Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: https://www.science-gate.com/IJAAS.html

Enhancing Grade 7 students' achievement in exponents through brain-based learning

Paweena Prasomsap [1], Chaweewan Jurutra [2], Apantee Pooputta [1,*]

[1]Department of Research and Development, Faculty of Education, Mahasarakham University, Maha Sarakham, Thailand
[2]Department of Mathematics, Triam Udom Suksa Patthanakarn School, Roi Et Province, Thailand

ARTICLE INFO

Article history:
Received 15 May 2026
Received in revised form
15 September 2026
Accepted 21 September 2026

Keywords:
Brain-based learning
Mathematics education
Academic achievement
Exponents
Student satisfaction

ABSTRACT

This study investigated the effectiveness of Brain-Based Learning (BBL) in improving Grade 7 students' academic achievement in the topic of exponents. A one-group pretest–posttest design was employed with 23 students over five weeks. The findings indicated that the BBL instructional plan exceeded the 75/75 effectiveness criterion and resulted in significant improvements in posttest scores. Students reported very high satisfaction with the learning process. Qualitative observations also confirmed active engagement and conceptual understanding. The study demonstrates that BBL supports both the cognitive and emotional aspects of learning, making it a promising approach for teaching abstract mathematical concepts in lower secondary education.

© 2026 The Authors. Published by IASE. This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Mathematics plays a fundamental role in the development of analytical thinking and problem-solving skills among students at all educational levels (Golding, 2018; Karagiannakis et al., 2014). In lower secondary education, particularly at the Grade 7 level, learners are introduced to increasingly abstract mathematical concepts that lay the groundwork for future learning in algebra, geometry, and advanced mathematics (Ragusa et al., 2024). Among these topics, the concept of exponents is both foundational and cognitively demanding. Mastery of exponents is essential for students to progress confidently in mathematics; however, many students struggle to internalize the abstract rules and symbolic representations involved. These difficulties are often compounded by traditional instructional approaches that rely heavily on memorization and procedural fluency without developing conceptual understanding.

Given these challenges, there is an increasing need for pedagogical approaches that align with how students naturally process, retain, and apply mathematical knowledge. One such approach is Brain-Based Learning (BBL), a neuroscience-informed instructional model that integrates findings from cognitive psychology and neuroeducation to optimize the learning process (Jensen and McConchie, 2020; Rodgers and Hales, 2021; Tang, 2017). BBL emphasizes principles such as emotional safety, pattern recognition, multisensory engagement, and active participation, all of which support long-term retention and meaningful learning (Jensen and McConchie, 2020). Applied to mathematics instruction, BBL provides opportunities for learners to engage in structured, emotionally resonant, and contextually rich experiences that promote conceptual understanding at a more sophisticated level. Recent research has highlighted the effectiveness of BBL in various domains of mathematics, such as enhancing logical reasoning (Kaewkumsai and Phusee-orn, 2024), improving mathematical communication (Effendi and Marlina, 2021), and supporting motivation and self-efficacy (Amjad et al., 2023; Amjad and Tabbasam, 2024).

While these studies provide preliminary evidence of BBL's effectiveness in upper secondary mathematics classrooms, they tend to focus on general skills or advanced content areas, such as quadratic functions, logic, or mathematical connections (Fitri and Zaeni, 2020; Thonsakul and Poonputta, 2023). Additionally, some studies have explored the integration of BBL with multimedia tools to enhance problem-solving and critical thinking (Saputra et al., 2024), while others emphasized its motivational benefits in middle school contexts (Amjad et al., 2022). However,

* Corresponding Author.
Email Address: apantree.poo@msu.ac.th (A. Pooputta)
https://doi.org/10.21833/ijaas.2026.09.011
Corresponding author's ORCID profile:
https://orcid.org/0000-0001-6182-7333
2313-626X/© 2026 The Authors. Published by IASE.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

limited research exists on the application of BBL to specific foundational topics such as exponents, particularly at the Grade 7 level, when students are transitioning into formal operational thinking. Despite exponents being a core component of algebraic understanding, little is known about how BBL can enhance student achievement in this specific area. This gap in the literature highlights the need to investigate the effectiveness of BBL strategies in supporting the conceptual and procedural understanding of exponents among early secondary students.

The present study aims to address this gap by examining the effectiveness of Brain-Based Learning in enhancing the academic achievement of Grade 7 students in the topic of exponents. Specifically, the study investigates whether a BBL-based instructional design can significantly improve student performance and engagement in learning exponents, thereby providing empirical insights into the pedagogical potential of neuroscience-informed practices in foundational mathematics education.

2. Literature review

2.1. Brain-based learning: Theoretical foundations

Brain-Based Learning (BBL) is an instructional approach grounded in neuroscience, which seeks to align teaching practices with the natural functioning of the brain to improve learning outcomes (Jensen and McConchie, 2020). Central to BBL is the idea that emotional engagement, sensory stimulation, and contextualized experiences enhance cognitive processing and memory retention (Tang, 2017). BBL emphasizes strategies such as pattern recognition, rehearsal, multisensory instruction, social interaction, and stress-free environments—conditions proven to activate multiple neural pathways essential for deep learning (Rodgers and Hales, 2021). The principles are increasingly applied across subject areas to improve learners' motivation, comprehension, and achievement.

2.2. Application of BBL in mathematics education

In the field of mathematics education, BBL has demonstrated promising effects across various cognitive and affective domains. Several studies have validated its effectiveness in supporting students' understanding of abstract mathematical concepts and improving overall achievement. For example, Kaewkumsai and Phusee-orn (2024) developed a BBL-based instructional model combined with skill practice for Grade 10 students, resulting in significantly improved performance in elementary logic and high levels of student satisfaction. Similarly, Thonsakul and Poonputta (2023) found that BBL-based instruction enhanced learning achievement in quadratic functions among Grade 11 students, suggesting that BBL facilitates the comprehension of complex mathematical structures through student-centered and brain-compatible learning activities.

Other studies have highlighted BBL's role in strengthening specific cognitive skills. Fitri and Zaeni (2020) reported that the application of BBL significantly improved students' mathematical connection abilities, while Effendi and Marlina (2021) showed that motivational factors mediated the relationship between BBL and students' mathematical communication skills. These findings underscore BBL's versatility in supporting procedural fluency and contributing to higher-order thinking, reasoning, and expressive capabilities in mathematics.

2.3. BBL and affective dimensions of learning mathematics

Beyond cognitive outcomes, BBL has been linked to positive affective changes in learners, such as increased motivation and self-efficacy. Amjad et al. (2022) employed a single-subject A-B-A design to demonstrate that BBL significantly increased Grade 8 students' self-efficacy to learn mathematics by incorporating techniques like brainstorming and visual imaging.

In a related study, Amjad and Tabbasam (2024) found that BBL-based strategies, including role-playing and visual storytelling, also enhanced students' extrinsic motivation to engage with mathematics learning tasks. In these cases, apart from academic performance, BBL was also suggested to provide emotional and motivational readiness, which is especially critical in middle school education where learners often experience declining interest in mathematics.

2.4. Multimedia-enhanced BBL in mathematical problem solving

Some research has integrated digital media with BBL strategies to further enrich the learning environment. Saputra et al. (2024) investigated the effect of a video-assisted BBL model on mathematical critical thinking and problem-solving in junior secondary students. The study showed that students exposed to the multimedia-enhanced BBL model significantly outperformed their peers in traditional and non-video-assisted BBL settings. This points to the adaptability of BBL to various instructional contexts and its compatibility with contemporary learning technologies.

Despite the wide application of BBL in upper secondary mathematics and its proven benefits in logic, functions, communication, and motivation, few studies have applied BBL to early secondary learners, particularly in teaching foundational yet abstract topics such as exponents. This could be noted, given that exponents are an essential building block for algebra and require both procedural fluency and conceptual clarity.

The existing literature does not adequately address how BBL can be adapted to meet the developmental needs of Grade 7 students who are in the early stages of formal operational thinking. This study seeks to fill that gap by implementing and evaluating a BBL-based instructional intervention targeting students' academic achievement in exponents. The purposes of the study were to investigate the effectiveness of brain-based learning on grade 7 students' learning achievement of exponents and to study the participants' satisfaction with brain-based learning.

3. Methodology

3.1. Design

This study employed a quasi-experimental one-group pretest-posttest design to examine the effectiveness of Brain-Based Learning (BBL) on Grade 7 students' academic achievement in the topic of exponents (Table 1).

Table 1: One-group pretest–posttest design

Design	Procedure
One-group experimental design	Pretest → brain-based learning (BBL) → posttest

3.2. Participants

The population consisted of 133 Grade 7 students enrolled in four classes at Triam Udom Suksa Patthanakarn School, Roi Et Province, Thailand, under the jurisdiction of the Roi Et Secondary Educational Service Area Office during the first semester of the 2024 academic year. The sample was obtained using cluster random sampling and included 23 students from Class 1/4.

3.3. Research instruments

Learning management plan: The instructional component of the study comprised nine BBL-based lesson plans designed to teach the topic of exponents to Grade 7 students. The lessons were implemented over five weeks, with students attending two 1-hour sessions per week. The ninth session was dedicated to post-instruction assessment and is not included in the teaching plan analysis.

Each BBL lesson followed the five-phase structure commonly associated with Brain-Based Learning: Engage (Preparation/Motivation), Presentation (New Knowledge Delivery), Practice (Skill Application/Group Work), Summarize (Consolidation and Reflection), and Transfer (Real-world Application/Review).

The content of the lessons addressed core subtopics of exponents appropriate for Grade 7, including understanding the meaning of exponents, writing numbers in exponential form, Laws of exponents (multiplication, division, zero exponent), Powers of 10 and scientific notation, and solving word problems involving exponents.

The lesson plans were evaluated by a panel of three experts in mathematics education, who assessed their content validity, pedagogical alignment, and suitability for BBL-based delivery. The plans were rated at a high level of appropriateness (M = 3.50-4.87).

Achievement test: The achievement test was developed in this study. It consisted of 25 items (20 multiple-choice and 5 open-ended questions) used to assess learning achievement in exponents. The items met content validity criteria (IOC ≥ 0.50). Item analysis showed difficulty indices (P = 0.21-0.67) and discrimination indices (B-index = 0.20-0.88) for multiple-choice items and P = 0.32–0.70, D = 0.25–0.90 for open-ended items. The test had a Cronbach's alpha reliability coefficient of 0.85.

Satisfaction questionnaire: The satisfaction questionnaire was developed specifically for this study to assess students' perceptions of the Brain-Based Learning instructional approach. Because the instrument was designed exclusively for the participants in the experimental group and administered only after the intervention, a pilot study was not conducted. Nevertheless, the questionnaire underwent content validation by three experts in mathematics education and educational measurement. The Item-objective Congruence (IOC) values ranged from 0.67 to 1.00,

Observation form: An observation form was developed to collect qualitative data on students' learning behaviors during the implementation of the Brain-Based Learning (BBL) activities. The form focused on students' participation, engagement, collaboration, and problem-solving behaviors. The instrument was reviewed by three experts, who confirmed its appropriateness for the study. Observation data were used to support and explain the quantitative findings.

3.4. Data collection

Data collection was conducted over a five-week period during the first semester of the 2024 academic year. The process began with an orientation session in which the researcher informed students of the study objectives and procedures. A pretest was administered to measure students' prior knowledge of exponents. Over the subsequent four weeks, students participated in eight instructional sessions based on the Brain-Based Learning (BBL) approach, delivered twice weekly. Following the instructional period, a posttest was administered to evaluate learning outcomes. In the final step, students completed a satisfaction questionnaire to assess their perceptions of the BBL-based learning experience.

3.5. Data analysis

The data obtained from the study were analyzed using both descriptive and inferential statistical methods. The effectiveness of the BBL-based learning management plan was evaluated using the

E_1/E_2 formula, where E_1 represents the average percentage score of students' performances during learning activities and E_2 indicates the average percentage score from the posttest. The criterion for acceptable instructional effectiveness was set at 75/75. To examine the improvement in students' academic achievement, a dependent-samples t-test was conducted to compare the mean scores between the pretest and posttest. In addition, students' satisfaction with the learning experience was analyzed using descriptive statistics, including mean and standard deviation. The interpretation of satisfaction levels followed the scale: mean scores ranging from 4.50 to 5.00 were classified as very high, 3.50 to 4.49 as high, 2.50 to 3.49 as moderate, 1.50 to 2.49 as low, and 1.00 to 1.49 as very low.

4. Results

The effectiveness of the Brain-Based Learning (BBL) instructional plan was assessed using the E_1/E_2 formula, where E_1 refers to students' average performance during the learning process (formative assessment), and E_2 reflects their average posttest score (summative assessment). The analysis showed that students achieved an average process score (E_1) of 123.30 out of 144 (85.63), and a product score (E_2) of 24.61 out of 30 (82.03%). Therefore, the effectiveness of learning management can be expressed as E_1/E_2 = 85.63/82.03, which exceeds the minimum threshold of 75/75. These results indicate that the brain-based learning instructional plan was highly effective in both facilitating learning engagement and improving academic outcomes (Table 2).

Table 2: The effectiveness of the learning management

Effectiveness	Fullmark	M	SD	%
Process (E_1)	144	123.30	5.82	85.63
Product (E_2)	30	24.61	2.68	82.03

The effectiveness of learning management (E_1/E_2) = 85.63/82.03

A Shapiro-Wilk test is conducted to determine whether the differences in achievement between the pretest and Posttest could have been produced by a normal distribution (Razali and Wah, 2011). The Shapiro-Wilk test indicates no significant abnormality in data distribution (Table 3).

Table 3: Normality of data (Shapiro-Wilk)

Achievement	W	P
Posttest - pretest	0.958	0.424

A low p-value suggests a violation of the assumption of normality

To examine the effect of the BBL instructional approach on students' academic achievement, a paired-samples *t*-test was conducted to compare pretest and posttest scores. The analysis revealed a statistically significant increase in posttest scores (M = 24.61, SD = 2.68) compared with pretest scores (M = 5.61, SD = 2.35), $t(22) = 24.43$, $p < 0.001$. The calculated effect size was very large ($d = 5.09$), suggesting that the Brain-Based Learning intervention was associated with a substantial improvement in students' academic achievement (Cohen, 1988). This result indicates that the BBL approach led to a substantial improvement in students' understanding of exponents (Table 4).

Table 4: The comparison between participants' learning achievement before and after using BBL learning management

Test	N	M	SD	Mean difference	t-test	p	Effect size
Pretest	23	5.61	2.35	19.00	24.43	0.00*	5.09
Posttest	23	24.61	2.68				

*: p < 0.05

The overall satisfaction with the Brain-Based Learning (BBL) instructional plan was rated at a very high level, with a mean score of 4.53 (SD = 0.64). This indicates that students responded positively to the learning approach implemented throughout the study. Considering each item of evaluation, it could be assumed that the BBL instructional approach created a supportive, interactive, and learner-centered environment that was well-received by the participants (Table 5).

Table 5: Participants' satisfaction with the BBL instructional plan

No.	Items	M	SD	Level of satisfaction
1	The activities were sequential and systematically organized.	4.57	0.65	Very high
2	The implemented activities helped students understand the content more easily.	4.70	0.55	Very high
3	Students felt enjoyment from engaging in hands-on activities.	4.65	0.56	Very high
4	Students were able to apply the acquired knowledge to real-life situations.	4.43	0.58	High
5	Students were able to solve mathematical problems.	4.35	0.70	High
6	Students were able to engage in discussion and summarize the content after learning.	4.30	0.69	High
7	Students enjoyed working collaboratively with their classmates.	4.57	0.65	Very high
8	The teacher allocated appropriate time for completing the skill exercises.	4.61	0.57	Very high
9	Students were able to complete the skill exercises independently.	4.52	0.65	Very high
10	The instructional materials used were clear and engaging.	4.61	0.64	Very high
	Overall	4.53	0.64	Very high

Classroom observations indicated that students became increasingly engaged and confident throughout the implementation of the Brain-Based Learning (BBL) activities. During the initial lessons, several students relied heavily on teacher guidance when interpreting exponential expressions and solving word problems. However, as the lessons progressed, students demonstrated greater independence in completing tasks and explaining their mathematical reasoning.

Observational records showed that students actively participated in discussions, exchanged ideas with peers, and used multiple solution strategies to solve exponent-related problems. During group

activities, students frequently explained exponent rules to classmates and collaboratively verified answers before submitting their work. Such interactions suggested that students were not merely memorizing procedures but were constructing understanding through social learning and active engagement.

Analysis of student worksheets further supported these observations. Students were able to organize calculations systematically, apply exponent rules correctly, and solve contextualized problems involving scientific notation, volume, and large numerical quantities. Several students demonstrated the ability to connect symbolic representations with real-world situations, indicating conceptual understanding beyond procedural computation.

In addition, students appeared enthusiastic when learning activities incorporated visual stimuli, real-life examples, and hands-on exercises. The classroom atmosphere became increasingly interactive, with students showing willingness to ask questions, share ideas, and participate in problem-solving activities. These observations suggest that the BBL approach promoted active learning behaviors and supported the development of both conceptual understanding and mathematical reasoning in the topic of exponents.

5. Discussion

The results of this study provide compelling evidence for the effectiveness of Brain-Based Learning (BBL) in enhancing Grade 7 students' understanding of exponents. The high E_1/E_2 score (85.63/82.03), statistically significant improvement from pretest to posttest, and very high student satisfaction ratings all point to the instructional model's success. These findings align with prior research indicating that BBL was beneficial for both academic achievement and learner engagement in mathematics education (Amjad et al., 2022; Amjad and Tabbasam, 2024; Effendi and Marlina, 2021; Fitri and Zaeni, 2020; Kaewkumsai and Phusee-orn, 2024; Saputra et al., 2024; Thonsakul and Poonputta, 2023).

At the core of this effectiveness lies the neuroscience-based structure of BBL, which is particularly well-suited to abstract topics such as exponents. Exponents require students to move beyond counting or arithmetic into multiplicative reasoning, pattern generalization, and symbolic representation. These cognitive processes involve working memory, abstract pattern recognition, and symbolic manipulation—all of which are supported by BBL strategies such as repetition with variation, emotional engagement, visualization, and contextualization (Jensen and McConchie, 2020; Rodgers and Hales, 2021; Tang, 2017).

The structured five-phase lesson format—engage, present, practice, summarize, and transfer—allowed students to activate prior knowledge, process new content incrementally, and apply concepts to real-world contexts. For instance, solving word problems involving moon distance or water flow through scientific notation helped situate learning in emotionally and visually meaningful frames. These types of stimuli are known to increase retention and promote deeper encoding in long-term memory (Jensen and McConchie, 2020).

Qualitative observations further reinforced the quantitative data. Students demonstrated the ability to decompose problems, apply exponent rules accurately, and express reasoning in multiple forms. In one example, students successfully calculated large quantities using exponential notation, explained their thought process, and transferred that learning to solve contextual problems involving volume or time-based rates. This suggests that BBL supports rote skill development and encourages conceptual transfer and higher-order thinking, consistent with constructivist principles of mathematics education (Rahmawati et al., 2024).

Student satisfaction ratings also underscored the holistic impact of BBL. Learners reported enjoyment from hands-on tasks, clarity in instructional materials, and positive experiences with peer collaboration. These factors contribute to a supportive and emotionally safe learning environment, which neuroscience research identifies as essential for cognitive flexibility and risk-taking in problem solving (Amjad et al., 2023; Sani et al., 2019).

In sum, BBL worked effectively in the context of teaching exponents because it provided a brain-compatible pathway for abstract concept formation. Through multisensory input, structured scaffolding, and emotionally engaging tasks, students were able to move from concrete examples to symbolic reasoning. The findings reinforce the value of BBL for teaching mathematical concepts and suggest that it may be particularly useful in middle school contexts where students are developing formal operational thinking.

Future studies could expand on this work by exploring long-term retention of exponent concepts, examining BBL's effectiveness in other mathematical domains (e.g., algebra or geometry), or investigating differentiated strategies for diverse learner profiles. Additionally, incorporating teacher reflection and classroom video data may further illuminate how BBL strategies can be adapted across instructional contexts.

6. Conclusion

This study aimed to investigate the effectiveness of Brain-Based Learning (BBL) in enhancing Grade 7 students' academic achievement in the topic of exponents. The findings revealed that the BBL instructional plan exceeded the 75/75 effectiveness criterion, with students demonstrating statistically significant gains in posttest performance and expressing very high satisfaction. Qualitative observations demonstrate that students were actively engaged in problem solving and conceptual understanding, especially when learning tasks were

embedded in real-world contexts. The contribution of this study lies in its demonstration of how BBL, grounded in neuroscience, can be effectively applied to teach abstract mathematical concepts such as exponents. Structuring lessons around cognitive and emotional principles, such as active engagement, visualization, and pattern recognition, is how BBL offers a brain-compatible approach that supports both conceptual understanding and motivation in early secondary school mathematics.

Despite these promising findings, several limitations should be acknowledged. The study employed a one-group pretest-posttest design and involved a relatively small sample drawn from a single classroom, which may limit the generalizability of the findings and the extent to which the observed improvements can be attributed solely to the intervention. In addition, the study focused on immediate learning outcomes and did not examine the long-term retention of exponent concepts. Although classroom observations and student work samples were incorporated to provide qualitative support for the findings, richer qualitative data could further enhance understanding of students' learning experiences. Future research should therefore employ experimental or quasi-experimental designs with comparison groups, involve larger and more diverse samples, incorporate delayed posttests, and explore students' learning processes through more extensive qualitative investigation.

List of abbreviations

BBL	Brain-based learning
D	Discrimination index of open-ended items
d	Cohen's d effect size
E1	Effectiveness of the learning process
E2	Effectiveness of the learning product
IOC	Item-objective congruence
M	Mean
N	Number of participants (sample size)
SD	Standard deviation
t	t-test statistic
W	Shapiro–Wilk test statistic
α	Cronbach's alpha reliability coefficient

Acknowledgment

This research project was financially supported by Mahasarakham University (ID: 680012389). The authors gratefully acknowledge Mahasarakham University, the experts, instructors, and students who contributed.

Compliance with ethical standards

Ethical considerations

This study involved human participants and was conducted in accordance with ethical principles for research involving human subjects. Permission to conduct the study was obtained from the school administration prior to data collection. Students were informed of the purpose and procedures of the study, and participation was voluntary. All collected information was treated confidentially and used solely for research purposes. The confidentiality and anonymity of all participants were strictly protected throughout the research process. The collected data were used solely for academic and research purposes. No personally identifiable information was disclosed in the reporting of the findings.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Amjad AI and Tabbasam U (2024). Effect of brain-based learning on students' extrinsic motivation to learn mathematics: Introducing neuroscience to schools. Journal of Sustainable Education, 1(1): 14-21.

Amjad AI, Habib M, Tabbasam U, Alvi GF, Taseer NA, and Noreen I (2023). The impact of brain-based learning on students' intrinsic motivation to learn and perform in mathematics: A neuroscientific study in school psychology. International Electronic Journal of Elementary Education, 16(1): 111-122. https://doi.org/10.26822/iejee.2023.318

Amjad AI, Tabbasam U, and Abbas N (2022). The effect of brain-based learning on students' self-efficacy to learn and perform mathematics: Implication of neuroscience into school psychology. Pakistan Languages and Humanities Review, 6(3): 683–695. https://doi.org/10.47205/plhr.2022(6-III)60

Cohen J (1988). Statistical power analysis for the behavioral sciences. 2nd Edition, Lawrence Erlbaum Associates, Hillsdale, USA.

Effendi KNS and Marlina R (2021). The effect of motivation towards mathematical communication in mathematics learning with brain-based learning model. AKSIOMA: Jurnal Program Studi Pendidikan Matematika, 10(2): 808-819. https://doi.org/10.24127/ajpm.v10i2.3488

Fitri A and Zaeni A (2020). The effect of application of the brain-based learning (BBL) approach on the connection ability of students. EduMa: Mathematics Education Learning and Teaching, 9(2): 66-78. https://doi.org/10.24235/eduma.v9i2.7373

Golding J (2018). Mathematics education in the spotlight: Its purpose and some implications. London Review of Education, 16(3): 460-473. https://doi.org/10.18546/LRE.16.3.08

Jensen E and McConchie L (2020). Brain-based learning: Teaching the way students really learn. Third Edition, SAGE Publications, Thousand Oaks, USA.

Kaewkumsai K and Phusee-orn S (2024). Developing achievement in mathematics, specifically in elementary logic, through brain-based learning (BBL) combined with skill practice exercises for grade 10 students. Higher Education Studies, 14(2): 130-136. https://doi.org/10.5539/hes.v14n2p130

Karagiannakis G, Baccaglini-Frank A, and Papadatos Y (2014). Mathematical learning difficulties subtypes classification. Frontiers in Human Neuroscience, 8: 57. https://doi.org/10.3389/fnhum.2014.00057 **PMid:24574997 PMCid:PMC3918643**

Ragusa G, Huang S, and Levonisova S (2024). Middle school mathematics achievement: Effects of Math teacher professional development. International Journal of Teacher Education and Professional Development, 7(1): 1-37. https://doi.org/10.4018/IJTEPD.337965

Rahmawati Y, Madlazim M, and Sudibyo E (2024). The role of brain-based learning in training students' critical thinking skills. IJORER: International Journal of Recent Educational Research, 5(2): 443-455. https://doi.org/10.46245/ijorer.v5i2.578

Razali NM and Wah YB (2011). Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. Journal of Statistical Modeling and Analytics, 2(1): 21-33.

Rodgers DL and Hales RL (2021). Brain-based learning. In: Johnston LC and Su L (Eds.), Comprehensive healthcare simulation: ECMO simulation: A theoretical and practical guide: 43–50. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-030-53844-6_5 **PMid:33833071**

Sani A, Rochintaniawati D, and Winarno N (2019). Enhancing students' motivation through brain-based learning. Journal of Physics: Conference Series, 1157(2): 022059. https://doi.org/10.1088/1742-6596/1157/2/022059

Saputra W, Andriani S, and Dewi NR (2024). The effect of video-assisted brain-based learning model on mathematical critical thinking and mathematical problem solving skills. AlphaMath: Journal of Mathematics Education, 10(2): 205–220. https://doi.org/10.30595/alphamath.v10i2.22115

Tang YY (2017). Brain-based learning and education: Principles and practice. Academic Press, San Diego, USA.

Thonsakul S and Poonputta A (2023). Development of grade 11 student learning achievements on quadratic functions using brain-based learning (BBL) management. Journal of Education and Learning, 12(1): 125-131. https://doi.org/10.5539/jel.v12n1p125