ar-Riyadhiyyat
JOURNAL OF MATHEMATICS EDUCATION
Vol. 7, No. 1, July 2026, pp. 31-39
ISSN: 2775-8990 DOI: 10.47766/arriyadhiyyat.v7i1.7581

# Effect of PhET-Assisted Discovery Learning on Junior High School Students' Mathematical Conceptual Understanding

**Janna Aprilia Azhara[1*], Muhammad Zaki[2], Guntur Maulana Muhammad[3]**
[1,2,3]Department Mathematics Education, Universitas Samudera, Kota Langsa, Indonesia

**Article Info**

***Article history:***

Received April 18, 2026
Revised July 10, 2026
Accepted July 25, 2026

***Keywords:***

Conceptual understanding
Discovery learning
PhET Simulation
Mathematics Education

**ABSTRACT**

This study examined whether discovery learning supported by PhET Simulation was associated with higher conceptual understanding of statistical measures of central tendency among junior secondary school students. A quantitative quasi-experimental method with a posttest-only control group design was employed. The participants were 50 Grade VIII students from SMP Negeri 2 Langsa, comprising 25 students in the experimental group and 25 students in the control group. The experimental group received discovery learning supported by PhET Simulation, whereas the control group received discovery learning without PhET Simulation. Data were collected using an essay-based test that assessed four indicators of conceptual understanding: classification, representation, example identification, and algorithmic application. Descriptive statistics and an independent-samples t-test were used after the normality and homogeneity assumptions had been examined. The experimental group achieved a higher mean posttest score ($M$ = 78.76, SD = 17.06) than the control group ($M$ = 62.88, $SD$ = 21.50). The difference was statistically significant, $t(48) = 2.89$, $p = .006$, with a large effect size (Cohen's $d$ = 0.82). These findings indicate that students who participated in PhET-assisted discovery learning demonstrated higher conceptual understanding than those who participated in discovery learning without simulation support. The results suggest that integrating interactive simulations into discovery learning may support the teaching of statistical concepts



***Corresponding Author:***

Janna Aprilia Azhara
e-mail: apriliajanna@gmail.com

## INTRODUCTION

Mathematics education plays an important role in developing students' logical, systematic, and analytical thinking. It also requires students to communicate ideas through symbols, diagrams, mathematical language, and multiple representations. These competencies help students connect mathematical knowledge with real-life situations and make reasoned decisions (Üredi & Doğanay, (2023). Effective instruction should therefore provide opportunities for students to reason, interpret information, and connect new concepts with their prior knowledge rather than merely memorize procedures. Haque (2024) further emphasizes that the use of multiple representations can support students' learning of mathematical and statistical concepts. Accordingly, mathematics instruction needs to be designed to promote active engagement and meaningful conceptual development.

Conceptual understanding is a fundamental component of mathematics learning because it enables students to explain concepts, recognize relationships, and apply knowledge in different situations. Students with strong conceptual understanding can connect mathematical topics and solve problems systematically (Baiduri et al., (2021). Conceptual understanding extends beyond recalling formulas; it involves restating concepts in one's own words, classifying mathematical objects, presenting concepts in different forms, identifying examples, and applying appropriate procedures. However, preliminary classroom observations and informal discussions with Grade VIII mathematics teachers at SMP Negeri 2 Langsa suggested that some students experienced difficulties in learning statistical concepts, particularly measures of central tendency. The teachers also indicated that students showed limited interest during predominantly teacher-directed instruction and had few opportunities to use visual or interactive learning media. Although these preliminary findings were not obtained through a formal diagnostic assessment, they indicated a need for a learning approach that could support students' active construction of statistical concepts.

Discovery learning offers a constructivist approach in which students develop knowledge through exploration, investigation, and guided problem-solving. Khasinah (2021) explains that discovery learning encourages students to construct knowledge by actively examining information and identifying conceptual relationships. Similarly, Handajani (2020) escribes discovery learning as a model that guides students to discover mathematical concepts through a structured investigative process. When students directly observe patterns, propose ideas, and test their reasoning, they may develop a more meaningful understanding of the relationships among concepts (Widia, (2020). Thus, discovery learning is relevant to the present study because it positions students as active participants while teachers provide guidance and facilitate the learning process.

Discovery learning is implemented through a sequence of interrelated stages. These stages generally include stimulation, problem identification, data collection, data processing, verification, and generalization (Kristin and Rahayu, (2016). During stimulation and problem identification, students are introduced to a situation that encourages curiosity and the formulation of questions. They subsequently collect and process relevant information to identify patterns or relationships. In the verification stage, students examine whether the evidence supports their initial ideas, while the generalization stage enables them to formulate broader conclusions. This sequence is consistent with concept-based mathematics learning because it engages students in observing, analyzing, verifying, and communicating mathematical relationships. Nevertheless, its effectiveness may depend on the availability of appropriate learning media that allow students to explore concepts directly.

Interactive technology can support discovery learning by providing visual and manipulable representations of mathematical ideas. Rahmah and Fitri Apriyani (2024) report that PhET Simulation can provide an interactive learning environment that supports students' learning outcomes. Through simulations, students can manipulate variables, observe changes, and examine relationships that may be difficult to represent through static explanations alone. Dy et al. (2024) also found that PhET interactive simulations supported students' performance by enabling exploration and experimentation in a simulated environment. Although much of the existing evidence comes from science education, the interactive and visual characteristics of PhET may also help students investigate statistical concepts, such as changes in the mean, median, and mode when data values are modified. Therefore, integrating PhET Simulation with discovery learning may provide students with a more concrete environment for exploring measures of central tendency.

Previous studies have reported positive outcomes from the use of PhET Simulation in different learning contexts. Astuti and Muzana (2020) applied PhET-based simulation learning to support students' understanding of physics concepts. In mathematics education, Hikmah et al. (2023) reported that the use of PhET Simulation influenced elementary students' mathematics learning outcomes. Marito et al. (2022) also described improvements in students' understanding of science learning through PhET-based activities. Collectively, these studies indicate that interactive simulations can provide students with opportunities to engage with learning content rather than receive information passively. However, the findings primarily concern science subjects or general learning outcomes, and they do not fully explain how PhET-assisted instruction supports specific indicators of mathematical conceptual understanding.

Research on the integration of PhET Simulation into mathematics instruction, particularly in learning measures of central tendency at the junior secondary level, remains limited. Previous studies have often focused on final achievement scores without examining conceptual understanding through indicators such as classification, representation, example identification, and algorithmic application. Moreover, the educational value of simulation media may depend on how the media are integrated into a structured instructional model. The use of digital media alone may not ensure meaningful learning when students are not guided to investigate, interpret, verify, and generalize the observed relationships. Comparing discovery learning supported by PhET Simulation with the same learning model without simulation support can therefore help clarify the additional contribution of interactive simulation media.

This study aimed to determine whether students taught through discovery learning supported by PhET Simulation demonstrated significantly higher mathematical conceptual understanding than students taught through discovery learning without PhET Simulation. It was hypothesized that students receiving PhET-assisted discovery learning would obtain significantly higher posttest scores than students receiving discovery learning without simulation support.

## METHOD

### Research Design

The study employed a quantitative approach with a quasi-experimental posttest-only control group design. The design was selected because the participants were organized in existing classes, making individual random assignment impractical. Two intact Grade VIII classes participated in the study. The experimental group received discovery learning supported by PhET Simulation, whereas the control group received discovery learning without PhET Simulation. Both groups studied the same mathematical content, followed the same discovery learning stages, received equivalent instructional time, and completed the same posttest at the end of the intervention. The research design is presented in Table 1.

**Table 1.** Posttest-only control group design

| Group | Treatment | Posttest |
|---|---|---|
| Experimental | Discovery learning supported by PhET Simulation ($X_1$) | $O_1$ |
| Control | Discovery learning supported by PhET Simulation ($X_2$) | $O_2$ |

In this design, ($X_1$) represents discovery learning supported by PhET Simulation, ($X_2$) represents discovery learning without simulation support, and $O_1$ and $O_2$ represent the posttest administered to the experimental and control groups, respectively.

Because the study did not administer a pretest, the initial comparability of the two classes was assessed using information provided by the mathematics teacher and the students' previous classroom assessment results. The teacher indicated that the two classes had relatively similar academic characteristics, prerequisite knowledge, and mathematics achievement. After the two classes had been identified as comparable, their assignment as the experimental and control groups was determined randomly. This procedure was intended to reduce systematic differences between the groups while preserving the natural classroom setting.

### Participants and Research Context

The study was conducted at SMP Negeri 2 Langsa during the second semester of the 2024–2025 academic year. The population comprised 216 Grade VIII students distributed across seven classes. The sample consisted of 50 students from two intact classes, with 25 students in each group. Class VIII-7 served as the experimental group, whereas Class VIII-6 served as the control group.

The two classes were selected through purposive sampling. The selection was based on information from the mathematics teacher and previous classroom assessment results indicating that the classes had relatively comparable mathematics achievement, prerequisite competencies, learning characteristics, and exposure to the statistical content examined in the study. Thus, the sampling procedure was used to identify two intact classes that were considered suitable for comparison within the quasi-experimental design.

After the classes had been selected, their designation as the experimental and control groups was determined randomly. The study was conducted during regular mathematics lessons to preserve the natural classroom context. Both groups studied measures of central tendency, including the mean, median, and mode. The learning objectives, subject matter, instructional duration, and posttest procedures were maintained as consistently as possible across the two groups. The primary difference between the groups was the use of PhET Simulation during discovery learning in the experimental group.

### Instructional Procedures

The instructional intervention in both groups followed the six stages of discovery learning: stimulation, problem identification, data collection, data processing, verification, and generalization Kristin and Rahayu (2016). In both groups, the teacher acted as a facilitator who guided students through the investigative process rather than directly presenting the concepts.

In the experimental group, PhET Simulation was integrated into each stage of discovery learning. During the stimulation stage, students observed data-related situations presented through the simulation. In the problem-identification stage, they formulated questions concerning changes in the mean, median, and mode. During data collection, students manipulated data values and recorded the resulting changes in measures of central tendency. They then processed the information to identify patterns and relationships among the data.

During the verification stage, students compared the results displayed in the simulation with their manual calculations and initial predictions. In the generalization stage, they formulated conclusions concerning the effects of changes in data values on the mean, median, and mode. The simulation was therefore used as an exploratory medium that allowed students to visualize and examine statistical relationships dynamically.

The control group followed the same discovery learning stages and studied the same mathematical content without PhET Simulation. Students explored the concepts through teacher-prepared examples, worksheets, classroom discussions, and manual calculations. They identified problems, collected and processed information, verified their calculations, and formulated conclusions using non-simulation learning resources. Thus, both groups received discovery learning, while interactive simulation support was provided only to the experimental group.

**Research Instruments**

The independent variable in this study was the instructional treatment, consisting of discovery learning supported by PhET Simulation and discovery learning without PhET Simulation. The dependent variable was students' mathematical conceptual understanding of measures of central tendency, as reflected in their posttest scores.

Data were collected using an essay-based test designed to measure students' mathematical conceptual understanding. The instrument was developed according to the curriculum objectives and the statistical content taught during the intervention. Essay items were selected because they allowed students to demonstrate their reasoning, present statistical information, and explain the procedures used to solve problems.

The instrument measured three indicators of conceptual understanding:

1. Classification, referring to students' ability to classify data or mathematical objects according to relevant statistical characteristics.
2. Representation, referring to students' ability to organize, present, and interpret statistical information in forms such as tables, diagrams, or mathematical expressions
3. Algorithmic application, referring to students' ability to select, apply, and explain appropriate procedures for calculating and interpreting the mean, median, and mode.

Each test item was aligned with one or more of these indicators. Students' responses were scored using a predetermined rubric that assessed the accuracy of the answer, the appropriateness of the representation or procedure, and the clarity of the reasoning provided.

The research instrument and supporting learning materials were reviewed by two expert validators before implementation. One validator served as a subject-matter expert, while the other served as a media expert. The subject-matter expert evaluated the accuracy of the mathematical content, its alignment with the curriculum and learning objectives, and the correspondence between the test items and the indicators of conceptual understanding. The media expert evaluated the clarity of the instructions, the suitability of the learning materials, the visual presentation, and the appropriateness of the PhET-assisted activities for Grade VIII students.

The validators also assessed the relevance of the test items, clarity of language, feasibility of classroom implementation, and consistency between the instructional activities and assessment instrument. Revisions were made based on their comments before the instrument was administered.

After expert validation, empirical item validity was examined using Pearson's product–moment correlation. Items were considered acceptable when their correlation coefficients met the predetermined validity criteria. Instrument reliability was assessed using Cronbach's alpha to determine the internal consistency of the essay-based test.

The quality of the test items was also examined through difficulty and discrimination analyses. The difficulty index was used to classify items as easy, moderate, or difficult, whereas the discrimination index was used to evaluate the ability of each item to distinguish between students with relatively high and low levels of conceptual understanding. Items that met the required validity, reliability, difficulty, and discrimination criteria were retained. Items that did not meet the criteria were revised or excluded before the final posttest was administered.

Supporting instructional instruments included learning modules and student worksheets developed according to the discovery learning stages. The experimental-group worksheets included instructions for exploring measures of central tendency through PhET Simulation, whereas the control-group worksheets addressed the same learning objectives through examples, discussion activities, and manual calculations.

**Data Collection**

Data collection was conducted after both groups had completed the instructional treatment. The experimental and control groups took the same essay-based posttest under comparable classroom conditions.

The same test instructions, completion time, scoring rubric, and administration procedures were applied to both groups.

No pretest was administered because the study used a posttest-only design. Therefore, the assumption of initial group comparability was based on the mathematics teacher's assessment, previous classroom achievement results, and the selection of two classes with relatively similar academic characteristics. The completed posttests were scored using the predetermined rubric, and the resulting scores were used as the primary data for analysis.

**Data Analysis**

The data were analyzed using descriptive and inferential statistics. Descriptive statistics included the number of participants, minimum and maximum scores, means, and standard deviations for the experimental and control groups. These statistics were used to describe the distribution and general pattern of students' posttest scores.

Before hypothesis testing, normality and homogeneity assumptions were examined. The Shapiro–Wilk test was used to assess the normality of the posttest scores in each group because each group consisted of 25 students. The data were considered normally distributed when the significance value was greater than .05. Levene's test was used to examine the equality of variances between the groups. The variances were considered homogeneous when the significance value was greater than .05.

After the assumptions had been satisfied, an independent-samples t-test was conducted to compare the mean posttest scores of the experimental and control groups. The significance level was set at (alpha=.05). A significance value below .05 indicated a statistically significant difference between the two groups. The research hypothesis was supported when the experimental group obtained a significantly higher mean posttest Table 2 presents the descriptive statistics for the posttest scores of the experimental and control groups In addition to statistical significance, Cohen's *d* was calculated to estimate the magnitude of the difference between the two groups. The effect size was calculated by dividing the difference between the group means by the pooled standard deviation. Based on the reported descriptive statistics, the estimated Cohen's *d* was 0.82, indicating a large effect. This value should be verified using the final dataset before publication.

**Ethical Considerations**

Permission to conduct the study was obtained from SMP Negeri 2 Langsa before data collection. The school administration and mathematics teacher were informed about the objectives, instructional procedures, and data-collection process.

Students' identities were anonymized during data analysis and reporting. The collected information was used solely for research purposes and was not presented in a way that allowed individual participants to be identified. Both groups continued to receive the mathematics content required by the school curriculum, and the instructional treatment was implemented as part of regular classroom learning activities.

## RESULTS AND DISCUSSION

### Results

This section presents the descriptive statistics, assumption tests, and inferential analysis of students' posttest scores. The analysis compared the mathematical conceptual understanding of students who received discovery learning supported by PhET Simulation with that of students who received discovery learning without simulation support.

*Descriptive Statistics of Students' Performance*

Table 2 presents the descriptive statistics for the posttest scores of the experimental and control groups.

**Table 2.** Descriptive Statistics of Students' Posttest Scores

| Group | N | Minimum | Maximum | Mean | Std Deviation |
|---|---|---|---|---|---|
| Experimental | 25 | 44 | 100 | 78.76 | 17.06 |
| Control | 25 | 28 | 97 | 62.88 | 21.50 |

The experimental group obtained a mean posttest score of 78.76 (*SD* = 17.06), whereas the control group obtained a mean score of 62.88 (*SD* = 21.50). The difference between the group means was 15.88 points. The experimental-group scores ranged from 44 to 100, while the control-group scores ranged from 28 to 97.

These descriptive results indicate that the experimental group achieved a higher overall posttest score than the control group. However, inferential analysis was required to determine whether the observed difference was statistically significant.

*Assumption Testing*

Before conducting the independent-samples *t*-test, the normality and homogeneity assumptions were examined. The Shapiro–Wilk test was used to assess the distribution of scores in each group. The results are presented in Table 3.

**Table 3.** Results of the Shapiro-Wilk normality test

| Group | Shapiro-Wilk Statistics | df | *p* |
|---|---|---|---|
| Experimental | .928 | 25 | .076 |
| Control | .923 | 25 | .061 |

The Shapiro–Wilk test produced a significance value of .076 for the experimental group and .061 for the control group. Both values were greater than .05, indicating that the posttest scores in both groups did not significantly deviate from a normal distribution.

Levene's test was subsequently conducted to examine the equality of variances between the two groups. The result is presented in Table 4.

**Table 4.** Results of Levene's test for homogeneity of variance

| Levene Statistics | $df_1$ | $df_2$ | *p* |
|---|---|---|---|
| 2.233 | 1 | 48 | .142 |

Levene's test yielded a significance value of .142, which was greater than .05. Therefore, the assumption of equal variances was satisfied. The normality and homogeneity results supported the use of an independent-samples *t*-test.

*Comparison of Posttest Scores*

An independent-samples *t*-test was conducted to determine whether the mean posttest scores differed significantly between the experimental and control groups. The results are presented in Table 5.

**Table 5.** Independent samples t-test results

| Comparison | t | df | *p* | Mean Difference | 95% CI for the diffrence | Cohen's *d* |
|---|---|---|---|---|---|---|
| Experimental-Control | 2.892 | 48 | .006 | 15.88 | [4.84, 26.91] | .82 |

The experimental group obtained a significantly higher mean posttest score than the control group, $t(48) = 2.892$, $p = .006$. The estimated mean difference was 15.88 points, with a 95% confidence interval ranging from 4.84 to 26.91. Because the confidence interval did not include zero, it supported the presence of a statistically significant difference between the groups.

Cohen's *d* was calculated using the difference between the two group means divided by their pooled standard deviation. The resulting effect size was 0.82, indicating a large standardized difference between the experimental and control groups. Accordingly, the null hypothesis was rejected, and the research hypothesis was supported. Students who received discovery learning supported by PhET Simulation demonstrated higher overall posttest scores in mathematical conceptual understanding than students who received discovery learning without simulation support.

## Discussion

This study examined differences in students' conceptual understanding of statistical measures of central tendency between two instructional conditions, discovery learning supported by PhET Simulation and discovery learning without media support. The results showed a statistically significant difference in posttest scores. Students in the experimental group achieved higher mean scores compared to the control group. This finding indicates that integrating PhET Simulation into discovery learning improves students' conceptual understanding of statistical concepts.

The findings align with constructivist learning theory. Conceptual understanding develops through active knowledge construction. Discovery learning requires students to engage in exploration, problem identification, data collection, data processing, verification, and generalization. These stages guide students to connect new knowledge with prior understanding. This process leads to structured and meaningful learning outcomes .

The higher performance in the experimental group reflects the added value of simulation media. PhET Simulation provides dynamic visual representations of abstract statistical concepts. Students observe how changes in data affect mean, median, and mode. This direct interaction supports conceptual clarity. Students do not rely only on symbolic or verbal explanations. Instead, they engage with visual and interactive representations. This process strengthens understanding of relationships among statistical concepts.

The findings support previous studies. Anisatu Rahmah and Fitri Apriyani (2024) reported that PhET Simulation helps students understand abstract concepts through interactive visualization. Syarifah and Desi (2020) found improved conceptual understanding in physics using simulation based learning. Nurul Hikmah et al. (2023), Azizah, et al. (2025), Aulia and Pramuditya (2025), Putri, et al. (2025) reported increased mathematics learning outcomes after implementing PhET Simulation. These studies confirm that simulation based learning enhances student understanding across disciplines .

From the perspective of discovery learning characteristics, simulation enhances exploratory learning activities. Students interact with data through manipulation and observation. They test ideas and receive immediate feedback. This condition supports deeper engagement. Activities such as classifying data, representing concepts, and applying algorithms become more structured. Visual support reduces cognitive load during learning. Students focus on understanding relationships rather than memorizing procedures.

The control group followed the same discovery learning stages without simulation. Learning relied on static representations such as textbooks and board explanations. This condition limits opportunities for experimentation. Students must rely on abstract reasoning without visual support. As a result, conceptual understanding develops at a lower level compared to simulation supported learning.

The findings indicate that instructional strategy alone does not determine learning outcomes. Media integration influences the effectiveness of the learning process. Discovery learning without appropriate media support does not fully address the challenges of abstract mathematical concepts. Students benefit from tools that provide concrete representations of abstract ideas.

The implications of this study relate to instructional design in mathematics education. Teachers should integrate interactive media into discovery learning. PhET Simulation provides opportunities for students to explore statistical concepts through direct manipulation. Instructional activities should focus on data exploration and interpretation. Learning tasks should guide students to construct meaning through interaction.

Several limitations should be noted. The sample size was limited to one school. The design used posttest only measurement without baseline comparison. The study focused on a single topic, central tendency in statistics. These factors limit generalization of findings.

Future research should involve larger samples across multiple schools. Studies should include pretest and posttest designs to measure learning gains. Additional variables such as student engagement and motivation should be examined. Further research should also explore the use of simulation in other mathematical topics.

Overall, the findings show that integrating discovery learning with PhET Simulation leads to higher conceptual understanding in statistics. The combination of student centered learning and interactive media provides a more effective learning environment. This approach supports students in constructing mathematical knowledge through active engagement.

## CONCLUSION

This study examined the effectiveness of discovery learning supported by PhET Simulation in facilitating students' conceptual understanding of statistical measures of central tendency at the junior secondary level. The findings showed that students who learned through discovery learning with PhET Simulation achieved higher posttest scores compared to those who learned through discovery learning without media support. The statistical analysis confirmed a significant difference between the two groups, indicating that the integration of simulation media enhances conceptual understanding.

The results indicate that discovery learning promotes active engagement through structured stages such as exploration, problem identification, and generalization. The addition of PhET Simulation strengthens this process by providing dynamic visual representations of abstract statistical concepts. Students interact directly with data, observe patterns, and test relationships among variables. This process supports deeper understanding of concepts such as mean, median, and mode. The findings also align with previous studies that report improved conceptual learning through simulation based environments.

This study contributes empirical evidence on the role of interactive media in mathematics learning, particularly in supporting conceptual understanding rather than procedural knowledge. The results suggest that instructional design should combine student centered learning models with appropriate technological tools. Such integration improves students' ability to represent, interpret, and apply mathematical concepts in meaningful ways.

The study has limitations. The sample size was limited to one school and involved a specific grade level. The design did not include pretest measurement, which limits analysis of learning gains. The focus was restricted to statistical material, so findings may not generalize to other mathematical topics. Future research should involve larger samples, include pretest and posttest designs, and examine other variables such as student engagement and reasoning processes across different mathematical domains.

## ACKNOWLEDGMENTS

The author would like to express sincere gratitude to Nursamsu, S.Pd., M.Pd., Head of the Department of Science and Mathematics Education, for his administrative support throughout this study. The author is especially grateful to Muhammad Zaki, S.Pd.I., M.Pd., as the first supervisor, for his invaluable guidance, constructive feedback, and continuous academic support throughout the research process. Sincere appreciation is also extended to Guntur Maulana Muhammad, S.Pd., M.PMat., for his insightful supervision and valuable suggestions, which contributed significantly to the completion of this study. Finally, the author acknowledges the importance of perseverance and commitment throughout the research journey and appreciates the opportunity for continuous learning. The author welcomes constructive feedback to further improve this work and support future academic development.

## REFERENCES

Arikunto, S. (2021). *Penelitian tindakan kelas: Edisi revisi*. Bumi Aksara.

Astuti, D., & Muzana, S. R. (2020). *Penerapan Pembelajaran Berbasis Simulasi PhET Untuk Meningkatkan Pemahaman Konsep Fisika Inti Pada Siswa SMA*.

Aulia, G.P. and Pramuditya, S. A. 2025. Interactive Learning Media Using Google Sites to Enhance Students' Understanding of Ratio Concepts in Grade VII. *Ar-Riyadhiyyat: Jurnal Pendidikan Matematika, Vol.6 No.1 Juli 2025.* https://doi.org/10.47766/arriyadhiyyat.v6i1.5923

Azizah, U.N., Sumiaty, E., Ulfa, N. 2025. Analyzing Epistemological Learning Obstacles on Limit Concept Using AVAE Framework in Prospective Mathematics Teacher. *Ar-Riyadhiyyat: Jurnal Pendidikan Matematika, Vol.6 No.1 Juli 2025.* https://doi.org/10.47766/arriyadhiyyat.v6i1.6243

Badruzaman, D., Istiarsono, Z., Nurlela, N., Udaya, L. O. M. R. A., Selly, O. A., Annisa, N. N., Mulyadi, A., Sijal, M., Maghfiroh, A. M., & Mutmainna, D. (2024). *Metode Penelitian Kuantitatif.* Yayasan Tri Edukasi Ilmiah.

Baiduri, Wardani, C., & Utomo, D. P. (2021). *Pemahaman Konsep Geometri Ditinjau Dari Kecerdasan Interpersional Dari Interpersonal*. UNM.

Diana, P., Andiani, & Aan. (2020). Kemampuan Pemahaman Konsep Matematis Siswa : Ditinjau Dari Kategori Kecemasan Matematik. *Supremum Journal Of Mathematics Education*.

Dy, A. U., Lagura, J. C., & Baluyos, G. R. (2024). Using PhET interactive simulations to improve the learners' performance in science. *EduLine: Journal of Education and Learning Innovation*, *4*(4), 520–530.

Ghozali, I. (2015). *Aplikasi analisis multivariate dengan program SPSS*. Badan Penerbit Universitas Diponegoro.

Handajani, B. (2020). *Model Discovery Learning Dalam Pembelajaran Matematika di SMP*. Penerbit Adab.

Haque, M. N. (2024). The role of multiple representations and attitudes in enhancing statistical and mathematical learning. *Smart Internet of Things*, *1*(4), 298–312.

Hikmah, N., Ili, L., & Amiruddin, B. (2023). Pengaruh Penggunaan Media PhET Simulation Dalam Pembelajaran Matematika Terhadap Hasil Belajar Siswa Kelas IV SD. *Jurnal Ilmiah Pembelajaran Sekolah Dasar*.

Khasinah, S. (2021). Discovery Learning : Definisi, Sintaksis, Keunggulan dan Kelemahan. *Jurnal Mudarrisuna : Media Kajian Pendidikan Agama Islam*.

Kristin, F., & Rahayu, D. (2016). Pengaruh Penerapan Model Discovery Learning Untuk Meningkatkan Hasil Belajar IPS Pada Peserta Didik Kelas 4 SD. *Scholaria : Jurnal Pendidikan Dan Kebudayaan*, *6*(1).

Marito, S., Abdullah, Khairani, S., & Devita, R. (2022). Peningkatan Pemahaman Mata Pelajaran Sains Menggunakan PhET Simulation di SMP AL-FARABI. *Jurnal Pengabdian Kepada Masyarakat*.

Midamba, D. C., Ndolo, O. F., Chepkoech, B., Agbolosoo, J. A., Ouya, F. O., & Jjengo, A. (2025). Data collection methods in social sciences: A primer for novice researchers and students. *South Asian Journal of Social Studies and Economics*, *22*(6), 217–229.

Nursichati, N., Susongko, P., & Mulyono, T. (2025). Critical Thinking Ability Test Instrument Design with Validity Test Pearson Correlation. *Journal of English Language and Education*, *10*(1), 329–341.

Putri, A., Yunita, A. Mardiyah, A. 2025. Enhancing Students' Conceptual Understanding in Mathematics through the Realistic Mathematics Education Model. *Ar-Riyadhiyyat: Jurnal Pendidikan Matematika, Vol.6 No.1 Juli 2025.* https://doi.org/10.47766/arriyadhiyyat.v6i1.5964

Rahmah, A., Ajeng, & Apriyani, I. F. (2024). Efektivitas Media PhET Simulation Untuk Meningkatkan Hasil Belajar Peserta Didik. *Jurnal Ilmiah Wahana Pendidikan*, *10*(2), 56–62.

Saptutyningsih, E., & Setyaningrum, E. (2019). *Penelitian Kuantitatif : metode dan alat analisis : dilengkapi dengan contoh proposal penelitian (1st ed.)*. Gosyen Publishing.

Sari, A. R., Al Husnawati, H., Suryono, J., Marzuki, M., & Mulyapradana, A. (2025). Metode Penelitian Kualitatif, Kuantitatif, Dan R&D. *YPAD Penerbit*.

Sugiyono. (2019). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D*. Alfabeta.

Üredi, P., & Doğanay, A. (2023). Developing the Skill of Associating Mathematics with Real Life Through Realistic Mathematics Education: An Action Research. *Journal of Theoretical Educational Science/Kuramsal Eğitimbilim Dergisi*, *16*(2).

Widia, I. W. (2020). Penerapan Model Discovery Learning Berbantuan Media PhET Untuk Meningkatkan Kompetensi Siswa. *Indonesian Journal Of Educational Development*.

Yakout, S. M., Hadi, K., Alolayan, M., Alasmari, M. M., Alhaji, K. M., Alobaid, L. M., Alonazi, M. A., & Alharbi, M. K. (2024). Analysis Of Difficulty Index, Discrimination Index And Distractor Efficiency In Multiple Choice Questions. *Journal of Advanced Zoology*, *45*(3).