flexible and interactive learning opportunities. In addition, the use of animation helps students visualize complex geometric concepts more effectively. The positive responses from users indicate that the e-module can increase students' motivation and engagement in learning mathematics. Despite some challenges in implementation, the overall findings suggest that the benefits of the e-module outweigh its limitations. Therefore, the animation-assisted e-module can be considered a valid, practical, and effective instructional medium for mathematics learning. Ultimately, this study contributes to the advancement of technology-based learning innovations and supports the integration of digital media in improving the quality of mathematics education.

## AUTHOR CONTRIBUTIONS STATEMENT

Chumaedi Sugihandardji conceived the study, designed the research framework, developed the animation-assisted e-module, collected and analyzed the data, and prepared the original manuscript draft. Wiwit Puji Rahayu contributed to the research methodology, validated the instructional content, supervised the development process, and critically reviewed the manuscript. Ari Wardayani contributed to data interpretation, validation of the research outcomes, manuscript revision, and overall supervision of the study. All authors contributed substantially to the research, reviewed the manuscript, and approved the final version for publication.

## REFERENCES

- Ahdhianto, E., Marsigit, Haryanto, & Santi, N. N. (2020). The effect of metacognitive-based contextual learning model on fifth-grade students' problem-solving and mathematical communication skills. *European Journal of Educational Research*, 9(2), 753–764. <https://doi.org/10.12973/eu-er.9.2.753>
- Akram, H., Abdelrady, A. H., Al-Adwan, A. S., & Ramzan, M. (2022). Teachers' perceptions of technology integration in teaching-learning practices: A systematic review. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.920317>
- Al-Amri, S., Hamid, S., Noor, N. F. M., & Gani, A. (2023). A framework for designing interactive mobile training course content using augmented reality. *Multimedia Tools and Applications*, 82(20), 30491–30541. <https://doi.org/10.1007/s11042-023-14561-4>
- Alenezi, M., Wardat, S., & Akour, M. (2023). The need of integrating digital education in higher education: Challenges and opportunities. *Sustainability*, 15(6). <https://doi.org/10.3390/su15064782>
- Almusharraf, A. I. (2024). An investigation of university students' perceptions of learning management systems: Insights for enhancing usability and engagement. *Sustainability*, 16(22). <https://doi.org/10.3390/su162210037>
- Alyusfitri, R., Gistituati, N., Yerizon, Fauzan, A., & Yarman. (2024). The effectiveness and relationship of student responses toward learning outcomes using interactive multimedia-based e-modules in elementary schools. *International Electronic Journal of Elementary Education*, 16(5), 573–584. <https://doi.org/10.26822/iejee.2024.354>
- Asad, M. M., Hussain, N., Wadho, M., Khand, Z. H., & Churi, P. P. (2021). Integration of e-learning technologies for interactive teaching and learning process: An empirical study on higher education institutes of Pakistan. *Journal of Applied Research in Higher Education*, 13(3), 649–663. <https://doi.org/10.1108/JARHE-04-2020-0103>
- Asad, M. M., & Qureshi, A. (2025). Impact of technology-based collaborative learning on students' competency-based education: Insights from the higher education institution of Pakistan. *Higher Education, Skills and Work-Based Learning*, 15(3), 562–575. <https://doi.org/10.1108/HESWBL-07-2024-0202>
- Awang, L. A., Yusop, F. D., & Danaee, M. (2024). Insights on usability testing: The effectiveness of an adaptive e-learning system for secondary school mathematics. *International Electronic Journal of Mathematics Education*, 19(3). <https://doi.org/10.29333/iejme/14621>
- Banda, H. J., & Nzabahimana, J. (2021). Effect of integrating physics education technology simulations on students' conceptual understanding in physics: A review of literature. *Physical Review Physics Education Research*, 17(2), 023108. <https://doi.org/10.1103/PhysRevPhysEducRes.17.023108>
- Blau, I., Shamir-Inbal, T., & Avdiel, O. (2020). How does the pedagogical design of a technology-enhanced collaborative academic course promote digital literacies, self-regulation, and perceived learning of students? *The Internet and Higher Education*, 45, 100722. <https://doi.org/10.1016/j.iheduc.2019.100722>
- Bos, R., & Wigmans, M. (2025). Dynamic visualization in animated mathematics videos: Students' experiences and learning outcomes. *International Journal for Technology in Mathematics Education*, 32(1), 29–48. [https://doi.org/10.1564/tme\\_v32.1.03](https://doi.org/10.1564/tme_v32.1.03)
- Bozkurt, A. (2022). A retro perspective on blended/hybrid learning: Systematic review, mapping and visualization of the scholarly landscape. *Journal of Interactive Media in Education*, 2022(1). <https://doi.org/10.5334/jime.751>
- Carless, D. (2022). From teacher transmission of information to student feedback literacy: Activating the learner role in feedback processes. *Active Learning in Higher Education*, 23(2), 143–153. <https://doi.org/10.1177/1469787420945845>
- Chang, H.-Y., Chang, Y.-J., & Tsai, M.-J. (2024). Strategies and difficulties during students' construction of data visualizations. *International Journal of STEM Education*, 11(1), 11. <https://doi.org/10.1186/s40594-024-00463-w>
- Chirinda, B., Ndlovu, M., & Spangenberg, E. (2021). Teaching mathematics during the COVID-19 lockdown in a context of historical disadvantage. *Education Sciences*, 11(4). <https://doi.org/10.3390/educsci11040177>

- Cirneanu, A.-L., & Moldoveanu, C.-E. (2024). Use of digital technology in integrated mathematics education. *Applied System Innovation*, 7(4). <https://doi.org/10.3390/asi7040066>
- Cong, L., & Ironsi, C. S. (2025). Integrating mobile learning and problem-based learning in improving students action competence in problem-solving and critical thinking skills. *Humanities and Social Sciences Communications*, 12(1), 1238. <https://doi.org/10.1057/s41599-025-05397-4>
- Delita, F., Berutu, N., & Nofrion, N. (2022). Online learning: The effects of using e-modules on self-efficacy, motivation and learning outcomes. *Turkish Online Journal of Distance Education*, 23(4), 93–107. <https://doi.org/10.17718/tojde.1182760>
- Demir, C. G., & Önal, N. (2021). The effect of technology-assisted and project-based learning approaches on students' attitudes towards mathematics and their academic achievement. *Education and Information Technologies*, 26(3), 3375–3397. <https://doi.org/10.1007/s10639-020-10398-8>
- Dintarini, M., Fuad, Y., & Budiarto, M. T. (2024). Examining undergraduate students' abstraction of conic sections in a dynamic geometry environment. *Journal on Mathematics Education*, 15(3), 717–734. <https://doi.org/10.22342/jme.v15i3.pp717-734>
- Drijvers, P., & Sinclair, N. (2024). The role of digital technologies in mathematics education: Purposes and perspectives. *ZDM—Mathematics Education*, 56(2), 239–248. <https://doi.org/10.1007/s11858-023-01535-x>
- Engelbrecht, J., & Borba, M. C. (2024). Recent developments in using digital technology in mathematics education. *ZDM—Mathematics Education*, 56(2), 281–292. <https://doi.org/10.1007/s11858-023-01530-2>
- Falloon, G. (2020). From digital literacy to digital competence: The teacher digital competency (TDC) framework. *Educational Technology Research and Development*, 68(5), 2449–2472. <https://doi.org/10.1007/s11423-020-09767-4>
- Farrokhnia, M., Meulenbroeks, R. F. G., & van Joolingen, W. R. (2020). Student-generated stop-motion animation in science classes: A systematic literature review. *Journal of Science Education and Technology*, 29(6), 797–812. <https://doi.org/10.1007/s10956-020-09857-1>
- Georgiou, Y., & Ioannou, A. (2021). Developing, enacting and evaluating a learning experience design for technology-enhanced embodied learning in math classrooms. *TechTrends*, 65(1), 38–50. <https://doi.org/10.1007/s11528-020-00543-y>
- Gopinathan, S., Kaur, A. H., Veeraya, S., & Raman, M. (2022). The role of digital collaboration in student engagement towards enhancing student participation during COVID-19. *Sustainability*, 14(11). <https://doi.org/10.3390/su14116844>
- Hackenberg, A. J., Creager, M., & Eker, A. (2021). Teaching practices for differentiating mathematics instruction for middle school students. *Mathematical Thinking and Learning*, 23(2), 95–124. <https://doi.org/10.1080/10986065.2020.1731656>
- Heber, S., Grasl, M. C., & Volf, I. (2023). A successful intervention to improve conceptual knowledge of medical students who rely on memorization of disclosed items. *Frontiers in Physiology*, 14. <https://doi.org/10.3389/fphys.2023.1258149>
- Hsu, S.-K., & Hsu, Y. (2025). Supporting young learners in learning geometric area concepts through static versus dynamic representation and imagination strategies. *International Journal of Science and Mathematics Education*, 23(2), 441–459. <https://doi.org/10.1007/s10763-024-10481-3>
- Hurrell, D. (2021). Conceptual knowledge or procedural knowledge or conceptual knowledge and procedural knowledge: Why the conjunction is important to teachers. *Australian Journal of Teacher Education*, 46(2), 57–71. <https://doi.org/10.14221/ajte.2021v46n2.4>
- İbili, E., Çat, M., Resnyansky, D., Şahin, S., & Billingham, M. (2020). An assessment of geometry teaching supported with augmented reality teaching materials to enhance students' 3D geometry thinking skills. *International Journal of Mathematical Education in Science and Technology*, 51(2), 224–246. <https://doi.org/10.1080/0020739X.2019.1583382>
- Jacinto, H., & Carreira, S. (2023). Knowledge for teaching mathematical problem-solving with technology: An exploratory study of a mathematics teacher's proficiency. *European Journal of Science and Mathematics Education*, 11(1), 105–122. <https://doi.org/10.30935/scimath/12464>
- Kravchenko, O., Dokuchaieva, V., Valentieva, T., Sbitnieva, L., & Chornobryva, N. (2023). The use of technology-based model of critical thinking development to reshape students' self-study

- process. *European Journal of Educational Research*, 12(1), 281–296. <https://doi.org/10.12973/eu-jer.12.1.281>
- Laksmi, N. K. P., Yasa, I. K. A., & Mirayani, K. A. M. (n.d.). The use of animation video as learning media for young learner to improve EFL students' motivation in learning English.
- Lo, C. K., & Hew, K. F. (2020). A comparison of flipped learning with gamification, traditional learning, and online independent study: The effects on students' mathematics achievement and cognitive engagement. *Interactive Learning Environments*, 28(4), 464–481. <https://doi.org/10.1080/10494820.2018.1541910>
- Machaba, F., Sibanda, A., & Vojo George, F. (2024). Grade 8 learners' perceptions and misconceptions on their learning of surface area and volume in mathematics. *International Journal of Management, Knowledge and Learning*, 13, 377–400. <https://doi.org/10.53615/2232-5697.13.377-400>
- Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). Virtual reality in education: A review of learning theories, approaches and methodologies for the last decade. *Electronics*, 12(13). <https://doi.org/10.3390/electronics12132832>
- Medina Herrera, L. M., Juárez Ordóñez, S., & Ruiz-Loza, S. (2024). Enhancing mathematical education with spatial visualization tools. *Frontiers in Education*, 9. <https://doi.org/10.3389/educ.2024.1229126>
- Milenkova, V., & Lendzhova, V. (2021). Digital citizenship and digital literacy in the conditions of social crisis. *Computers*, 10(4). <https://doi.org/10.3390/computers10040040>
- Mjenda, M., Mutarutinya, V., & Owiti, D. (2023). Assessing the effectiveness of computer-aided instructional techniques in enhancing students' 3D geometry spatial visualization skills among secondary school students in Tanzania. *International Journal of Learning, Teaching and Educational Research*, 22(6), 613–637. <https://doi.org/10.26803/ijlter.22.6.31>
- Mou, T.-Y. (2023). Science learning with designed animation: Investigation of primary school children's attitudes toward science learning, animation integration, and understanding level. *International Journal of Educational Research Open*, 4, 100246. <https://doi.org/10.1016/j.ijedro.2023.100246>
- Mutodi, P., & Mosimege, M. (2021). Learning mathematical symbolization: Conceptual challenges and instructional strategies in secondary schools. *Bolema: Boletim de Educação Matemática*, 35, 1180–1199. <https://doi.org/10.1590/1980-4415v35n70a29>
- Nkundabakura, P., Nsengimana, T., Nyirahabimana, P., Nkurunziza, J. B., Mukamwambali, C., Dushimimana, J. C., Uwamariya, E., Batamuliza, J., Byukusenge, C., Nsabayeze, E., Twahirwa, J. N., Iyamuremye, A., Mboniyirivuze, A., Ukobizaba, F., & Ndiokubwayo, K. (2023). Usage of modernized tools and innovative methods in teaching and learning mathematics and sciences: A case of 10 districts in Rwanda. *Education and Information Technologies*, 28(9), 11379–11400. <https://doi.org/10.1007/s10639-023-11666-z>
- Nuryadi, M. H., & Widiatmaka, P. (2023). Strengthening civic literacy among students through digital literacy in Society 5.0. *Journal of Education and Learning (EduLearn)*, 17(2), 215–220. <https://doi.org/10.11591/edulearn.v17i2.20746>
- Ozkan, G., & Umdü Topsakal, U. (2021). Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics. *Research in Science & Technological Education*, 39(4), 441–460. <https://doi.org/10.1080/02635143.2020.1769586>
- Palinussa, A. L., Tupamahu, P. Z., Sabandar, V. P., Makaruku, Y. H., & Sabandar, J. (2025). Realistic mathematics education: Mathematics e-modules in improving student learning outcomes. *Infinity Journal*, 14(1), 45–64. <https://doi.org/10.22460/infinity.v14i1.p45-64>
- Peng, R., Razak, R. A., & Halili, S. H. (2023). Factors influencing in-service teachers' technology integration model: Innovative strategies for educational technology. *PLOS ONE*, 18(8), e0286112. <https://doi.org/10.1371/journal.pone.0286112>
- Ploetzner, R., Berney, S., & Bétrancourt, M. (2020). A review of learning demands in instructional animations: The educational effectiveness of animations unfolds if the features of change need to be learned. *Journal of Computer Assisted Learning*, 36(6), 838–860. <https://doi.org/10.1111/jcal.12476>

- Pozas, M., Löffler, P., Schnotz, W., & Kauertz, A. (2020). The effects of context-based problem-solving tasks on students' interest and metacognitive experiences. *Open Education Studies*, 2(1), 112–125. <https://doi.org/10.1515/edu-2020-0118>
- Rahimi, R. A., & Oh, G. S. (2024). Rethinking the role of educators in the 21st century: Navigating globalization, technology, and pandemics. *Journal of Marketing Analytics*, 12(2), 182–197. <https://doi.org/10.1057/s41270-024-00303-4>
- Rohendi, D., & Wihardi, Y. (2020). Learning three-dimensional shapes in geometry using mobile-based augmented reality. *International Journal of Interactive Mobile Technologies*, 14(9), 48. <https://doi.org/10.3991/ijim.v14i09.13035>
- Selfa-Sastre, M., Pifarré, M., Cujba, A., Cutillas, L., & Falguera, E. (2022). The role of digital technologies to promote collaborative creativity in language education. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.828981>
- Setiadi, D., Nurhayati, S., Ansori, A., Zubaidi, M., & Amir, R. (2023). Youth's digital literacy in the context of community empowerment in an emerging Society 5.0. *Society*, 11(1), 1–12. <https://doi.org/10.33019/society.v11i1.491>
- Shapiro, B. R., & Silvis, D. (2025). Animated movements, animating methods: An interaction geography approach to space and affect in early childhood education. *Journal of Early Childhood Literacy*, 25(3), 901–932. <https://doi.org/10.1177/14687984231212723>
- Shapiro, B. R., Silvis, D., & Hall, R. (2025). Visualization as theory and experience: Interactive qualitative data visualization for the learning sciences. *Journal of the Learning Sciences*, 34(5), 840–871. <https://doi.org/10.1080/10508406.2025.2537945>
- Shé, C. N., Ní Fhloinn, E., & Mac an Bhaird, C. (2023). Student engagement with technology-enhanced resources in mathematics in higher education: A review. *Mathematics*, 11(3). <https://doi.org/10.3390/math11030787>
- Shreiner, T. L., & Dykes, B. M. (2021). Visualizing the teaching of data visualizations in social studies: A study of teachers' data literacy practices, beliefs, and knowledge. *Theory & Research in Social Education*, 49(2), 262–306. <https://doi.org/10.1080/00933104.2020.1850382>
- Trujillo-Cayado, L. A., Santos, J., Cordobés, F., & Ramos-Payán, M. (2024). Influence of the use of 3D printing technology for teaching chemistry in STEM disciplines. *Computer Applications in Engineering Education*, 32(4), e22738. <https://doi.org/10.1002/cae.22738>
- Utaminingsih, S., Machfud, Santosa, & Kassymova, G. (2024). Development of learning management with animated video to increase motivation and learning outcomes. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 41, 31–42. <https://doi.org/10.37934/araset.41.2.3142>
- Wang, H., Xu, H., Zhang, J., Yu, S., Wang, M., Qiu, J., & Zhang, M. (2020). The effect of 3D-printed plastic teeth on scores in a tooth morphology course in a Chinese university. *BMC Medical Education*, 20(1), 469. <https://doi.org/10.1186/s12909-020-02390-0>
- Weinhandl, R., Mayerhofer, M., Houghton, T., Lavicza, Z., Eichmair, M., & Hohenwarter, M. (2023). Mathematics student personas for the design of technology-enhanced learning environments. *Research and Practice in Technology Enhanced Learning*, 18, 32. <https://doi.org/10.58459/rptel.2023.18032>
- Xiao, Y.-P., Lai, Y.-K., Zhang, F.-L., Li, C., & Gao, L. (2020). A survey on deep geometry learning: From a representation perspective. *Computational Visual Media*, 6(2), 113–133. <https://doi.org/10.1007/s41095-020-0174-8>
- Žakelj, A., & Klančar, A. (2022). The role of visual representations in geometry learning. *European Journal of Educational Research*, 11(3), 1393–1411. <https://doi.org/10.12973/eu-jer.11.3.1393>
- Zhang, Q., & Lin, C. (2026). A study on the impact of project-based learning on students' learning motivation in animation programs. *Frontiers in Psychology*, 16. <https://doi.org/10.3389/fpsyg.2025.1722170>
- Ziatdinov, R., & Valles, J. R., Jr. (2022). Synthesis of modeling, visualization, and programming in GeoGebra as an effective approach for teaching and learning STEM topics. *Mathematics*, 10(3). <https://doi.org/10.3390/math10030398>