International Journal of Education and Psychological Science (IJEPS)
Vol. 4 No. 4, 2026: 461-476

Augmented Reality-Based Experiential Learning for Geometrical Thinking

Yani Supriani[1*], Indri Lestari[2], Giyanti[3], Maya Selvia Lauryn[4]
[1,2,3]Mathematics Education, Universitas Serang Raya, Banten
[4]Informatics Engineering Universitas Serang Raya, Banten
Corresponding Author: Yani Supriani yani.supriani2@gmail.com

A R T I C L E I N F O

Keywords: Augmented Reality, GeoGebra AR, Experiential Learning, Van Hiele Theory, Geometrical Thinking, Geometry Education, Mathematics Education, Spatial Reasoning

Received: 28, May
Revised: 27, June
Accepted: 30, July

A B S T R A C T

Many junior high school students experience difficulties in understanding abstract geometric concepts, limiting the development of their geometrical thinking. This quasi-experimental study employed a non-equivalent control group design involving 150 seventh-grade students. The experimental group received GeoGebra Augmented Reality (AR)-based experiential learning, while the control group received conventional instruction. Data were analyzed using the Kolmogorov-Smirnov, Wilcoxon Signed-Rank, and Mann-Whitney U tests. The experimental group demonstrated significantly greater improvement than the control group ($p < .001$) with a large effect size ($r = .614$), particularly in visual-spatial reasoning, concept application, and applied problem solving. Integrating GeoGebra AR with Kolb's experiential learning effectively enhances students' geometrical thinking and supports higher-order geometric reasoning in secondary mathematics education.

DOI: https://doi.org/10.59890/ijeps.v4i4.21
ISSN-E: 3030-8410
https://journalijeps.my.id/index.php/ijeps

INTRODUCTION

Geometry is a fundamental branch of mathematics education that plays a crucial role in developing students' reasoning, visualization, and spatial understanding skills. Through learning geometry, students not only study shapes, sizes, and properties of geometric figures but also develop geometric thinking abilities that support a comprehensive understanding of mathematical concepts (Sudirman et al., 2023; Trimurtini et al., 2022; Žakelj & Klančar, 2022). These abilities contribute to problem-solving skills, logical reasoning, and the application of mathematical concepts across various contexts, including science and technology (Bistari et al., 2025; Marzuki et al., 2025; Meouer et al., 2024). In an era of rapid scientific and technological development, geometric thinking skills are increasingly important to equip students to face global challenges (Nazarovich & Kurudirek, 2024; Tavdgiridze et al., 2024; Xu, 2025).

However, previous studies have shown that students still experience significant difficulties in understanding geometric concepts, including recognizing shapes, comprehending relationships among figures, and linking visual representations with symbolic ones (Brijlall, 2022; Jablonski & Ludwig, 2023; Kania et al., 2024; Ünal et al., 2023). Classroom practices that tend to emphasize memorization of formulas without conceptual understanding also hinder the gradual development of geometric thinking (Abbas et al., 2025; Manandhar et al., 2022; Tretiakova, 2025). As a result, students' ability to transfer geometric knowledge to real-world situations remains low, highlighting the need for more effective instructional strategies (Danlami et al., 2025; Wahyuni et al., 2026).

This issue is not only caused by the complexity of the material but also by the instructional approaches employed. Geometry instruction in classrooms often remains procedural, emphasizing mechanical problem-solving without adequate concrete and visual experiences (Andini & Cahyaningsih, 2024; Coetzer et al., 2023; Lichtenberger et al., 2024). This condition hinders the gradual development of students' geometric thinking and highlights the need for approaches that integrate concrete experiences, visualization, and symbolic representation (Hsu & Hsu, 2025; Muhammad et al., 2022).

The advancement of educational technology offers new opportunities in geometry instruction through Augmented Reality (AR), which enables the visualization of geometric objects in three dimensions that students can directly observe and interact with, thereby facilitating a more concrete understanding of shapes, sizes, and spatial relationships (Nadzeri et al., 2024; K. A. Rahman & Halim, 2025; Singh et al., 2024; Supli & Yan, 2024). However, the use of AR does not automatically enhance mathematical thinking, as it is often employed merely as a visualization tool without a clear pedagogical framework (AlGerafi et al., 2023; Alqahtani & AlNajdi, 2024; Shihab et al., 2023). Therefore, the integration of AR should be combined with instructional approaches that emphasize learning experiences, such as experiential learning. This approach positions direct experience as the foundation for knowledge construction, whereby students observe, reflect, and build understanding through interaction with learning objects (Eklund & Graham, 2025; Malik & Behera, 2024; Salinas-Navarro et al., 2024; Umkabu & Lestari, 2023). In the context of geometry, experiential learning allows students to engage with concepts concretely before generalizing them into symbolic and abstract forms, thereby supporting the gradual development of geometric thinking (Chan, 2023; Yılmaz & Kesebir, 2023). The integration of experiential learning with interactive media such as AR has the potential to strengthen students' geometric thinking, with AR serving as a facilitator of the learning experience (Chonchaiya & Srithammee, 2025).

Nevertheless, empirical studies on the integration of AR and experiential learning in geometry instruction remain limited. Most research has focused on general learning outcomes or student motivation, while in-depth analyses of the processes and patterns of geometric thinking development are relatively scarce (Cetintav & Yilmaz, 2023; Li et al., 2024). This indicates a research gap that needs to be addressed to design more effective and sustainable geometry learning.

This study aims to fill this gap by investigating the effect of integrating AR and experiential learning on students' geometric thinking development. Specifically, the study seeks to analyze the differences and patterns of improvement in geometric thinking between students participating in AR-based experiential learning and those in conventional instruction. In addition, the study aims to identify the role of AR as a facilitator of learning experiences. Based on these objectives, the research hypothesis posits that there is a difference in the improvement of geometric thinking between the two groups. The findings are expected to provide a conceptual contribution to the development of more meaningful geometry instruction and to strengthen the understanding of technology's role as a facilitator of learning experiences in mathematics education.

LITERATURE REVIEW

Experiential Learning Theory (ELT)

Previous studies have demonstrated that experiential learning has a positive impact on mathematics education. Chan (2023) found that experience-based learning gradually improves students' understanding of geometric concepts. Malik and Behera (2024), as well as Salinas-Navarro et al. (2024), also reported that experiential learning enhances students' engagement and higher-order thinking skills by providing meaningful learning experiences.

H1: Experiential learning supported by Augmented Reality significantly improves students' geometrical thinking compared with conventional instruction.

Van Hiele Theory of Geometric Thinking

Previous studies have consistently supported the Van Hiele framework in explaining students' development of geometric thinking. Sudirman et al. (2023), Trimurtini et al. (2022), and Žakelj and Klančar (2022) reported that students' geometric thinking develops more effectively through conceptual and visualization-based learning than through procedural instruction. Conversely, Brijlall (2022), Ünal et al. (2023), and Kania et al. (2024) found that conventional instruction often fails to promote higher levels of geometric thinking because students receive limited opportunities to explore geometric relationships.

H2: Students who learn through AR-based experiential learning demonstrate higher levels of geometric thinking than students receiving conventional learning.

Augmented Reality in Mathematics Learning

Previous studies have shown that Augmented Reality (AR) enhances students' visualization and understanding of geometric concepts (Nadzeri et al., 2024; Singh et al., 2024). However, AlGerafi et al. (2023) and Alqahtani and AlNajdi (2024) argued that the use of AR alone, without an appropriate instructional strategy, does not necessarily improve students' mathematical thinking skills. Therefore, integrating AR with experiential learning is expected to create a more effective learning environment and promote the development of students' geometric thinking.

H3: The integration of Augmented Reality and experiential learning has a positive effect on the improvement of students' geometrical thinking.

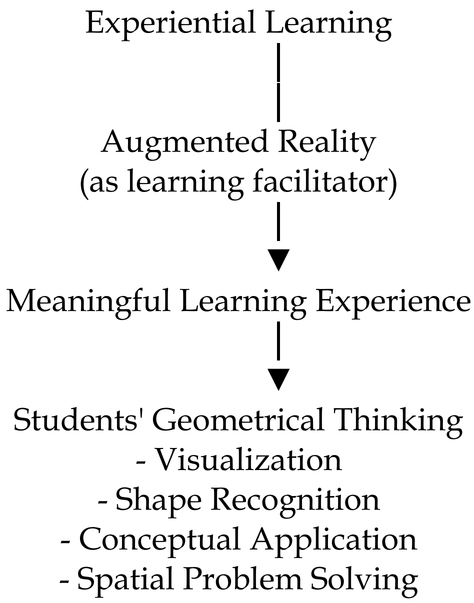

Figure 1. Conceptual Framework

METHODOLOGY

Methods

This study employed a quasi-experimental design using a non-equivalent control group design. The population comprised seventh-grade students at a public junior high school in Indonesia. Two intact classes were selected through cluster sampling, involving a total of 150 students. One class was assigned as the experimental group, which received geometry instruction through Augmented Reality (AR)-based experiential learning, while the other served as the control group and received conventional teacher-centered instruction. The intervention was conducted over three weeks.

Students' geometrical thinking was assessed using equivalent pretest and posttest instruments covering four indicators: geometric shape recognition, visual-spatial reasoning, conceptual application, and applied problem solving. Data were collected before and after the instructional intervention.

Data analysis began with the Kolmogorov–Smirnov normality test. Because the data were not normally distributed, nonparametric statistics were employed. The Mann–Whitney U test was used to examine baseline equivalence and compare gain scores between the experimental and control groups, while the Wilcoxon signed-rank test was applied to analyze within-group improvements. The magnitude of the intervention effect was evaluated using effect size (r), and statistical significance was determined at the 0.05 level.

RESULTS & DISCUSSION

This study involved 150 seventh-grade students from a public junior high school, divided into an experimental group (n = 75) and a control group (n = 75). The experimental group received geometry instruction through Augmented Reality (AR) integrated with an experiential learning approach, while the control group was taught using conventional instructional methods. All participants were aged 12–13 years and enrolled at the same grade level, ensuring relatively homogeneous baseline characteristics and minimizing external variability.

Prior to the intervention, both groups completed a pretest to measure their initial geometrical thinking ability. Following the instructional period, a posttest was administered to assess improvement. The pretest and posttest data were first examined to test the assumption of normality, which determined the selection of appropriate statistical procedures.

Table 1. Normality Test Results for Pretest and Posttest Data

Group	**N**	**Sig.(K-S)**	**Decision**
Eksperimental	Pretest	<.001	Non-normal
	Posttest	<.001	Non-normal
Control	Pretest	<.001	Non-normal
	Posttest	.010	Non-normal

The Kolmogorov–Smirnov test indicated that all p-values were below .05 (Table 1). Thus, the data were not normally distributed. Consequently, nonparametric statistical procedures were applied in subsequent analyses (Borucka et al., 2023; Vrbin, 2022).

Because the data were non-normal, descriptive statistics are presented using medians and interquartile ranges (IQR) (Danlami et al., 2025; Nyantah et al., 2025).

Table 2. Descriptive Statistics of Pretest and Posttest Geometrical Thinking Ability

Group	Test	Median	Q1	Q3	IQR
Eksperimental	Pretest	5.00	4.00	7.00	3.00
Control	Pretest	5.00	3.00	6.00	3.00
Eksperimental	Posttest	9.00	8.00	13.00	5.00
Control	Posttest	6.00	4.00	7.00	3.00

In the pretest phase, both groups showed identical median scores (5.00) and similar IQR values (3.00), indicating comparable baseline distributions. In the posttest phase, the experimental group's median increased to 9.00 (IQR = 5.00), whereas the control group's median increased to 6.00 (IQR = 3.00), suggesting greater improvement and variability in the experimental group.

To examine baseline equivalence statistically, a Mann–Whitney U test was conducted on pretest scores.

Table 3. Mann-Whitney U Test Results

	Skor
Mann Whitney U	1858.500
Z	3.637
Asymp. Sig. (2-tailed)	<.001

The significant result indicates initial differences between groups. Therefore, improvement was analyzed using gain scores rather than direct posttest comparison.

Table 4. Wilcoxon Signed Rank Test Results for Pretest and Posttest Scores

Group	Median Pretest	Median Posttest	Z	Asym. Sig (2-tailed)
Eksperimental	5.00	9.00	6.856	<.001
Control	5.00	6.00	2.600	.009

Both groups demonstrated significant improvement. However, the magnitude of increase was substantially larger in the experimental group. To compare improvement between groups, gain scores were analyzed using the Mann–Whitney U test.

Table 5. Mann-Whitney U Test Results for Gain Scores of Geometrical Thinking Ability

Group	Median Gain	Mean Rank		Gain
Eksperimental	4.00	96.92		
Control	1.00	54.08		
			U	1206,000
			Z	6.074
			Asymp. Sig. (2-tailed)	<.001

The experimental group achieved significantly higher gain scores than the control group, indicating greater instructional effectiveness. To assess practical significance, effect size was calculated using the nonparametric formula $r = Z/\sqrt{N}$.

Table 6. Effect Size of the Mann-Whitney U Test for Gain Scores

Statistic	**Value**
Z	6.074
N	150
Effect Size	0.614
Category	Large

The effect size (r = .614) indicates a large effect, demonstrating strong practical impact of the intervention. Further analysis examined gain scores across four indicators of geometrical thinking.

Table 7. Mann-Whitney U Test Results for Gain Scores by Indicator of Geometric Thinking Skills

Indicator	**Median Gain Eksperimental**	**Median Gain Control**	**U**	**Z**	**Asym. Sig (2-tailed)**
Visual-Spatial Reasoning	1.00	0.00	1449.000	5.225	<.001
Geometry Shape Recognition	1.00	0.00	2344.500	1.806	.071
Applied Problem Solving	1.00	0.00	1764.000	4.301	<.001
Concept Application	2.00	0.00	1656.000	4.662	<.001

Significant differences favoring the experimental group were found in visual-spatial reasoning, applied problem solving, and concept application. However, no significant difference was observed for shape recognition (p = .071). These findings indicate that AR-based experiential learning particularly enhances higher-order geometrical thinking processes, while basic recognition skills can be developed effectively through conventional instruction.

The significant improvement in visual-spatial reasoning suggests that AR's three-dimensional visualization enhances students' ability to interpret and manipulate spatial representations. This aligns with prior research emphasizing the benefits of immersive environments in strengthening spatial cognition (Nshimiyimana & Ndayambaje, 2025; Price et al., 2021; Yadav, 2025). Similarly, improvements in applied problem solving indicate that AR facilitates contextualization of geometric concepts, enabling students to connect abstract principles with real-world situations. The strong results in concept application further suggest that dynamic and manipulable representations support deeper conceptual transfer.(Coştu, 2025; Lee et al., 2025; Rosita et al., 2025).

In contrast, geometric shape recognition—primarily involving recall of basic properties—did not show significant differences. This suggests that foundational recognition skills can be effectively developed through conventional instruction, while AR provides greater added value in higher-order processes such as visualization, conceptual integration, and problem solving. For the applied problem-solving indicator, a significant difference in improvement was also found between the two groups. AR enables students to directly link geometric concepts with real-world situations, for example by projecting objects or geometric figures into environmental contexts. This allows students to better understand the relationship between mathematical concepts and their applications in everyday life. The improvement in this indicator suggests that AR-based instruction not only strengthens conceptual understanding but also encourages students to apply these concepts in contextual problem-solving, an essential component of higher-level geometric thinking.

The concept application indicator showed the most substantial improvement in the experimental group, with a much larger median difference compared to the control group and statistically significant results. This demonstrates that AR effectively supports conceptual understanding by providing dynamic, manipulable, and easily accessible representations. Strengthening conceptual understanding through visual and exploratory experiences allows students to build stronger connections between abstract concepts and concrete representations, resulting in a significant increase in their ability to apply concepts.

Meanwhile, the only indicator that did not show a significant difference between the two groups was geometric shape recognition. This is likely due to the nature of the material, which is relatively simple, largely based on recall, and can be learned effectively even through conventional instruction. Recognizing basic shapes and their properties does not require advanced visual manipulation or complex conceptual application. Therefore, AR-based learning does not offer a substantial advantage over traditional methods for this indicator. This finding suggests that AR yields greater benefits for indicators requiring high spatial visualization, concept application, and problem-solving abilities.

Overall, the findings of this study demonstrate that Augmented Reality-based geometry instruction, combined with an experiential learning approach, is an effective strategy for enhancing students' higher-level geometric thinking skills. The strength of this instructional model lies not only in improving academic performance but also in providing more immersive, interactive, and meaningful learning experiences. The use of AR enables students to develop deeper conceptual understanding through exploration and direct engagement, making it a promising solution for addressing the limitations of conventional geometry instruction, which often tends to be abstract and difficult to visualize.

CONCLUSIONS

The results of the study indicate that geometry learning based on Augmented Reality, combined with an experiential learning approach, has been proven effective in significantly improving students' geometrical thinking abilities compared to conventional instruction. This learning model not only results in higher gain scores but also exerts a strong influence on the development of various aspects of geometrical thinking, particularly in visual-spatial reasoning, applied problem-solving, and concept application skills. These findings affirm that the integration of AR technology can facilitate a more immersive and meaningful learning experience, thereby accelerating the development of students' geometrical thinking abilities. Although mastery of basic material such as the recognition of geometric shapes does not show a significant difference, AR still plays an important role as a facilitator that enhances conceptual understanding and visualization skills in geometry learning. Based on these findings, the use of AR is recommended as an alternative instructional strategy to support the development of geometrical thinking skills at the secondary school level.

FURTHER STUDY

This study has several limitations that should be acknowledged. First, the participants were drawn from a single public junior high school in Indonesia, which may limit the generalizability of the findings to other educational contexts. Second, the study employed a quasi-experimental design using intact classes rather than random assignment, which may have introduced potential selection bias despite efforts to ensure baseline equivalence. Third, the instructional intervention was conducted over a relatively short period of three weeks, allowing the study to examine only the short-term effects of AR-based experiential learning on students' geometrical thinking. Finally, the study focused exclusively on seventh-grade geometry topics and assessed only students' geometrical thinking, without considering other important outcomes such as learning motivation, engagement, knowledge retention, or attitudes toward mathematics.

Future research is recommended to involve larger and more diverse samples from multiple schools and educational settings to enhance the generalizability of the findings. Longitudinal studies are also needed to investigate the long-term effects of AR-based experiential learning on the development of geometrical thinking. In addition, future studies could examine the effectiveness of this instructional approach across different mathematical domains and educational levels, while also exploring its impact on cognitive and affective outcomes, including mathematical reasoning, motivation, engagement, and learning retention.

REFERENCES

Abbas, L., Sumathi, D., Syed Bahurudeen, R., & Dinesh Kumar, A. (2025). *Contemporary Techniques in Math Education* (1 ed.). TULSI Global Publishing House.

Ahmed, S. K. (2024). How to choose a sampling technique and determine sample size for research: A simplified guide for researchers. *Oral Oncology Reports*, *12*, 100662. https://doi.org/10.1016/j.oor.2024.100662

AlGerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the Potential: A Comprehensive Evaluation of Augmented Reality and Virtual Reality in Education. *Electronics*, *12*(18), 3953. https://doi.org/10.3390/electronics12183953

Alqahtani, E. S., & AlNajdi, S. M. (2024). Potential obstacles to adopting augmented reality (AR) technologies as pedagogical tools to support students learning in higher education. *Interactive Learning Environments*, *32*(7), 3136–3145. https://doi.org/10.1080/10494820.2023.2167840

Andini, I., & Cahyaningsih, U. (2024). An analysis of students' learning difficulties in solving plane geometry problems among seventh-grade students. *International Journal of Advance Research in Mathematics Education*, *2*(2), 110–121. https://doi.org/10.56916/ijr.v2i2.2657

Ardiya, A., & Syahfutra, W. (2021). The Implementation of Hypnoteaching Method in Increasing Motivation to Learn English for Senior High School in Pekanbaru. *ELT-Lectura*, *8*(1), 56–64. https://doi.org/10.31849/elt-lectura.v8i1.6218

Arslan, A., & Kayhan Altay, M. (2021). Spatial Strategies Used by Students With Visual Impairments to Solve Questions of Spatial Visualization. *Journal of Visual Impairment & Blindness*, *115*(5), 436–447. https://doi.org/10.1177/0145482X211046668

Aziiza, Y. F., & Juandi, D. (2021). Student's learning obstacle on understanding the concept of prism surface area. *Journal of Physics: Conference Series*, *1806*(1), 012115. https://doi.org/10.1088/1742-6596/1806/1/012115

Bhagat, K. K., Yang, F.-Y., Cheng, C.-H., Zhang, Y., & Liou, W.-K. (2021). Tracking the process and motivation of math learning with augmented reality. *Educational Technology Research and Development*, *69*(6), 3153–3178. https://doi.org/10.1007/s11423-021-10066-9

Bistari, B., Rustam, R., Tomo, T., & Marlinda, M. (2025). The "VLOKS" Geometrical Thinking Model of Students in Relation to Meaningful Learning Processes and Teacher Pedagogy. *JPMI (Jurnal Pendidikan Matematika Indonesia)*, *11*(1), 1–14. https://doi.org/10.26737/jpmi.v11i1.7876

Borucka, A., Kozłowski, E., Antosz, K., & Parczewski, R. (2023). A New Approach to Production Process Capability Assessment for Non-Normal Data. *Applied Sciences*, *13*(11), 6721. https://doi.org/10.3390/app13116721

Brijlall, D. (2022). High School Learners' challenges in Solving Circle Geometry Problems. *International Journal of Sciences and Research*, *78*(12). https://doi.org/10.21506/j.ponte.2022.12.9

Cetintav, G., & Yilmaz, R. (2023). The Effect of Augmented Reality Technology on Middle School Students' Mathematic Academic Achievement, Self-Regulated Learning Skills, and Motivation. *Journal of Educational Computing Research*, *61*(7), 1483–1504. https://doi.org/10.1177/07356331231176022

Chan, C. K. Y. (2023). *Assessment for Experiential Learning* (1 ed.). Taylor & Francis. https://doi.org/10.4324/9781003018391

Chonchaiya, R., & Srithammee, N. (2025). Augmented Reality as a Tool for Enhancing Geometry Learning and Improving Mathematical

Understanding. *ECTI Transactions on Computer and Information Technology (ECTI-CIT)*, *19*(2), 350–363. https://doi.org/10.37936/ecti-cit.2025192.260291

Coetzer, T., Livingston, C., & Barnard, E. (2023). Using visual representations to enhance isiXhosa home language learners' mathematical understanding. *South African Journal of Childhood Education*, *13*(1), 1–8. https://doi.org/10.4102/sajce.v13i1.1297

Coştu, F. (2025). Exploring augmented reality (AR) in science education: Perspectives from gifted students. *The Journal of Educational Research*, *118*(1), 19–36. https://doi.org/10.1080/00220671.2024.2431681

Danlami, K. B., Zakariya, Y. F., Balarabe, B., Alotaibi, S. B., & Alrosaa, T. M. (2025). Improving students' performance in geometry: An empirical evidence of the effectiveness of brainstorming learning strategy. *Frontiers in Psychology*, *16*. https://doi.org/10.3389/fpsyg.2025.1577912

Demir, S. (2022). Comparison of Normality Tests in Terms of Sample Sizes under Different Skewness and Kurtosis Coefficients. *International Journal of Assessment Tools in Education*, *9*(2), 397–409. https://doi.org/10.21449/ijate.1101295

Eklund, M. A., & Graham, K. W. (2025). *Practical Applications of Experiential and Community-Engaged Learning Methods in Business: High-Impact Teaching Practices in Business Education, Volume 1* (1 ed.). Edward Elgar Publishing.

Em, S. (2025). Exploring experimental research: Methodologies, designs, and applications across disciplines. *Cambodian Journal of Educational and Social Sciences (CJESS)*, *2*(2), 1–8. https://doi.org/10.69496/cjess.v2i2.78

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

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

Juman, Z. A. M. S., Mathavan, M., Ambegedara, A. S., & Udagedara, I. G. K. (2022). Difficulties in Learning Geometry Component in Mathematics and Active-Based Learning Methods to Overcome the Difficulties. *Shanlax International Journal of Education*, *10*(2), 41–58.

Kania, N., Kusumah, Y. S., Dahlan, J. A., Nurlaelah, E., & Kyaruzi, F. (2024). Decoding Student Struggles in Geometry: Newman Error Analysis of Higher-Order Thinking Skills. *International Journal of Geometry Research and Inventions in Education*, *1*(1), 31–47. (-). https://doi.org/10.56855/gradient.v1i01.1146

Kusuma, A. P., Aslamia, A. S., Sintiya, H., Rahayu, R. G., & Rahmawati, N. K. (2023). Analysis of Students' Difficulties in Solving Problems Related to Solid Geometry. *Brillo Journal*, *2*(2). https://doi.org/10.56773/bj.v2i2.37

Lee, S., Kong, N., Ahn, S., & Park, J.-I. (2025). AR-Based Multi-sensory Human Interaction in Rehabilitation: Enhancing User Experience in Exercise.

Dalam M. Rauterberg (Ed.), *Culture and Computing* (hlm. 120–136). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-93163-5_9

Li, S., Jiao, X., Cai, S., & Shen, Y. (2024). Enhancing AR-based learning environments for STEM education: A design-based study on design features, kinematics learning and mathematics self-efficacy. *British Journal of Educational Technology*, *54*(4), 1438–1462. https://doi.org/10.1111/bjet.13528

Lichtenberger, A., Kokkonen, T., & Schalk, L. (2024). Learning with multiple external representations in physics: Concreteness fading versus simultaneous presentation. *Journal of Research in Science Teaching*, *61*(9), 2258–2290. https://doi.org/10.1002/tea.21947

Malik, P., & Behera, S. (2024). The Transformative Power of Experiential Learning: Bridging Theory and Practice. *The International Journal of India Psychology*, *12*(2). https://doi.org/10.25215/1202.007

Manandhar, N. K., Pant, B. P., & Dawadi, S. D. (2022). Conceptual and Procedural Knowledge of Students of Nepal in Algebra: A Mixed Method Study. *Contemporary Mathematics and Science Education*, *3*(1). https://www.conmaths.com/

Marzuki, Jumiati, Karim, A., Jasmaniah, & Hayati, R. (2025). Mathematical Thinking Of Elementary School Students In Geometry Through 4C-Based Problem-Based Learning. *IOSR Journal of Research & Method in Education (IOSR-JRME)*, *15*(3). http://www.iosrjournals.org/

Mbonyiryivuze, A., Yadav, L. L., & Amadalo, M. M. (2021). Students' Attitudes towards Physics in Nine Years Basic Education in Rwanda. *International Journal of Evaluation and Research in Education*, *10*(2), 648–659. https://doi.org/10.11591/ijere.v10i2.21173

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

Meouer, B., Faouzi, L., Zennou, F. O., Sbaa, M., & Nachit, B. (2024). Effects of Employing Mind Mapping Techniques in Geometry Instruction on Logical Thinking Abilities. *International Journal on Technical and Physical Problems of Engineering*, *16*(60). https://www.researchgate.net/profile/Sbaa-Mohamed/publication/390399456_IJTPE_Journal/links/67ec77619b1c6c48776d3f22/IJTPE-Journal.pdf

Muhammad, N., Rehman, D. S., & Naeemullah, D. M. (2022). An Investigation into Spatial Ability in Geometry among Secondary School Students. *Sjesr*, *5*(3), 22–28. https://doi.org/10.36902/sjesr-vol5-iss3-2022(22-28)

Nadzeri, M. B., Musa, M., Meng, C. C., & Ismail, I. M. (2024). The Effects of Augmented Reality Geometry Learning Applications on Spatial Visualization Ability for Lower Primary School Pupils. *International Journal of Interactive Mobile Technologies*, *18*(16), 104. https://doi.org/10.3991/ijim.v18i16.47079

Nazarovich, S. T., & Kurudirek, A. (2024). An Overview of Existing Problems in Teaching the Science "Fundamentals of Geometry". *International Journal of*

Social Sciences & Educational Studies, *11*(2), 91–106. https://doi.org/10.23918/ijsses.v11i2p91

Ningsih, I. P., Budiarto, M. T., & Khabibah, S. (2021). Literasi Spasial Siswa SMP dalam menyelesaikan Soal Geometri Ditinjau dari Perbedaan Gaya Belajar. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *10*(3). https://doi.org/10.24127/ajpm.v10i3.3650

Nshimiyimana, E., & Ndayambaje, I. (2025). Enhancing Students' Understanding of Earth's Spatial Relationships Using Virtual Reality: A Case Study of Secondary Schools in Nyamasheke District, Rwanda. *African Journal of Empirical Research*, *6*(1), 773–791. https://doi.org/10.51867/ajernet.6.1.66

Nyantah, R. O., Frempong, N. K., & Larbi, E. (2025). Enhancing Student Achievement in Circle Theorems: Integrating Computer Animation with the Jigsaw Cooperative Learning Model. *International Journal of Mathematics and Mathematics Education (IJMME)*, *3*(2), 91–112. https://doi.org/10.56855/ijmme.v3i2.1299

Obilor, & Isaac, E. (2023). Convenience and Purposive Sampling Techniques: Are they the Same? *International Journal of Innovative Social & Science Education Research*, *11*(1). www.seahipaj.org

Price, S., Yiannoutsou, N., Johnson, R., & Outhwaite, L. (2021). Enacting Elementary Geometry: Participatory 'Haptic' Sense-Making. *Digital Experiences in Mathematics Education*, *7*(1), 22–47. https://doi.org/10.1007/s40751-020-00079-z

Prosser, S. K., & Bismarck, S. F. (2023). Concrete–Representational–Abstract (CRA) Instructional Approach in an Algebra I Inclusion Class: Knowledge Retention Versus Students' Perception. *Education Sciences*, *13*(10), 1061. https://doi.org/10.3390/educsci13101061

Radović, S., Hummel, H. G. K., & Vermeulen, M. (2023). The mARC instructional design model for more experiential learning in higher education: Theoretical foundations and practical guidelines. *Teaching in Higher Education*, *28*(6), 1173–1190. https://doi.org/10.1080/13562517.2021.1872527

Rahman, K. A., & Halim, N. D. A. (2025). Augmented Reality in Learning Geometry: A Review of its Advantages and Challenges. *International Journal of Academic Reseach in Progressive Education and Development*, *14*(4). https://doi.org/10.6007/IJARPED/v14-i4/26676

Rahman, Md. M., Tabash, M. I., Salamzadeh, A., Abduli, S., & Rahaman, Md. S. (2022). Sampling Techniques (Probability) for Quantitative Social Science Researchers: A Conceptual Guidlines With Examples. *SEEU Review*, *17*(1). https://doi.org/10.2478/seeur-2022-0023

Rosita, D., Dewanti, S. S., & Ibrahim, I. (2025). The Impact of Augmented Reality-based Learning Media on Primary Students' Retention of Human Sensory System Concepts. *Journal of Integrated Elementary Education*, *5*(2), 407–420. https://doi.org/10.21580/jieed.v5i2.25276

Salinas-Navarro, D. E., Vilalta-Perdomo, E., Michel-Villarreal, R., & Montesinos, L. (2024). Using Generative Artificial Intelligence Tools to Explain and

Enhance Experiential Learning for Authentic Assessment. *Education Sciences*, *14*(1), 83. https://doi.org/10.3390/educsci14010083

Selvira, & Albina, M. (2025). Model Penelitian Eksperimental dalam Pendidikan: Jenis, Tujuan, dan Aplikasinya. *Jurnal Media Akademik (JMA)*, *3*(6). https://doi.org/10.62281/v3i6.2365

Serrano-Ausejo, E., & Mårell-Olsson, E. (2024). Opportunities and Challenges of Using Immersive Technologies to Support Students' Spatial Ability and 21st-Century Skills in K-12 Education. *Education and Information Technologies*, *29*(5), 5571–5597. https://doi.org/10.1007/s10639-023-11981-5

Shihab, S. R., Sultana, N., & Samad, A. (2023). Pedagogy Designing With Augmented Reality: A Paradigm Shift in Educational Approaches. *Interdiciplinary Journal and Hummanity (INJURITY)*, *2*(11), 878–892. https://doi.org/10.58631/injurity.v2i11.136

Singh, Gurwinder, Singh, Gurjinder, Tuli, N., & Mantri, A. (2024). Hyperspace AR: An augmented reality application to enhance spatial skills and conceptual knowledge of students in trigonometry. *Multimedia Tools and Applications*, *83*(21), 60881–60902. https://doi.org/10.1007/s11042-023-17870-w

Sudirman, Kusumah, Y. S., & Martadiputra, B. A. P. (2022). Investigating the Potential of Integrating Augmented Reality into the 6E Instructional 3D Geometry Model in Fostering Students' 3D Geometric Thinking Processes. *International Journal of Interactive Mobile Technologies*, *16*(6), 61. https://doi.org/10.3991/ijim.v16i06.27819

Sudirman, S., Rodríguez-Nieto, C. A., Dhlamini, Z. B., Chauhan, A. S., Baltaeva, U., Abubakar, A., Dejarlo, J. O., & Andriani, M. (2023). Ways of thinking 3D geometry: Exploratory case study in junior high school students. *Polyhedron International Journal in Mathematics Education*, *1*(1), 15–34. https://doi.org/10.59965/pijme.v1i1.5

Sudyana, I. N., Sudrajat, D., Sudadi, S., Fitriyah, H., & Pranajaya, S. A. (2023). The Influence of The Probing Prompting Learning Model on The Development of Students' Critical Thinking Ability. *Journal on Education*, *06*(01). https://doi.org/10.31004/joe.v6i1.3454

Supli, A. A., & Yan, X. (2024). Exploring the effectiveness of augmented reality in enhancing spatial reasoning skills: A study on mental rotation, spatial orientation, and spatial visualization in primary school students. *Education and Information Technologies*, *29*(1), 351–374. https://doi.org/10.1007/s10639-023-12255-w

Susdarwono, E. T. (2021). Testing through the Mann-Whitney Method and the Wilcoxon Signed Level on Learning Cube and Perfect Cube Roots. *Journal of Education and Learning Mathematics Research (JELMaR)*, *2*(1). https://doi.org/10.37303/jelmar.v2i1.43

Tarng, W., Huang, J.-K., & Ou, K.-L. (2024). Improving Elementary Students' Geometric Understanding Through Augmented Reality and Its Performance Evaluation. *Systems*, *12*(11), 493. https://doi.org/10.3390/systems12110493

Tavdgiridze, L., Didmanidze, I., Khasaia, I., Sherozia, N., Dobordginidze, D., Akhvlediani, D., & Akhvlediani, Z. (2024). STEM Teaching in Contemporary Education. *Challenges to National Defence in Contemporary Geopolitical Situation*, *1*(1). https://doi.org/10.3849/cndcgs.2024.296

Tretiakova, K. (2025). *Mathematical Reasoning and Communication: Analyzing Skills Development in University Students and High-Level Math Competitors* [Thompson Rivers University]. http://hdl.handle.net/11375/31573

Trimurtini, Waluya, S. B., Sukestiyarno, Y. L., & Kharisudin, I. (2022). A Systematic Review on Geometric Thinking: A Review Research between 2017-2021. *European Journal of Educational Research*, *11*(3), 1535–1552. https://doi.org/10.12973/eu-jer.11.3.1535

Tursynkulova, E., Madiyarov, N., Sultanbek, T., & Duysebayeva, P. (2023). The effect of problem-based learning on cognitive skills in solving geometric construction problems: A case study in Kazakhstan. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1284305

Umkabu, T., & Lestari, N. S. (2023). Strategi Pembelajaran Experential Learning terhadap Peningkatan Akademik Siswa di SD Muhammadiyah Abepura. *EDUKASIA Jurnal Pendidikan Dan Pembelajaran*, *4*(1), 459–468. https://doi.org/10.62775/edukasia.v4i1.284

Ünal, Z. E., Ala, A. M., Kartal, G., Özel, S., & Geary, D. C. (2023). Visual and Symbolic Representations as Components of Algebraic Reasoning. *Journal of Numerical Cognition*, *9*(2), 327–345. https://doi.org/10.5964/jnc.11151

Uyen, B. P., Tong, D. H., & Lien, N. B. (2022). The Effectiveness of Experiential Learning in Teaching Arithmetic and Geometry in Sixth Grade. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.858631

Vrbin, C. M. (2022). Parametric or nonparametric statistical tests: Considerations when choosing the most appropriate option for your data. *Cytopathology*, *33*(6), 663–667. https://doi.org/10.1111/cyt.13174

Wahyuni, R., Efuansyah, E., & Fitriyana, N. (2026). Analisis Kesalahan Siswa dalam Menyelesaikan Masalah Geometri Berdasarkan Tahapan Newman. *JURNAL E-DuMath*, *12*(1), 90–98.

Wardhani, I. S., Nusantara, T., Parta, I. N., & Permadi, H. (2023). The Model of Geometry Learning With Spatial Skills Features: Is It Possible? *Journal of Higher Education Theory & Practice*, *23*(14), 225. https://doi.org/10.33423/jhetp.v23i14.6397

Xu, C. (2025). Improving Mathematical Skills of Mathematics Education Students Through Integrated Use of Graphing Software and Programming Techniques. *International Journal of Education and Humanities*, *5*(1), 13–24. https://doi.org/10.58557/(ijeh).v5i1.277

Yadav, S. (2025). Revolutionizing Classroom Learning With Advanced Technology: Harnessing Augmented Reality (AR) and Virtual Reality (VR) for Immersive Education. Dalam *Blending Human Intelligence With Technology in the Classroom* (1 ed., hlm. 223–246). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-0771-8.ch010

Yılmaz, D., & Kesebir, G. (2023). Evaluation of Mathematical Modeling Activities of 4th-Grade Students: The Case of Experiential Learning Theory. *Ankara*

University Journal of Faculty of Educational Sciences (JFES), *56*(2), 585–650. https://doi.org/10.30964/auebfd.1037725
Young, S. (2021). *A Case Study of Teachers of Elementary Gifted Students and Their Perceptions of Best Practices for Teaching Visual Spatial Activities in the Classroom* [Liberty University]. https://digitalcommons.liberty.edu/doctoral/3120
Yuyun, H., & Febrianto, P. T. (2026). Efektifitas Model Project Based Collaborative Blended Learning dalam Implementasi Kurikulum Merdeka di SDN Keleyan 1 Socah Madura. *Cendikia: Jurnal Pendidikan Dan Pengajaran*, *4*(1), 279–307.
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
Zhao, F., & Schuchardt, A. (2021). Development of the Sci-math Sensemaking Framework: Categorizing sensemaking of mathematical equations in science. *International Journal of STEM Education*, *8*(1), 10. https://doi.org/10.1186/s40594-020-00264-x