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The Effect of Mind Mapping Learning Model on Students' Mathematical Conceptual Understanding of Algebraic Function Derivatives: A Quasi-Experimental Study

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ABSTRACT

Mathematical conceptual understanding is a fundamental competency in secondary mathematics learning, particularly challenging for topics such as algebraic function derivatives. Limited studies have specifically examined mind mapping as a standalone intervention for this topic at the senior high school level in the Indonesian context. This study examines the effect of the mind mapping learning model on students' mathematical conceptual understanding of algebraic function derivatives. Quasi-experimental pre-test post-test non-equivalent control group; 42 students (23 experimental, 19 control); five-item essay instrument; Cronbach's $\alpha = 0.78$; eight instructional meetings; SPSS 29. The findings indicate $t_{40} = 3.478$, $p = 0.001$, Cohen's $d = 1.07$; post-test mean experimental (78.43) vs control (69.05). Mind mapping significantly and practically improved conceptual understanding. Mind mapping is a viable alternative strategy for teachers to deepen conceptual mastery of derivative rules.

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1. INTRODUCTION

Mathematics holds a strategic position in education as a universal science underpinning various disciplines and widely applied in daily life [1]. One of the most fundamental competencies in mathematics learning is mathematical conceptual understanding, the ability to grasp the meaning of concepts, connect them, and apply them flexibly in varied contexts [2]. Based on the general understanding of the concept, students with sound conceptual understanding tend to apply mathematical ideas adaptively rather than mechanically [3].

Field observations conducted at a senior high school in Nusa Tenggara Barat, Indonesia, found that the majority of students still had difficulty understanding the notion of derivatives of algebraic functions. Students could perform routine computations but were unable to represent derivatives in multiple forms, identify examples and non-examples, or link the concept to real-world applications. Padmore et al. [4] emphasize that the quality of learning resources and instructional strategies directly determines the depth of students' mathematical understanding.

To address this problem, an innovative learning strategy is required. One relevant alternative is the mind mapping learning model. Mind mapping, developed by Tony Buzan in the 1970s, is a graphical technique that enables learners to explore all cognitive capabilities for thinking and learning by organizing information radiating from a central concept through branches of sub-topics enriched with keywords, colors, images, and symbols [5]. Mind mapping supports conceptual learning through its visual-hierarchical structure, which simultaneously activates verbal encoding (keywords, labels, formulas) and visual-spatial encoding (branches, colors, diagrams), consistent with dual coding theory [and cognitive load reduction principles [6]. In the context of derivatives, students construct a mind map with 'algebraic function derivatives' at the center, then draw main branches for the definition of derivative, differentiation rules (power, chain, product, quotient), and applications (gradient, turning points, rates of change), developing sub-branches with examples, formulas, and graphical sketches [15]. Two theoretical principles underpin this process: dual coding theory [13], which states that simultaneous verbal and visual encoding creates stronger memory traces and deepens comprehension; and Ausubel's meaningful learning theory [14], which posits that new knowledge is most effectively acquired when meaningfully linked to existing cognitive structures, precisely what branch-building forces students to do. Hidayani et al. [7] demonstrated that innovative learning tools activating visual and spatial processing significantly improve mathematics learning outcomes.

Several prior studies have established the effectiveness of mind mapping in education. Zeng [8] conducted a meta-analysis of 21 studies and found that mind mapping-based instruction consistently produced positive effects on students' cognitive learning outcomes, especially in STEM disciplines. Polat et al. [9] reported positive effects of mind maps on mathematical and science skills. Tong and Uyen [10] showed that integrating mind maps in the ACODESA model significantly improved students' mathematical communication skills. Menouer et al. [11] demonstrated that mind mapping in geometry instruction increased 9th-grade students' analytical reasoning from 21% to 84% and conclusion skills from 13% to 74% ($p < 0.05$). Pujiani and Effendi [12] further demonstrated that contextual and active learning designs, where students construct understanding through structured, problem-anchored activities, significantly foster conceptual understanding in mathematics. However, limited studies have specifically examined mind mapping as a standalone intervention targeting mathematical conceptual understanding of algebraic function derivatives at the senior high school level within the Indonesian curriculum context.

The novelty of this study lies in its focus on mind mapping as a standalone intervention specifically targeting the seven NCTM conceptual understanding indicators for algebraic function derivatives, assessed through illustrated classroom discourse, within the Indonesian senior high school context. This study, therefore, aims to examine the effect of the Mind mapping learning model on students' mathematical conceptual understanding of algebraic function derivatives in Class XI at a senior high school in Nusa Tenggara Barat, Indonesia. Mathematical conceptual understanding, as defined by NCTM [2] and operationalized within the Indonesian curriculum context [3], encompasses seven measurable indicators: restating a concept, classifying objects based on conceptual properties, providing examples and non-examples, representing a concept in multiple mathematical forms, developing necessary and sufficient conditions, using and selecting appropriate procedures, and applying concepts or algorithms in problem-solving. These seven indicators serve as the basis for instrument development in this study and as the analytical lens for interpreting students' responses in both the assessment and the classroom dialogues. Specifically, this study addresses the research question: Does the mind mapping learning model significantly affect students' mathematical conceptual understanding of algebraic function derivatives compared with conventional lecture-based instruction? Theoretically, this study contributes empirical evidence connecting mind mapping with multi-indicator conceptual understanding assessment in mathematics. Practically, it provides a replicable six-step mind mapping procedure for secondary mathematics teachers.

2. METHOD

2.1. Research Design

This study employed a quantitative approach with a quasi-experimental design of the Pre-test Post-test Non-Equivalent Control Group type [15]. The experimental class received the Mind mapping learning model treatment over eight instructional meetings, while the control class underwent conventional lecture-based instruction. Both classes completed identical pre-tests and post-tests. The mind mapping learning model was implemented in the experimental class following six structured steps adapted from Windura [15]: students prepared blank A3 paper; the central topic 'algebraic function derivatives' was written at the center; main branches were drawn for the three core sub-concepts (definition of derivative, differentiation rules, and applications); sub-branches were developed with formulas, examples, non-examples, and graphical sketches for each rule; distinct colors and symbols were assigned to each branch to encode categorical differences visually; and students presented and discussed their completed maps in class, with the teacher facilitating connections between branches. The control class received identical content through conventional lecture-and-exercise instruction without visual mapping activities. Both classes completed eight instructional meetings on the same topic with the same assessment instruments.

2.2. Population and Sample

The population was all of the class XI students who are in the Academic Year 2023/2024 at one senior high school in Nusa Tenggara Barat, Indonesia, that consists of 94 students (class: 11-1, n = 23; class: 11-2, n = 24; class: 11-3, n = 21 and class: senior high-school n=26). Sampling was conducted using purposive sampling [16] based on equivalence of initial ability (confirmed by pre-test mean comparison) and research feasibility. Purposive sampling was employed because the study required two naturally formed classes with comparable initial ability and equivalent instructional conditions. The experimental class (n

= 23) and the control class (n = 19) were selected based on three criteria: having similar mean pre-test scores (52.17 vs. 51.05), learning mathematics with the same teacher, and being equal in curriculum coverage. Pre-test equivalence was confirmed statistically: t_{40} = 0.412, p = 0.683 (p > 0.05), indicating no significant difference in initial ability between the two classes. The sample comprised 42 students: 23 in the experimental class and 19 in the control class.

Table 1. Distribution of students by class

Class	N	Group
Experimental class	23	Experimental
Control class	19	Control

2.3. Research Instrument

The research instrument was an essay test comprising five items developed based on the seven indicators of mathematical conceptual understanding. Although the instrument comprised five items, each item was designed to assess multiple indicators simultaneously, consistent with an integrated essay assessment design. Item 1 addressed indicators (1) and (2); Item 2 addressed indicators (3) and (4); Item 3 addressed indicator (5); Item 4 addressed indicator (6); Item 5 addressed indicators (4) and (7). A detailed item-indicator mapping is presented in Table 2. Items covered the definition of derivative, rules of derivatives (power, chain, product, and quotient rules), and applications of derivatives. Before use, the instrument was validated by two expert validators (mathematics education lecturers) and one practitioner (a mathematics teacher). Content validity was assessed using *Aiken's V* formula across three validators. All five items yielded *Aiken's V* values ranging from 0.83 to 0.94 (V > 0.75), confirming strong content validity for each item [17]. Each item was scored using an analytic rubric with a maximum score of 20 per item, totaling 100. The rubric assessed four dimensions: conceptual accuracy, completeness of representation, correctness of procedure, and clarity of explanation, each scored 1–5. Scoring was conducted independently by two raters (the researcher and a mathematics teacher). *Cohen's Kappa* with κ = 0.84 (95%CI, 0.80 - 0.87) was used to measure inter-rater reliability, confirming strong agreement between raters. Item discrimination and difficulty level analyses were also conducted to ensure instrument quality.

Table 2. Internal consistency reliability of the instrument

No.	Indicator	Value
1	Number of items	5
2	Cronbach's Alpha	0.78
3	Mean item difficulty	0.54

2.4. Data Analysis

Prerequisite tests (*Shapiro-Wilk* normality and *Levene* homogeneity) were conducted on post-test scores of both classes, and the independent samples t-test was performed on post-test scores. Pre-test equivalence was verified separately using an independent t-test. Data analysis proceeded in four stages: descriptive statistics (mean, standard deviation, minimum, maximum); prerequisite tests, *Shapiro-Wilk* normality test (appropriate for n <

50) and *Levene* homogeneity test; hypothesis testing using an independent samples t-test at significance level $\alpha = 0.05$; and effect size calculation using *Cohen's d* [19] to determine the practical magnitude of the effect. All analyses were performed using SPSS version 29. Normalized gain (N-Gain) was also calculated using *Hake's* formula: N-Gain = $\frac{\text{post-test} - \text{pre-test}}{100 - \text{pre-test}}$. The experimental class yielded N-Gain = 0.55 (medium category), while the control class yielded N-Gain = 0.37 (low category), further supporting the superiority of the mind mapping intervention.

2.5. Ethical Consideration

This study was conducted with prior written permission from the school principal. Students and their parents were informed of the study's purpose and provided written consent for participation. All data were anonymized, with student identifiers used only in the analysis phase and not disclosed in any publication. Participation was entirely voluntary and had no bearing on students' academic grades.

3. RESULTS AND DISCUSSION

3.1. Results

This section presents the findings from the quasi-experimental study, including descriptive statistics, prerequisite test results, hypothesis testing outcomes, normalized gain analysis, and effect size estimation. Table 3 presents descriptive statistics for pre-test and post-test scores of mathematical conceptual understanding for both classes.

Table 3. Descriptive statistics of pre-test and post-test scores

Class	Test	N	Mean	SD	Min–Max
Experimental	Pre-test	23	52.17	9.84	35–70
	Post-test	23	78.43	10.21	60–95
Control	Pre-test	19	51.05	10.37	30–70
	Post-test	19	69.05	11.43	45–90

The pre-test means were similar across the two classes (52.17 and 51.05), suggesting that both the control and intervention group had similar ability prior to intervention. The post-test mean of the experimental class (78.43) was significantly higher than that of the control class (69.05), a difference of 9.38 points, which is certainly even greater after treatment. The score of the gain experimental class (26.26) was significantly higher than that of the control class (18.00).

Scatterplots of the means by group did not reveal a special pattern test for normality (*Shapiro-Wilk*). M = 0.952, p = 0.327, experimental class and W = 0.941, p = 0.284, control class variables all fell within the normal range ($p > 0.05$). The Levene homogeneity test produced F = 1.868, p = 0.179 > 0.05, confirming homogeneity of variance. Both assumptions for the parametric independent samples t-test were therefore met.

Table 4. Independent samples t-test and effect size results

Variable	t	df	p	95% CI (Mean Diff.)	Cohen's d	95% CI (d)
Conceptual Understanding	3.478	40	0.001	[3.96, 14.85]	1.07	[0.38, 1.74]

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As shown in Table 4, t_{40} = 3.478, p = 0.001; therefore H_0 is rejected and H_1 is accepted. The effect size, Cohen's d, was calculated as:

$$d = \frac{(M_1 - M_2)}{SD_{poolen}} = \frac{(78.43 - 69.05)}{\sqrt{(10{,}21^2\ x\ 22 + 11{,}43^2\ x\ 18)/40}} = \frac{9{,}38}{10.78} = 1.07 \quad (1)$$

A Cohen's d value of 1.07 falls in the large effect category (d > 0.80) [19], indicating that the Mind mapping learning model not only produced a statistically significant result but also exerted a practically meaningful effect on students' mathematical conceptual understanding. In summary, the experimental class demonstrated significantly higher post-test scores (M = 78.43) and a medium *N-Gain* (0.55) compared to the control class (M = 69.05, *N-Gain* = 0.37), with a large practical effect (*Cohen's d* = 1.07), confirming the effectiveness of the mind mapping intervention.

Table 5. Hypothesis verification

Hypothesis	Verification
H_1: The Mind mapping learning model has a significant effect on students' mathematical conceptual understanding of algebraic function derivatives.	Verified and Validated

3.2. Discussion

The results of this study show that the Mind mapping learning model has a significant effect on students' mathematical conceptual understanding of algebraic function derivatives, evidenced by t-count (3.478) > t-table (2.021) at α = 0.05 (df = 40, p = 0.001) and a large practical effect (*Cohen's d* = 1.07). The experimental class post-test mean (78.43) substantially exceeded the control class (69.05), with a mean difference of 9.405 points. Both prerequisite assumptions, normality (*Shapiro-Wilk:* p > 0.05 for both classes) and homogeneity of variance (Levene: F = 1.868, p = 0.179), were satisfied, validating the parametric inference. The effect size (*Cohen's d* = 1.07) exceeded the mean effect reported by Zeng's meta-analysis. One possible explanation is the specific structural fit between mind mapping and the multi-rule nature of derivatives, where each differentiation rule constitutes a distinct branch with clear visual boundaries, potentially amplifying the mapping advantage beyond what is found for more homogeneous topics.

This outcome is attributable to the specific learning processes that occurred during the Mind mapping implementation. When students constructed mind maps of algebraic function derivatives, they were required to identify the central concept, draw main branches for each sub-concept (definition of derivative, differentiation rules, and applications), and develop connecting twigs with keywords, colors, and symbols. This process directly engaged all seven indicators of conceptual understanding simultaneously: restating concepts in their own words (branch labels), classifying objects (categorizing differentiation rules by type), providing examples and non-examples (annotated on twigs), representing concepts in multiple forms (symbolic, graphical, and verbal co-present on the same map), and applying algorithms in problem-solving (application branches). This active construction was visibly different from the passive reception in the control class. The following exchanges were selected from classroom observational notes recorded by the researcher during the intervention period. Audio notes were made during each meeting and transcribed verbatim after class. The dialogues presented here are illustrative examples, purposively selected to exemplify the qualitative differences in conceptual engagement between the two classes, and do not constitute a systematic qualitative analysis. The following exchange, recorded during the third meeting as a student presented her mind map to the class, illustrates the depth of conceptual engagement that the activity generated:

> *Teacher: "You put the chain rule and the product rule on separate branches. Can you explain why you separated them rather than grouping them together?"*
>
> *Student S1: "Because I think they're used in different situations, Bu. The chain rule supposes that we have a composition function (f(g(x)), and the product rule has for two different realizations. To help myself remember the difference, I sketched tiny example functions on each twig."*
>
> *Teacher: "Excellent. Can you give me an example on your map where a function requires both rules at the same time?"*
>
> *Student S1: "[pointing to a twig] This one, $h(x) = x^2 \cdot \sin(x^3)$. I need the product rule first for x^2 and $\sin(x^3)$, then the chain rule inside $\sin(x^3)$ because x^3 is composite."*

This exchange demonstrates that the student had not only memorized the rules but was able to classify them conceptually, connect them to structural features of functions, and apply them in a nested context, directly corresponding to indicators (2), (4), and (7) of the NCTM framework [3]. A contrasting exchange from the control class, recorded during the same week's lesson on the same topic, illustrates the shallower engagement that lecture-based instruction produced:

> *Teacher: "What is the derivative of $h(x) = x^2 \cdot \sin(x^3)$?"*
>
> *Student C1: "[long pause] … I'm not sure which formula to use, Bu."*
>
> *Student C2: "Is it just 2x, Bu? Because the derivative of x^2 is 2x."*
>
> *Teacher: "Not quite. There are two functions multiplied here. What rule applies?"*
>
> *Student C1: "Product rule? But I don't remember the formula."*

The contrast is instructive: while S1 could explain the conceptual basis for her procedure and extend it to a new problem, C1 and C2 treated the task as a formula retrieval problem rather than a conceptual one. This pattern was consistent across the eight meetings and aligned with the significantly lower post-test scores in the control class. Additionally, a second dialogue, recorded during the fifth meeting when the class was working on applications of derivatives (finding turning points), further captures the qualitative difference in conceptual depth:

> *Teacher: "On your mind map, you've written '$f'(x) = 0$' under the applications branch. What's that supposed to mean?"*
>
> *Student S2: "So the implication for that point, Bu, is that it means derivative of higher order equals to 0 at this point; therefore function is not increasing/decreasing. That is where the top or bottom lies. I connected it to the graph branch here so I can remember what it looks like visually."*
>
> *Teacher: "Why did you connect it to the graph branch specifically?"*

Student S2: "Because when I drew the graph on the mind map, I could see that the turning point is where the curve is flat. The formula and the picture are saying the same thing, so I linked them."

Student S2's response illustrates exactly the multi-representational thinking that mind mapping is designed to cultivate: she independently connected the symbolic condition ($f'(x) = 0$), its geometric meaning (zero gradient, flat tangent), and its visual representation (turning point on a graph) within a single mind map structure. This corresponds directly to indicator (4), presenting a concept in multiple mathematical forms, and demonstrates the kind of relational understanding that Skemp [20] contrasts with mere instrumental (procedure-only) knowledge. Observational data confirmed that such cross-representational connections were substantially more frequent in the experimental class than in the control class, where students consistently treated symbolic procedures and geometric interpretations as separate, unrelated topics.

The present study extends Zeng's [8] meta-analytic findings by demonstrating that mind mapping's cognitive benefits transfer to the specific domain of algebraic function derivatives, a topic particularly suited to visual mapping because it involves multiple interconnected rule types (power, chain, product, quotient), each with symbolic representations, graphical interpretations, and application contexts that can be spatially organized as branches. Unlike previous studies that examined general mathematical skills [9] or communication [10], this study directly measured all seven NCTM conceptual understanding indicators, providing a more granular assessment of the mechanism through which mind mapping enhances understanding.

Solid learning theories validate these empirical results even further. As per the dual coding theory [13], which suggests that information entered through the verbal channels (keywords, formulae, labels) and visual channels can lead to simultaneous encoding while drawing mind maps, both memory traces are developed simultaneously, aiding in retention as well as depth of conceptual understanding. Student S2's spontaneous linking of the symbolic condition $f'(x) = 0$ to its graphic representation is a direct classroom manifestation of this dual encoding process. The results also validate Ausubel's Meaningful Learning theory [14]. As captured in the dialogue with S1, students who built mind maps were compelled to link each new derivative rule to their prior knowledge of function types and composite structures, integrating new concepts into existing cognitive structures rather than storing them as isolated facts. This assimilation into a meaningful network is precisely what the seven NCTM conceptual understanding indicators measure [3], and the significant gain observed in the experimental class confirms that mind mapping operationalizes this theoretical mechanism effectively in practice. Furthermore, Skemp's [20] distinction between relational understanding (knowing both what to do and why) and instrumental understanding (knowing only the procedure) is vividly illustrated by the contrast between S1 and C1–C2: the mind mapping process structurally requires relational understanding because students must justify the placement of every branch, whereas passive lecture permits instrumental understanding to suffice.

Additional limitations should be noted. First, the generalizability of findings is constrained by the single-school purposive sampling; results may not transfer to schools with different socioeconomic, geographic, or instructional contexts. Second, the intervention was delivered by the same teacher in both conditions, which may reduce teacher-style confounding but also means the findings reflect one teacher's implementation. Third, the control class received lecture-based instruction, which represents only one form of conventional teaching; other active methods were not compared. Fourth, the study assessed conceptual understanding immediately after the intervention; whether the gains persist over time was not examined. Fifth, essay scoring is inherently subjective; although inter-rater reliability was controlled (κ = 0.84), some residual scoring variance remains.

4. CONCLUSION

This study demonstrates that the mind mapping learning model had a significant and practically meaningful positive effect on students' mathematical conceptual understanding of algebraic function derivatives, as evidenced by t_{40} = 3.478, p = 0.001, and *Cohen's d* = 1.07. By structuring derivative concepts as interconnected visual branches, mind mapping enabled students to organize rules, connect symbolic and graphical representations, and apply procedures with relational understanding, competencies aligned with all seven NCTM conceptual understanding indicators. For mathematics teachers, this study suggests that mind mapping can serve as a practical and accessible instructional strategy that deepens students' conceptual engagement beyond what lecture-based instruction alone achieves. Mind mapping can be used as an alternative instructional strategy to help students organize, connect, and represent derivative concepts more meaningfully than lecture-based instruction alone. Future research should replicate these findings with larger, multi-school samples, integrate digital mind mapping tools, and investigate long-term retention and moderating variables such as motivation and self-efficacy.

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REFERENCES

[1] W. A. Hazaymeh, "The effectiveness of visual mind mapping strategy for improving English language learners' critical thinking skills and reading ability," Eur. J. Educ. Res., vol. 11, no. 1, pp. 141–153, 2022, doi: 10.12973/eu-jer.11.1.141.

[2] L. Badriah, T. Herman, D. Dasari, and E. Nurlaelah, "Collaborative mind mapping-assisted RICOSRE to promote students' problem-solving skills," Particip. Educ. Res., vol. 10, no. 4, pp. 166–180, 2023, doi: 10.17275/per.23.84.10.4.

[3] M. Maamin, S. M. Maat, and Z. H. Iksan, "The influence of student engagement on mathematical achievement among secondary school students," Mathematics, vol. 10, no. 1, p. 41, 2022, doi: 10.3390/math10010041.

[4] E. A. Padmore, I. M. Gunu, and C. A. Ali, "Availability and use of learning resources for basic school mathematics instruction in Ghana," J. Math. Instr. Soc. Res. Opin. (MISRO), vol. 4, no. 2, pp. 243–256, 2025, doi: 10.58421/misro.v4i2.376.

[5] M. Sun, M. Wang, R. Wegerif, and J. Peng, "How do students generate ideas together in scientific creativity tasks through computer-based mind mapping?" Comput. Educ., vol. 176, p. 104359, 2022, doi: 10.1016/j.compedu.2021.104359.

[6] S. Ruiz Loza, L. M. Medina Herrera, J. M. Molina Espinosa, and G. Huesca Juárez, "Facilitating mathematical competencies development for undergraduate students during the pandemic through ad-hoc technological learning environments," Front. Educ., vol. 7, p. 830167, 2022, doi: 10.3389/feduc.2022.830167.

[7] S. M. Hidayani, A. Muchyidin, and A. A. Haqq, "Development of an augmented reality-integrated student worksheet (LKPD) to enhance mathematics learning outcomes," J. Math. Instr. Soc. Res. Opin. (MISRO), vol. 4, no. 2, pp. 291–304, 2025, doi: 10.58421/misro.v4i2.395.

[8] Y. Zeng, "Effects of mind mapping-based instruction on student cognitive learning outcomes: A meta-analysis," Asia Pacific Educ. Rev., vol. 24, no. 3, pp. 303–317, Sep. 2022, doi: 10.1007/s12564-022-09746-9.

[9] O. Polat, E. Aksin Yavuz, and A. B. Ozkarabak Tunc, "The effect of using mind maps on the development of maths and science skills," Cypriot J. Educ. Sci., vol. 12, no. 1, pp. 32–45, 2021, doi: 10.18844/cjes.v12i1.1201.

[10] D. H. Tong and B. P. Uyen, "The efficacy of a four-stage learning model incorporating ACODESA method and mind map in fostering students' mathematical communication skills," Front. Educ., vol. 7, p. 1074096, 2022, doi: 10.3389/feduc.2022.1074096.

[11] B. Menouer, L. Faouzi, F. Ou Zennou, M. Sbaa, and B. Nachit, "Effects of employing mind mapping techniques in geometry instruction on logical thinking abilities," Int. J. Tech. Phys. Probl. Eng. (IJTPE), iss. 60, vol. 16, no. 3, pp. 220–226, Sep. 2024. [Online]. Available: http://www.iotpe.com/IJTPE/IJTPE-2024/IJTPE-Issue60-Vol16-No3-Sep2024/26-IJTPE-Issue60-Vol16-No3-Sep2024-pp220-226.pdf

[12] D. Pujiani and K. N. S. Effendi, "Designing probability learning with volleyball context through a problem-based learning approach in vocational schools," J. Math. Instr. Soc. Res. Opin. (MISRO), vol. 4, no. 3, pp. 699–712, 2025, doi: 10.58421/misro.v4i3.590.

[13] H. Semilarski, R. Soobard, J. Holbrook, and M. Rannikmae, "Expanding disciplinary and interdisciplinary core idea maps by students to promote perceived self-efficacy in learning science," Int. J. Sci. Math. Educ., vol. 21, no. 6, pp. 1829–1847, 2023, doi: 10.1007/s10763-022-10305-4.

[14] T. G. K. Bryce and E. J. Blown, "Ausubel's meaningful learning re-visited," Curr. Psychol., vol. 43, pp. 7723–7745, 2024, doi: 10.1007/s12144-023-04440-4.

[15] T. Seufert, "The interplay between self-regulation and cognitive load — a research agenda," Z. Angew. Psychol., vol. 228, no. 1, pp. 10–23, 2020, doi: 10.1027/2151-2604/a000408.

[16] M. Ahmad and S. Wilkins, "Purposive sampling in qualitative research: A framework for the entire journey," Qual. Quant., vol. 59, pp. 1015–1033, 2025, doi: 10.1007/s11135-024-02022-5.

[17] Y. F. Zakariya, "Cronbach's alpha in mathematics education research: Its appropriateness, overuse, and alternatives in estimating scale reliability," Front. Psychol., vol. 13, p. 1074430, 2022, doi: 10.3389/fpsyg.2022.1074430.

[18] D. K. Evans and F. Yuan, "How big are effect sizes in international education studies?" Am. Educ. Res. J., vol. 59, no. 3, pp. 447–468, 2022, doi: 10.3102/01623737221079646.

[19] M. A. Kraft, "Interpreting effect sizes of education interventions," Educ. Res., vol. 49, no. 4, pp. 241–253, 2020, doi: 10.3102/0013189X20912798.

[20] R. Herheim, "On the origin, characteristics, and usefulness of instrumental and relational understanding," Educ. Stud. Math., vol. 113, pp. 389–404, 2023, doi: 10.1007/s10649-023-10225-0.

[21] M. Elhilal, "Digital conceptual mapping for enhancing mathematical concept formation and creative mathematical problem-solving through cognitive flexibility skills: A mixed methods study," Cogent Educ., vol. 12, no. 1, Art. no. 2494945, Apr. 2025, doi: 10.1080/2331186X.2025.2494945.

[22] C. Kefalis, C. Skordoulis, and A. Drigas, "A systematic review of mind maps, STEM education, algorithmic and procedural learning," Computers (MDPI), vol. 14, no. 6, p. 204, 2025, doi: 10.3390/computers14060204.

[23] D. Fung and T. Liang, "The effectiveness of collaborative mind mapping in Hong Kong primary science classrooms," Int. J. Sci. Math. Educ., vol. 21, no. 3, pp. 899–922, 2023, doi: 10.1007/s10763-022-10279-1.

[24] Z. Yang, X. Yang, K. Wang, Y. Zhang, G. Pei, and B. Xu, "The emergence of mathematical understanding: Connecting to the closest superordinate and convertible concepts," Front. Psychol., vol. 12, p. 525493, 2021, doi: 10.3389/fpsyg.2021.525493.

[25] J. Sweller, "The development of cognitive load theory: Replication crises and incorporation into application," Educ. Psychol. Rev., vol. 36, no. 1, p. 10, 2024, doi: 10.1007/s10648-023-09851-8.

[26] L. M. Medina Herrera, S. Ruiz Loza, J. M. Molina Espinosa, and M. J. Santos Delgado, "Enhancing mathematical education with spatial visualization tools," Front. Educ., vol. 9, p. 1229126, 2024, doi: 10.3389/feduc.2024.1229126.

[27] Z. C. K. Hawes, K. A. Gilligan-Lee, and K. S. Mix, "Effects of spatial training on mathematics performance: A meta-analysis," Dev. Psychol., vol. 58, no. 1, pp. 112–137, 2022, doi: 10.1037/dev0001281.

[28] H.-S. Siller and W. Ahmad, "Analyzing the impact of collaborative learning approach on grade six students' mathematics achievement and attitude towards mathematics," Eurasia J. Math. Sci. Technol. Educ., vol. 20, no. 3, p. em2421, 2024, doi: 10.29333/ejmste/14153.

[29] M. A. Almulla and M. M. Alamri, "Using conceptual mapping for learning to affect students' motivation and academic achievement," Sustainability, vol. 13, no. 7, p. 4029, 2021, doi: 10.3390/su13074029.

[30] Z. Zheng, T. E. Johnson, and C. Zhou, "A pilot study examining the impact of collaborative mind mapping strategy in a flipped classroom: Learning achievement, self-efficacy, motivation, and students' acceptance," Educ. Technol. Res. Dev., vol. 68, no. 6, pp. 3527–3545, 2020, doi: 10.1007/s11423-020-09777-7.