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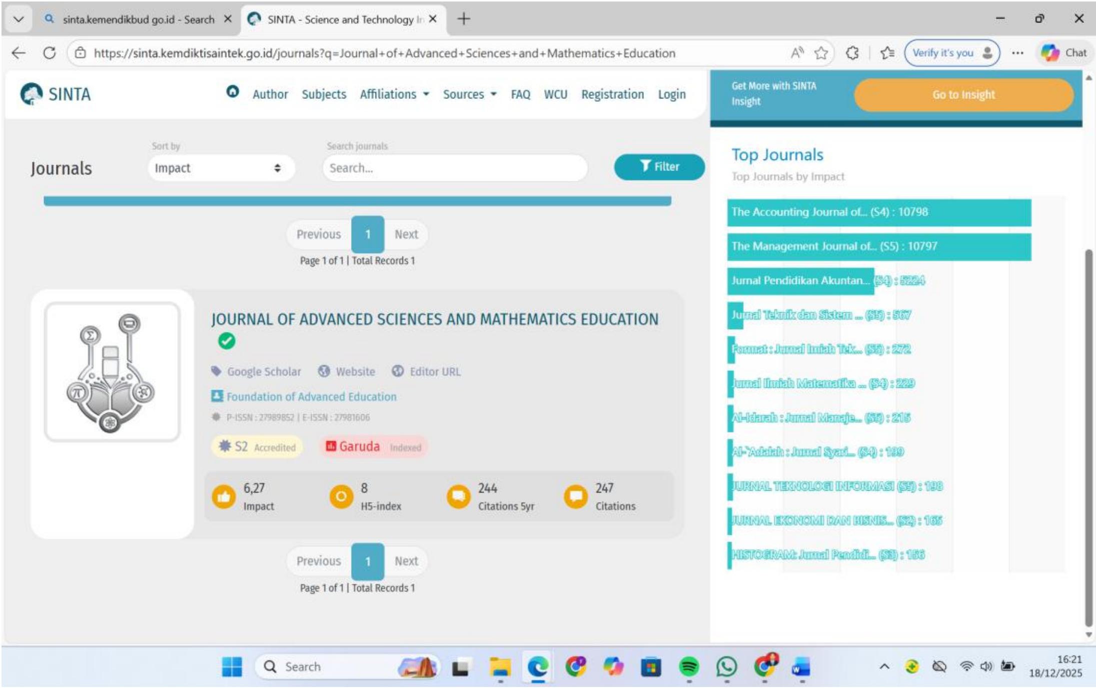
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Exploring how augmented reality enriches realistic mathematics education to strengthen students' understanding of curved-sided geometric ideas

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Abstract

Background: Students often find curved-sided geometric shapes difficult to grasp because the material is usually introduced in a highly symbolic way. This condition creates a clear need for learning materials that can present ideas more visually and in contexts that feel relevant to students.
Aim: The study seeks to design and examine a learning module that blends Augmented Reality with the principles of Realistic Mathematics Education to support stronger conceptual understanding.
Method: Using a Research and Development approach, the study followed the ADDIE sequence from early analysis to final evaluation. The module was reviewed by subject and media experts, tested in a small group to gauge usability, and later implemented in larger classes. Its effectiveness was assessed by comparing posttest scores from a class using the AR–RME module and another class taught with standard materials.
Results: Expert feedback showed that both the content and media components reached valid to very valid levels. Students and teachers also reported that the module was easy to use and fit well within classroom activities. The experimental class recorded higher posttest scores than the control group, indicating meaningful gains in conceptual understanding.
Conclusion: Augmented Reality, when embedded in a Realistic Mathematics Education setting, offers a learning experience that helps students connect abstract geometric ideas with clearer mental models. The module developed in this study meets the criteria for validity, practicality, and effectiveness, and can serve as a valuable learning resource for geometry instruction.

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INTRODUCTION

This study is urgent because students' persistent difficulties in understanding curved-sided geometric shapes continue to surface across grade levels despite repeated exposure to the topic. Many learners fail to build clear mental images of these shapes, and their understanding often depends on memorized formulas rather than conceptual insight (Hagos, 2026; Janssen et al., 2021; Ncube & Luneta, 2025). Such reliance on symbolic procedures reflects a deeper gap between instructional delivery and students' cognitive processing. When concepts are presented solely through symbols, students lose the opportunity to connect mathematical representations with the physical forms they describe. As a result, misconceptions form easily and tend to persist because students have no strong visual foundation to correct them. These misconceptions then limit their performance when encountering more complex applications involving volume, surface area, or spatial properties. Over time, these accumulated difficulties reduce students' confidence and motivation in learning geometry. Hence, improving instructional approaches becomes a pressing necessity.

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One of the core problems lies in instructional practices that emphasize formulas and procedures rather than meaningful understanding (Chen, 2025; Wardat et al., 2023). When students meet geometry primarily through notations, examples, and procedural demonstrations, they struggle to grasp the conceptual meaning behind the symbols (Ristroph, 2025; Schifter & Russell, 2022). Without concrete experiences or visual anchors, mathematical ideas remain disconnected from students' lived reality. This situation is especially challenging in the study of curved-sided solids, whose spatial characteristics cannot be fully captured through flat illustrations. Although textbooks provide diagrams, these images often oversimplify shapes and fail to communicate their three-dimensional nature. As a result, students interpret the figures as isolated drawings rather than representations of real forms with measurable properties. Weak conceptual grounding then diminishes students' ability to reason and apply formulas appropriately. This problem signals the need for instructional strategies that integrate symbolic and visual understanding more effectively.

Another contributing factor is the limited opportunity for students to explore geometric shapes through interactive experiences (Puig et al., 2022; Sudirman et al., 2025). Traditional learning materials usually present static images that cannot be rotated, enlarged, or examined from different angles (Choudhary et al., 2022; Goceri, 2023). Such limitations prevent students from fully appreciating the structure and internal relationships within curved-sided forms. Instead of investigating shapes and constructing meaning, students merely observe and accept information as it is given. This passive learning environment reduces the depth of conceptual development and restricts students' spatial reasoning. Without hands-on exploration, learners struggle to identify patterns or infer principles that naturally arise from direct observation. Consequently, the process of learning becomes detached from the intuitive reasoning that forms the basis of strong conceptual understanding. Addressing this limitation requires materials that allow students to engage actively with geometric objects.

Meaningful contexts, which are essential to support deeper learning, are also underutilized in many geometry classrooms (Jablonski & Ludwig, 2023; Lee, 2023). Realistic Mathematics Education (RME) emphasizes that students learn best when mathematical ideas emerge from situations they can recognize and interpret (Susanti, 2025). However, many instructional examples remain abstract and disconnected from students' everyday experiences. On topics such as curved-sided solids, missed opportunities to use familiar objects weaken students' ability to relate formulas to real-world shapes. When learners cannot see the relevance of geometry to their environment, they perceive the material as mechanical and distant. This perception undermines their willingness to reason, explore, and make sense of the concepts. RME offers a promising pathway because it positions mathematics as something to be reinvented through meaningful situations. Yet its integration into geometry learning, particularly for curved-sided shapes, remains inconsistent.

Visualization tools used in classrooms often lack the capacity to represent geometric shapes with sufficient clarity and flexibility (Korkut & Surer, 2023; Medina Herrera et al., 2024). Teachers typically rely on two-dimensional drawings, simple models, or quick sketches, which provide only partial insight into the structure of the shapes (Koddenberg, 2025; Wang et al., 2022). These representations limit students' understanding of spatial relationships, especially in shapes that require three-dimensional interpretation. Inconsistent or incomplete visual information results in mental images that do not accurately reflect the properties of the objects. Developments in educational technology, however, offer new possibilities for enhancing visualization. Augmented Reality allows students to view and manipulate virtual objects directly through their devices, enabling more accurate observation. Through AR, learners can rotate shapes, examine hidden components, and explore spatial relationships with greater precision. Such capabilities create a learning environment that supports stronger conceptual retention.

Interactive technology does more than enhance visualization; it can also elevate students' cognitive engagement (Muir et al., 2022; Pandita & Kiran, 2023). Research in mathematics education consistently shows that active involvement strengthens comprehension, particularly in areas requiring spatial reasoning (Harris, 2023; Lowrie et al., 2021). Geometry is one such area, where intuition about space develops through manipulation and observation. Despite this, digital learning resources for curved-sided solids rarely incorporate dynamic or immersive technology. The mismatch between students' learning needs and available instructional tools limits the effectiveness of geometry instruction. Integrating AR into RME-inspired materials can restore the exploratory dimension of learning by encouraging students to manipulate shapes while grounding their understanding in meaningful contexts. This combination presents a pedagogical opportunity to deepen conceptual insight in ways traditional materials cannot fully support.

Nevertheless, the adoption of technology alone does not guarantee meaningful learning unless guided by a supportive pedagogical framework (Abedi, 2024; Ahmed et al., 2024). RME offers principles that promote progressive formalization, where students transition from concrete contexts to abstract mathematical structures (González-Polo & Castaneda, 2024; Susanti, 2025). When AR is used within this framework, visualization becomes part of the conceptual construction process rather than a decorative addition. Students can observe geometric forms in real-world scenarios, experiment with them, and gradually articulate the properties they discover. However, empirical studies examining this integration remain scarce, and many existing digital materials lack systematic validation. Limited research attention and minimal classroom testing indicate that further investigation is necessary. This gap underscores the relevance of exploring how AR and RME can be combined effectively.

Given these challenges, developing a learning module that integrates AR with the principles of RME presents a timely and meaningful response. Such a module has the potential to bridge the gap between visual perception, contextual understanding, and mathematical abstraction (Alam & Mohanty, 2024; Kokkonen & Schalk, 2021; Madrazo & Dio, 2020). By offering three-dimensional representations, realistic contexts, and opportunities for exploration, the module addresses shortcomings in conventional materials. Ensuring that the module is validated, practical, and effective is essential for its adoption in actual classrooms. This development contributes not only to the improvement of teaching practices but also to the scholarly discourse on technology-enhanced mathematics education. It responds directly to students' difficulties and aligns with current educational priorities aimed at strengthening conceptual understanding. Consequently, this study holds significant potential to enrich geometry instruction, particularly on topics involving curved-sided geometric forms.

Research on the use of augmented reality in mathematics education increasingly points to its role in strengthening students' visualization and conceptual understanding, particularly in geometry. Kaźmierczak et al. (2025) show that AR allows learners to interact with abstract geometric objects in more concrete and observable ways, which supports spatial reasoning. From a design perspective, Salahuddin et al. (2025) argue that AR becomes pedagogically meaningful only when it is embedded within a structured learning framework. This view is echoed in broader educational contexts by Arango-Caro et al. (2025), who find that interactive and design-based learning environments foster sustained engagement with complex material. In mathematics-specific settings, Wulandari et al. (2025) demonstrate that AR-based ethnomathematics materials help students link mathematical concepts with cultural experiences. Ramnarain et al. (2025) emphasize that extended reality technologies gain educational value when connected to learners' real-world and indigenous contexts. Evidence from synthesis studies further strengthens these claims. Sofroniou et al. (2025) conclude that digital technologies improve conceptual understanding when guided by clear instructional goals. In geometry learning, Na et al. (2025) highlight that different AR designs shape students' learning experiences in distinct ways. Classroom-level findings from Zekeik et al. (2025) indicate that mobile AR applications support students' understanding of spatial properties. Rahman (2025) notes emerging trends such as gamification in educational AR, while Flavin et al. (2025) confirm that AR generally has a positive impact on mathematics achievement, with outcomes strongly influenced by instructional design.

The growing use of augmented reality in mathematics classrooms reflects an increasing awareness of the importance of visualization in learning abstract concepts. Nevertheless, many AR-based learning initiatives still prioritize technological novelty over the way students construct mathematical meaning. In geometry learning, particularly in topics involving curved-sided shapes, students are often required to reconcile formulas, diagrams, and spatial reasoning simultaneously, which can be cognitively demanding. While augmented reality can support visualization, its instructional value depends on how it is embedded within a coherent learning approach. Realistic Mathematics Education offers a pedagogical foundation that encourages students to develop concepts through meaningful situations and gradual abstraction. Placing AR within this framework allows visualization to function as a tool for reasoning rather than mere illustration. Therefore, the development of an AR-supported learning module grounded in RME principles is justified as a response to persistent conceptual difficulties in geometry.

Previous research has shown that augmented reality can improve engagement and visualization in mathematics learning, while other studies highlight the benefits of contextual and meaningful instruction. However, much of the existing literature examines these aspects separately. Many AR-focused studies concentrate on learning outcomes without detailing how the instructional materials were systematically developed. Conversely, studies grounded in contextual pedagogies often do not incorporate immersive technologies that could strengthen spatial understanding. Research that explicitly integrates augmented reality with Realistic Mathematics Education remains limited, especially in the context of junior high school geometry and curved-sided shapes. Furthermore, few studies report a comprehensive evaluation process that includes validity, practicality, and effectiveness within a single investigation. This situation leaves a gap in understanding how AR and RME can be combined into a well-designed, classroom-ready learning module that is both pedagogically sound and empirically tested.

Building on the identified gap, this study aims to develop a mathematics learning module that integrates Augmented Reality within the framework of Realistic Mathematics Education to enhance students' conceptual understanding of curved-sided geometric shapes. The study also seeks to examine the validity of the module through expert judgment and its practicality through classroom implementation involving students and teachers. In addition, the study aims to evaluate the effectiveness of the module by comparing students' conceptual understanding with that achieved through conventional instruction. Accordingly, the study hypothesizes that students who learn using the AR-supported RME module will demonstrate significantly higher conceptual understanding than those who learn through traditional learning materials.

METHOD

Research Design

This study was carried out using a Research and Development approach, which allowed the researchers to refine the learning module gradually while responding to the needs identified in the field. The ADDIE framework—consisting of analysis, design, development, implementation, and evaluation—served as the backbone of the process because it supports structured yet flexible development. During the analysis stage, the team examined curriculum expectations and explored the specific conceptual barriers students encountered with curved-sided geometric shapes. Insights from this stage informed the design phase, in which the initial structure of the learning module was drafted by blending Realistic Mathematics Education principles with Augmented Reality elements. The development phase involved shaping this draft into a functioning module and submitting it to expert reviewers for both content and media evaluation. Implementation took place in two stages, beginning with a small-group usability test and continuing with a larger classroom trial. The final evaluation stage examined how well the module met criteria of validity, practicality, and effectiveness.

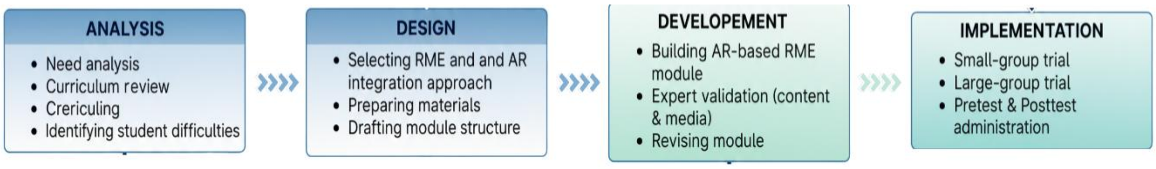

Figure 1. Flowchart of the Research Procedure

The overall workflow of the research process is illustrated in the flowchart below, which summarizes the sequence of activities conducted in each ADDIE stage.

Participants

The participants were ninth-grade students from Muhammadiyah At-Tanwir Metro Junior High School. Two intact classes were selected using random sampling, each consisting of 25 students. The experimental class used the AR-supported RME module, while the control class received instruction through conventional materials. In addition, six students representing high, medium, and low performance levels were involved in the preliminary small-group trial to provide early feedback on clarity, usability, and navigation of the module.

Instrument

Several instruments were used to collect data at different stages of development. Expert validation sheets assessed the accuracy, consistency, and pedagogical appropriateness of both the content and media components of the module. Student and teacher response questionnaires were administered during the practicality testing stage to gather impressions about ease of use, clarity of instructions, and overall learning experience. A pretest–posttest instrument was developed to measure conceptual understanding, particularly students' ability to interpret, visualize, and apply properties of curved-sided geometric shapes. All instruments were reviewed to ensure alignment with learning objectives and curriculum standards.

Data Analysis

Data were analyzed using a combination of quantitative techniques. Validation scores from experts were converted into index values to determine whether the module met valid or very valid criteria. Practicality scores based on student and teacher responses were transformed into percentage indices to classify the module as practical or highly practical. To evaluate effectiveness, posttest scores from the experimental and control groups were compared using an independent samples t-test at a significance level of 0.05. This analysis allowed the researchers to determine whether the AR-supported RME module produced statistically meaningful improvements in conceptual understanding.

RESULTS AND DISCUSSION

Results

The outcome of this study is a mathematics learning module developed by integrating the principles of Realistic Mathematics Education with Augmented Reality technology. The development process followed the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. Through this structured process, a learning module was produced to support students' understanding of curved-sided geometric shapes. The final appearance and structure of the developed module are presented in Figure 1.

Figure 1. RME-Based Mathematics Module with Augmented Reality

After the development stage, the module was reviewed by material experts and media experts to determine its level of validity. The assessment results from these experts are summarized in Table 1.

Table 1. Validation Results by Material Experts and Media Experts

Aspect	Validity of Material	Media Validity
	V1	V2
Scores Total	28	29
Almost Ideal	32	32
Yield Index	0.83	0.875
Information	Very valid	Very valid

The validation results indicate that the developed module achieved scores within the valid to very valid categories for both content and media aspects. These findings show that the module is suitable for use in learning activities and meets the required quality standards.

Following expert validation, the module was tested to examine its practicality when used in classroom settings. Practicality data were collected through student and teacher response questionnaires, and the results are presented in Table 2.

Table 2. Student and Teacher Practicality Assessment Results

Aspect	Student Response	Teacher Response
	S1	S2
Scores Total	39	35
Almost Ideal	40	40
Yield Index	0.96	0.83
Information	Very Practical	Very Practical

The results in Table 2 show that the module was rated as practical to very practical by both students and teachers. This indicates that the module is easy to use, understandable, and appropriate for classroom implementation. After the practicality stage, a large-group trial was conducted to evaluate the effectiveness of the module. The effectiveness analysis was carried out by comparing posttest scores between the experimental and control classes using an independent samples t-test. The results of this analysis are presented in Table 3.

Table 3. Posttest t-Test Results

Data	t	df	Sig.	Result
Posttest	1.916	48	0.001	Rejected

The significance value obtained was below 0.05, indicating a statistically significant difference in posttest results between the two groups. A further comparison of students' posttest scores is presented in Table 4 to illustrate differences in conceptual understanding between the experimental and control classes.

Table 4. Posttest Conceptual Understanding Scores

Class	Minimum Score	Maximum Score	Mean Score
Experimental	70	100	84.60
Control	50	90	76.20

The data in Table 4 show that the experimental class achieved a higher average posttest score than the control class. This finding indicates that students who learned using the RME-based module supported by Augmented Reality demonstrated better conceptual understanding of curved-sided geometric shapes.

Discussion

The results of this study demonstrate that the developed learning module successfully meets the criteria of validity, practicality, and effectiveness, indicating that the integration of augmented reality within a Realistic Mathematics Education framework is pedagogically sound. Expert validation confirms that both the mathematical content and media design are aligned with instructional standards, suggesting that the module was developed with sufficient academic rigor. This finding reinforces the argument that AR-based learning materials require careful instructional planning rather than simple technological enhancement. In this regard, the present study echoes the view of Kaźmierczak et al. (2025) and Wu et al. (2013), who emphasize that augmented reality contributes meaningfully to learning only when embedded in a coherent pedagogical structure.

The positive practicality responses from both students and teachers further indicate that the module is usable in real classroom conditions. This suggests that the inclusion of AR does not necessarily complicate instruction when the interface and learning flow are designed thoughtfully. Students were able to navigate the module without extensive guidance, while teachers reported that the module fit well within existing lesson structures. Similar observations were reported by Salahuddin et al. (2025), who found that AR-based applications are more readily adopted when their design aligns with classroom realities. In the present study, the RME-oriented structure appears to have played a key role in maintaining this alignment.

The effectiveness results show a clear difference between students who learned using the AR-supported module and those who learned through conventional materials. The higher posttest scores achieved by the experimental group suggest that the combination of visualization and contextual learning supported deeper conceptual understanding. Interactive and design-oriented learning environments, as discussed by Arango-Caro et al. (2025), are known to increase student engagement, which may help explain why students in the experimental class were better able to internalize geometric concepts. Engagement in this sense is not merely affective but closely related to cognitive involvement.

Contextual learning also appears to have strengthened students' understanding by connecting abstract geometric ideas with situations that felt meaningful. The use of realistic contexts allowed students to interpret formulas and properties as part of a logical structure rather than isolated rules. This aligns with findings by Wulandari et al. (2025), who show that contextual and culturally grounded materials can support conceptual clarity. Although the present study does not explicitly adopt an ethnomathematical approach, the emphasis on realism serves a similar cognitive function.

The role of meaningful context is further supported by the work of Ramnarain et al. (2025), who argue that immersive technologies gain instructional value when they resonate with learners' experiences. In the developed module, augmented reality was used to bridge abstract formulas and tangible representations, helping students visualize properties of curved-sided shapes more accurately. This approach likely contributed to reducing misconceptions that commonly arise from static two-dimensional diagrams.

From a broader theoretical perspective, the findings of this study are consistent with synthesis research on digital technologies in mathematics education. Sofroniou et al. (2025) emphasize that digital tools improve conceptual understanding only when guided by explicit pedagogical intentions. The present study supports this view by showing that AR alone is insufficient; its effectiveness emerges when paired with the structured learning trajectory offered by Realistic Mathematics Education.

Design decisions related to augmented reality also appear to influence learning outcomes. Na et al. (2025) demonstrate that different AR configurations lead to different learning experiences, highlighting the importance of instructional restraint. In this study, AR features were intentionally limited to visualization and exploration, avoiding excessive interactivity that might distract from conceptual goals. This design choice may explain why students remained focused on understanding geometric properties rather than on technological novelty.

The classroom implementation results are also in line with the findings of Zekeik et al. (2025), who report that mobile AR applications can support spatial understanding in geometry learning. The improvement in posttest scores suggests that direct interaction with three-dimensional representations helped students form more accurate mental models of curved-sided shapes. Such interaction appears particularly valuable for topics that require spatial reasoning beyond what two-dimensional images can convey.

At the same time, the study adopts a cautious stance toward technological complexity. Rahman (2025) warns that advanced AR features, including gamification and adaptive storytelling, may introduce cognitive overload if not carefully controlled. The present module prioritizes conceptual clarity over technological sophistication, which may explain why it was perceived as both practical and effective by teachers and students alike.

Overall, the findings of this study support the conclusions of Flavin et al. (2025), who report that augmented reality has a generally positive effect on mathematics achievement, with outcomes strongly influenced by instructional design. By integrating AR within the pedagogical structure of Realistic Mathematics Education and evaluating the module through systematic validation, practicality testing, and effectiveness analysis, this study contributes evidence that AR-supported RME modules can enhance students' conceptual understanding of curved-sided geometric shapes in a meaningful and classroom-ready manner.

CONCLUSION

The findings of this study indicate that the learning module developed through the integration of Augmented Reality and Realistic Mathematics Education fulfills essential quality criteria as an instructional resource. Expert assessments show that both the mathematical content and media design are appropriate and aligned with learning objectives related to curved-sided geometric shapes. Classroom implementation further demonstrates that the module is practical, as students and teachers are able to use it effectively without encountering major difficulties. The comparative analysis of learning outcomes reveals that students who engaged with the AR-supported RME module achieved higher levels of conceptual understanding than those who relied on conventional learning materials. This improvement suggests that contextual learning supported by three-dimensional visualization can help students form clearer and more coherent geometric concepts. Taken together, these results confirm that the AR-supported RME module represents a viable and pedagogically grounded approach to enhancing students' conceptual understanding of curved-sided geometry.

AUTHOR CONTRIBUTIONS STATEMENT

Tri Suranti was responsible for the overall research design and acted as the principal investigator of the study. She led the development of the AR-supported RME module, conducted the needs analysis and material design, developed the research instruments, collected the data during classroom trials, and drafted the initial version of the manuscript.

Sugeng Sutiarso contributed to the conceptual and methodological refinement of the study, provided academic supervision throughout the research process, and critically reviewed the manuscript to strengthen its theoretical grounding and coherence.

Rangga Firdaus supported the research by assisting in data analysis, interpreting the findings, and contributing to the revision of the manuscript to improve clarity and academic quality. All authors reviewed and approved the final version of the manuscript.

REFERENCES

Abedi, E. A. (2024). Tensions between technology integration practices of teachers and ICT in education policy expectations: Implications for change in teacher knowledge, beliefs and teaching practices. *Journal of Computers in Education*, *11*(4), 1215–1234. https://doi.org/10.1007/s40692-023-00296-6

Ahmed, I., Saara, T. H., & Elma, I. H. (2024). The Confluence of Divine Law and Modern Legal Systems: Insights from Sharia on Achieving Balance between Justice and Equity. *Journal of Islamic Law Research*, *25*, [83].

Alam, A., & Mohanty, A. (2024). Unveiling the complexities of 'Abstract Algebra' in University Mathematics Education (UME): Fostering 'Conceptualization and Understanding' through advanced pedagogical approaches. *Cogent Education*, *11*(1), 2355400. https://doi.org/10.1080/2331186X.2024.2355400

Arango-Caro, S., Langewisch, T., Ying, K., Haberberger, M. A., Ly, N., Branton, C., & Callis-Duehl, K. (2025). 3D plants: The impact of integrating science, design, and technology on high school student learning and interests in STEAM subjects and careers. *Disciplinary and*

Interdisciplinary Science Education Research, *7*(1). https://doi.org/10.1186/s43031-025-00120-4

Chen, X. (2025). Teaching characteristics and students' achievement emotions in rural and urban areas: A multi-group analysis. *Social Psychology of Education*, *28*(1). https://doi.org/10.1007/s11218-024-09976-2

Choudhary, K., DeCost, B., Chen, C., Jain, A., Tavazza, F., Cohn, R., Park, C. W., Choudhary, A., Agrawal, A., Billinge, S. J. L., Holm, E., Ong, S. P., & Wolverton, C. (2022). Recent advances and applications of deep learning methods in materials science. *Npj Computational Materials*, *8*(1), 59. https://doi.org/10.1038/s41524-022-00734-6

Flavin, E., Hwang, S., & Flavin, M. T. (2025). Augmented Reality for Mathematics Achievement: A Meta-Analysis of Main and Moderator Effects. *International Journal of Science and Mathematics Education*, *23*(7), 2305–2330. https://doi.org/10.1007/s10763-025-10546-x

Goceri, E. (2023). Medical image data augmentation: Techniques, comparisons and interpretations. *Artificial Intelligence Review*, *56*(11), 12561–12605. https://doi.org/10.1007/s10462-023-10453-z

González-Polo, R. I., & Castaneda, A. (2024). Progressive mathematics of functions in secondary school students using a free-fall activity. *International Electronic Journal of Mathematics Education*, *19*(1), em0765. https://doi.org/10.29333/iejme/14108

Hagos, T. (2026). Socratic method of questioning: The effect on improving students' understanding and application of chemical kinetics concepts. *Chemistry Education Research and Practice*. https://doi.org/10.1039/D5RP00216H

Harris, D. (2023). Spatial reasoning in context: Bridging cognitive and educational perspectives of spatial-mathematics relations. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1302099

Jablonski, S., & Ludwig, M. (2023). Teaching and Learning of Geometry—A Literature Review on Current Developments in Theory and Practice. *Education Sciences*, *13*(7), 682. https://doi.org/10.3390/educsci13070682

Janssen, T. W. P., Grammer, J. K., Bleichner, M. G., Bulgarelli, C., Davidesco, I., Dikker, S., Jasińska, K. K., Siugzdaite, R., Vassena, E., Vatakis, A., Zion-Golumbic, E., & van Atteveldt, N. (2021). Opportunities and Limitations of Mobile Neuroimaging Technologies in Educational Neuroscience. *Mind, Brain, and Education*, *15*(4), 354–370. https://doi.org/10.1111/mbe.12302

Kaźmierczak, R., Grunwald, G., Skowroński, R., Kaźmierczak, L., & Kowalczyk, C. (2025). Augmented reality tools for mathematics and geoscience education. *Scientific Reports*, *15*(1). https://doi.org/10.1038/s41598-025-02090-z

Koddenberg, T. (2025). A new dimension in wood anatomy education: Exploring softwood and hardwood structures in 3D. *European Journal of Wood and Wood Products*, *83*(6), 201. https://doi.org/10.1007/s00107-025-02329-6

Kokkonen, T., & Schalk, L. (2021). One Instructional Sequence Fits all? A Conceptual Analysis of the Applicability of Concreteness Fading in Mathematics, Physics, Chemistry, and Biology Education. *Educational Psychology Review*, *33*(3), 797–821. https://doi.org/10.1007/s10648-020-09581-7

Korkut, E. H., & Surer, E. (2023). Visualization in virtual reality: A systematic review. *Virtual Reality*, *27*(2), 1447–1480. https://doi.org/10.1007/s10055-023-00753-8

Lee, M. (2023). The Geometry of Feature Space in Deep Learning Models: A Holistic Perspective and Comprehensive Review. *Mathematics*, *11*(10), 2375. https://doi.org/10.3390/math11102375

Lowrie, T., Harris, D., Logan, T., & Hegarty, M. (2021). The Impact of a Spatial Intervention Program on Students' Spatial Reasoning and Mathematics Performance. *The Journal of Experimental Education*, *89*(2), 259–277. https://doi.org/10.1080/00220973.2019.1684869

Madrazo, A. L., & Dio, R. V. (2020). Contextualized Learning Modules in Bridging Students' Learning Gaps in Calculus with Analytic Geometry through Independent Learning. *Journal on Mathematics Education*, *11*(3), 457-476. https://doi.org/10.22342/jme.11.3.12456.457-476

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/feduc.2024.1229126

Muir, T., Wang, I., Trimble, A., Mainsbridge, C., & Douglas, T. (2022). Using Interactive Online Pedagogical Approaches to Promote Student Engagement. *Education Sciences*, *12*(6), 415. https://doi.org/10.3390/educsci12060415

Na, H., Staudt Willet, K. B., & Kim, C. (2025). Investigating the impact of AR technologies on geometric learning in primary school: A comparison between marker-based and markerless AR. *British Journal of Educational Technology*, *56*(6), 2502–2521. https://doi.org/10.1111/bjet.13584

Ncube, M., & Luneta, K. (2025). Concept-based instruction: Improving learner performance in mathematics through conceptual understanding. *Pythagoras*, *46*(1), 1–18. https://doi.org/10.4102/pythagoras.v46i1.815

Pandita, A., & Kiran, R. (2023). The Technology Interface and Student Engagement Are Significant Stimuli in Sustainable Student Satisfaction. *Sustainability*, *15*(10), 7923. https://doi.org/10.3390/su15107923

Puig, A., Rodríguez, I., Baldeón, J., & Múria, S. (2022). Children building and having fun while they learn geometry. *Computer Applications in Engineering Education*, *30*(3), 741–758. https://doi.org/10.1002/cae.22484

Rahman, A. (2025). Integrating Quantum AI, Gamification, and Adaptive Storytelling in educational augmented reality: A systematic review. *International Journal of Electronics and Telecommunications*, *71*(4). https://doi.org/10.24425/ijet.2025.155468

Ramnarain, U., Penn, M., Thiza Gumbo, M., Mokhele-Ramulumo, M., Ngcoza, K., & Rodil, K. (2025). Afrocentric Extended Reality Technology Design to Infuse Indigenous Knowledge into African STEM Education. *Proc. Bienn. Afr. Hum.-Comput. Interact. Conf., AfriCHI*, 401–404. https://doi.org/10.1145/3757232.3757274

Ristroph, I. (2025). Elementary teachers' treatment of mathematical conventions in lessons introducing coordinate graphing. *Journal of Mathematics Teacher Education*. https://doi.org/10.1007/s10857-025-09719-w

Salahuddin, M., Juliawan, R., & Fathurrahmaniah, F. (2025). Development of a culturally integrated augmented reality learning application using deep learning to promote critical thinking and support sdgs in mathematics education. *Journal of Engineering Science and Technology*, *20*, 25–32.

Schifter, D., & Russell, S. J. (2022). The centrality of student-generated representation in investigating generalizations about the operations. *ZDM – Mathematics Education*, *54*(6), 1289–1302. https://doi.org/10.1007/s11858-022-01379-x

Sofroniou, A., Patel, M. H., Premnath, B., & Wall, J. (2025). Advancing Conceptual Understanding: A Meta-Analysis on the Impact of Digital Technologies in Higher Education Mathematics. *Education Sciences*, *15*(11). https://doi.org/10.3390/educsci15111544

Sudirman, Rodríguez-Nieto, C. A., Susandi, A. D., Isnawan, M. G., & Pauzan, M. (2025). Massive open online course in mathematics: perspectives on country, publication trends, research approaches, participants, and content element. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *9*(2), 452–464. Scopus. https://doi.org/10.22437/jiituj.v9i2.36805

Susanti, E. (2025). Enhancing problem-solving skills in elementary students through realistic mathematics education. *SCIENCE : Jurnal Inovasi Pendidikan Matematika Dan IPA*, *5*(1), 48–59. https://doi.org/10.51878/science.v5i1.4344

Wang, Q. H., Bedoya-Pinto, A., Blei, M., Dismukes, A. H., Hamo, A., Jenkins, S., Koperski, M., Liu, Y., Sun, Q.-C., Telford, E. J., Kim, H. H., Augustin, M., Vool, U., Yin, J.-X., Li, L. H., Falin, A., Dean, C. R., Casanova, F., Evans, R. F. L., … Santos, E. J. G. (2022). The Magnetic Genome of Two-Dimensional van der Waals Materials. *ACS Nano*, *16*(5), 6960–7079. https://doi.org/10.1021/acsnano.1c09150

Wardat, Y., Tashtoush, M. A., AlAli, R., & Jarrah, A. M. (2023). ChatGPT: A revolutionary tool for teaching and learning mathematics. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7), em2286. https://doi.org/10.29333/ejmste/13272

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & education*, *62*, 41-49. https://doi.org/10.1016/j.compedu.2012.10.024

Wulandari, R., Rachmawati, I. D., & Rofiki, I. (2025). Ethnomathematics Teaching Material: Learning Mathematics Used an Electronic Encyclopedia Based on Augmented Reality of Madurese Traditional House. *AIP Conf. Proc.*, *3446*(1). https://doi.org/10.1063/5.0309066

Zekeik, H., Mouali, S., Sefian, M. L., & Khalfouni, M. (2025). Enhancing Geometry Learning with Mobile Augmented Reality: Evaluating the GeoFormeAR Application in Middle School Education. *International Journal of Interactive Mobile Technologies*, *19*(20), 113–131. https://doi.org/10.3991/ijim.v19i20.56381