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Effectiveness of Brain-Based Learning Toward Improving Students' Conceptual Understanding: A Meta-Analysis

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This study explores the effectiveness of brain-based learning (BBL) as a pedagogical approach to address the challenges of poor conceptual understanding, which may have worsened due to the COVID-19 pandemic aftermath. In this meta-analysis, 14 studies qualified using the Publish or Perish software and the Preferred Reporting Items for Systematic Reviews and Meta-analyses. Statistical analysis conducted using Comprehensive Meta-Analysis (CMA) Version 4 software by Biostat, Inc. Based on the results, the overall effect size (ES = 3.135) indicates that the use and integration of BBL principles and strategies have a significantly large and positive effect on student conceptual understanding. The moderator analysis revealed a significant difference between individual studies ($p < .001$); however, the overall results for academic level ($p > .05$) and discipline ($p > .05$) revealed no significant differences. Hence, each study included in this analysis may differ from one another due to the differences in various BBL strategies implemented; however, when grouped, they shared common effect sizes. With these findings, the researchers advocate the use of BBL principles and strategies to improve students' conceptual understanding at various levels in basic education, be it in English and STEM. Moreover, empirical studies focusing on a particular BBL variable, such as health and nutrition, are recommended for in-depth analysis and discussion.

Keywords: brain, brain-based pedagogy, education, learning poverty, reading comprehension, meta-analysis

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INTRODUCTION

Low- and middle-income countries in East Asia, the Pacific, and South Asia, including the Philippines, are more at risk of learning poverty, which was worsened by the COVID-19 pandemic (Azevedo, 2020). Learning poverty, as defined by World Bank (2019), is the inability to read and comprehend a basic text by the age of ten. It is a critical issue, as it hinders students' ability to comprehend and apply knowledge in different academic disciplines, including conceptual understanding. Hence, the Organization for Economic Cooperation and Development (OECD), in their study, found that Filipino students have low knowledge and comprehension of science topics (OECD, 2019). Their ability to apply scientific information to various real-life events, including unfamiliar ones, is limited (Mullis et al., 2020). Their limited capacity had placed them bottom in both science and mathematics in the 2018 and 2019 Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) exams (OECD, 2019). Much more so, Filipino students' knowledge and comprehension abilities may have deteriorated as a result of the COVID-19 pandemic's aftermath.

The relationship between learning poverty and good health is significant. Research has shown that poor nutrition can lead to cognitive impairment, which can negatively impact academic performance, particularly in reading, writing, and math (Jomaa et al., 2020). Conversely, good nutrition can enhance cognitive development and academic achievement (Black et al., 2013). Moreover, good nutrition and health have been found to be associated with psychological well-being and positive academic performance, while poor nutrition may hinder students' ability to reach their full intellectual capacity (Schmunck, 2010). Malnutrition in children has long-term adverse effects on their verbal, reading, spatial, and full-scale cognitive abilities (the combination of verbal and spatial information indicators) as they grow old; hence, addressing malnutrition at a younger age is significant (Liu et al., 2003). Cristuta et al. (2019) highlighted in their study that students who lack sufficient nourishment may be distracted in class and have poor concentration, suggesting that monitoring their eating habits may alter their nutrition, which in turn may positively influence their academic performance. Similarly, Cotman et al. (2007) underscored that good health is vital for better brain functioning, learning, and memory. These previous findings show how good nutrition and health are important variables to consider in honing the capacity and functioning of the brain vis-à-vis the students' academic performance, which in turn would eventually address learning poverty.

To address the challenges of learning poverty and poor conceptual understanding, with an emphasis on promoting good health, the present researchers embarked on an investigation into a pedagogical approach, beginning with an exploration of the effectiveness of brain-based learning (BBL). BBL is among the pedagogies that consider students' health and nutrition as important variables for optimal functioning of the brain and improving students' academic performance. Jensen (2000) described BBL as learning the way the brain is naturally built to learn. Proponents of BBL argue that this approach can lead to improved health outcomes for students. For example, it has

been suggested that brain-based teaching strategies can help students develop greater self-awareness, which can lead to better mental health (Jensen, 2008). Additionally, brain-based learning techniques can help reduce stress and anxiety in the classroom, which can have positive effects on both mental and physical health (Zull, 2002).

Cercone (2006) proposed various strategies for BBL that considers several principles and theories such as a paradigm shift toward constructivism. Likewise, the 12 BBL principles of Caine and Caine (2000) are a classic framework that helps teachers integrate BBL into their lessons. It is composed of the following principles: all learning engages the physiology, the brain/mind is social, the search for meaning is innate, the search for meaning occurs, emotions are critical to patterning, the brain/mind processes parts, learning involves both focused, learning is both conscious and unconscious, there are at least two approaches to memory, learning is developmental, complex learning is enhanced by and/or fatigue, and each brain is uniquely organized.

In addition, BBL tackles the concept of brain functioning along health that considers explanations from cognitive neurology. Cognitive neurology emphasized the significance of understanding the nature of neural networks in the brain, the information-gathering process, and the functions and activities of different brain regions to gain insight into how students learn and maximize their learning (Bellah et al., 2008; Brandoni, 2007; de Jong et al. 2009; Morris, 2010; Richardson, 2011; Taylor & Lamoreaux, 2008). Studies suggest that brain functions such as synaptic plasticity can be strengthened through good nutrition and exercise leading to enhanced memory and learning (Cotman et al., 2007; Cristuta et al., 2019). In this regard, monitoring students' nutrition and activities is a vital factor to ensure that students achieve their maximum learning potential. In this study, however, the present researchers investigated more of the critical variables involved in BBL implementation, particularly how BBL research are being conducted in the field of education.

Accordingly, this study aims to provide a systematic review of empirical research and valuable information on the effectiveness of BBL on students' conceptual understanding. BBL is a rapidly evolving field that has significant implications for educators, learners, and researchers. Advances in technology and cognitive neuroscience have led to new findings that can improve the effectiveness of educational practices. By staying up to date with the latest research on BBL, educators can make informed decisions about instructional methods and strategies to optimize learning outcomes. Learners can also benefit from this information by gaining insights into how they can improve their own learning strategies. Additionally, researchers can use the latest findings to develop and test new theories, which can help advance the field of BBL. Specifically, the researchers answered the following questions:

1. What is the effectiveness of BBL in improving students' conceptual understanding?
2. Is there a significant difference between the effect sizes of various grade levels concerning their conceptual understanding?
3. Is there a significant difference between the effect sizes of students' level of understanding concerning various academic courses?
4. What were the BBL strategies that were explored?

METHOD

Research Design

The researchers used a meta-analysis of the obtained studies to determine the effectiveness of BBL, as a pedagogy, on the level of students conceptual understanding. Through meta-analysis, the researchers systematically synthesized the quantitative findings from previous research studies based on the objectives of the present research and the data available (Borenstein et al., 2021).

Study Search Procedure

Initially, the researchers set the inclusion and exclusion criteria. Based on the set criteria, the researchers explored peer-reviewed research studies using the Publish or Perish software (Harzing, 2007), focusing on the following search engines: Google Scholar, Education Resources Information Center (ERIC), and Journal Storage (JSTOR). The search was purposely limited from 2008 to 2022.

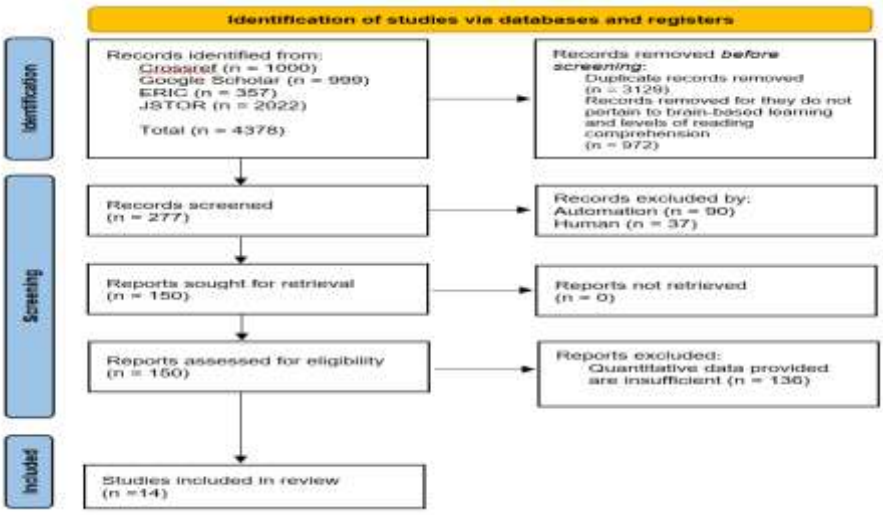

Figure 1
PRISMA search strategy results on the effectiveness of BBL toward students' reading comprehension.

The descriptors entered are relevant to BBL; specifically, "brain-based learning," "brain-based pedagogy," and "brain-based strategies." These words were entered on the search bar with and without the hyphen so that both studies that included and excluded the hyphen for the word "brain-based" were obtained. Further, the researchers used Boolean operators "AND" and "OR" with the words, "comprehension," "conceptual understanding," and "learning poverty." The collected studies were reduced based on the inclusion and exclusion criteria following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) search strategy of 2020 (Figure 1).

Inclusion and Exclusion Criteria

The researchers examined relevant studies that employed quantitative research design within 15 years from 2008 to 2022. Specifically, the following inclusion criteria were established: (a) must be published in a peer-reviewed journal from 2008 to 2022; (b) must include an explicit reference to brain-based learning; (c) must use a level of conceptual understanding or academic performance as dependent variables; (d) must be in the basic education level; (e) must utilize quasi-experimental or pre-experimental design with pretest and posttest results; and (f) must provide sufficient quantitative data, such as sample size, mean, and standard deviation, to allow effect size computations. The researchers filtered the obtained articles with the given inclusion criteria following the PRISMA search strategy diagram in Figure 1.

Coding Procedures

Research studies from qualified peer-reviewed journals were coded as follows: (a) study identification (author's last name, year of publication, and country of publication); (b) databases; (c) grade level of the participants; (d) focused discipline; (e) instrument used; and (f) outcome measure characteristics (sample size, mean, and standard deviation).

Effect Size Calculation

The researchers used Hedges *g* to calculate the effect size of the obtained data. According to Glen (2016) and Hedges and Olkin (1985), Hedges *g* is more reliable than Cohen's *d* when the sample size is less than 20 (Glen, 2016; Hedges & Olkin, 1985). The researchers interpreted the data as large, medium, and small using the values .8, .5, and .2, respectively (Cohen, 1988). Comprehensive Meta-Analysis software (CMA) Version 4 (Borenstein et al., 2014) compared effect sizes, generated forest plot, and determined heterogeneity and publication bias. To better illustrate the calculation of the effect size and identification of publication bias, the researchers adopted the process in the study of Funa and Prudente (2021) and Ramallosa et al. (2022) (Figure 2).

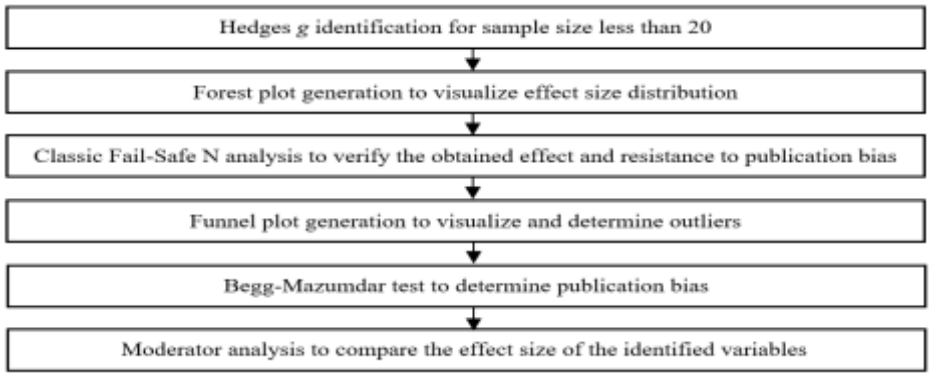

Figure 2
Data analysis procedure on the effect size calculation and publication bias identification adopted from Funa and Prudente (2021) and Ramallosa et al. (2022).

FINDINGS

As shown in Figure 1, there are 14 empirical research studies qualified in this meta-analysis. These studies were composed of participants from elementary (n = 120), junior high school (JHS) (n = 245), and senior high school (SHS) (n = 77), totaling a sample size of 442. Table 1 presents the number of qualified research in relation to grade levels and disciplines studied.

Table 1
Number of qualified studies concerning grade levels and disciplines

	Frequency (*f*)	Percentage (%)
Level		
Elementary	4	28.57
Junior High School (JHS)	8	57.15
Senior High School (SHS)	2	14.28
Discipline		
English language	8	57.14
STEM-related	6	42.86

Table 1 shows that BBL as a pedagogy was used in basic education levels from elementary to SHS. In addition, BBL as a pedagogy to enhance students' conceptual understanding was used in the English language as well as STEM-related subjects, including Biology, Chemistry, Physics, Math, and Technology. These results show that studies on BBL used this pedagogy in a wide variety of students and courses. Table 2 depicts the overall effect size of BBL on students' conceptual understanding based on the results of the qualified studies.

Table 2
Overall effect size

					95% CI				Heterogeneity			
	k	ES	SE	Variance	Lower	Upper	*Z*	*p*	Q	df (Q)	*p*	I^2
Fixed	14	2.403	.093	.009	2.221	2.585	25.906	<.001	189.577	13	<.001	93.143
Random	14	3.135	.364	.132	2.422	3.849	8.617	<.001				

As shown in Table 2, the computed Q statistics (Q > df) and p-value (p < .001) show significant heterogeneity, indicating that the qualified studies included in this meta-analysis do not share common effect sizes; therefore, according to Borenstein et al. (2021), the random-effect method should be used to synthesize the studies. In addition, the overall weighted random effect size of 3.135 indicates that the use of BBL to enhance conceptual understanding has a significantly large and positive effect. In addition, the value of I^2 which is 93.143 indicates that moderator or subgroup analysis is worthwhile (Borenstein et al., 2021). To illustrate the distribution of effect sizes, the researcher generated a forest plot in Figure 3 alongside a comprehensive analysis of each meta-analyzed study, which provides context for the analysis.

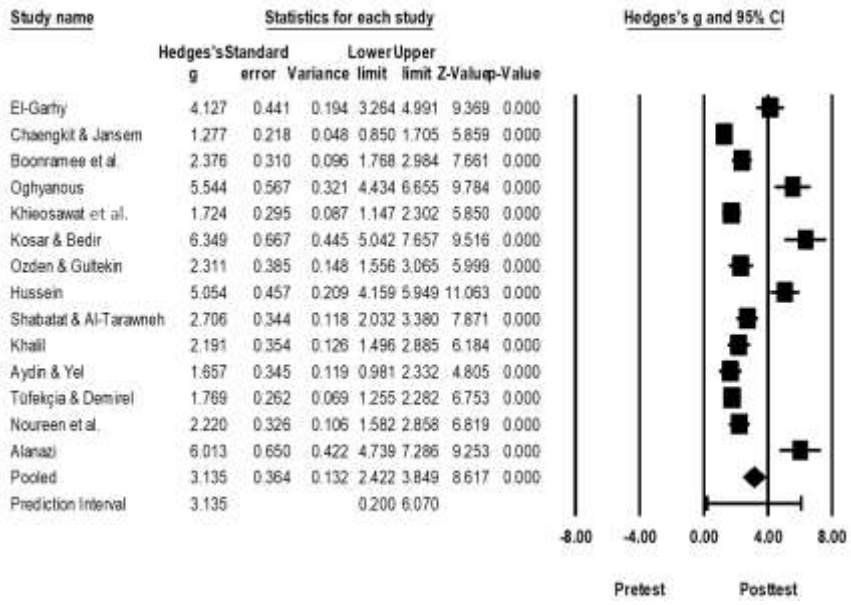

Figure 3
Forest plot of the studies on BBL included in the meta-analysis

Figure 3 shows that the overall distribution of the effect sizes favored the posttest over the pretest. This is expected because there was an intervention done. The researchers compared the pretest and posttest as studies on BBL from 2008 to 2022 that compare control and experimental groups are limited. The 95% prediction interval (random-effect model) shows a binary outcome with a lower limit of .200 and an upper limit of 6.070, which signifies that predicting the effect of BBL on students' comprehension may vary from small to large effect sizes. Figure 4 illustrates the distribution of true effects.

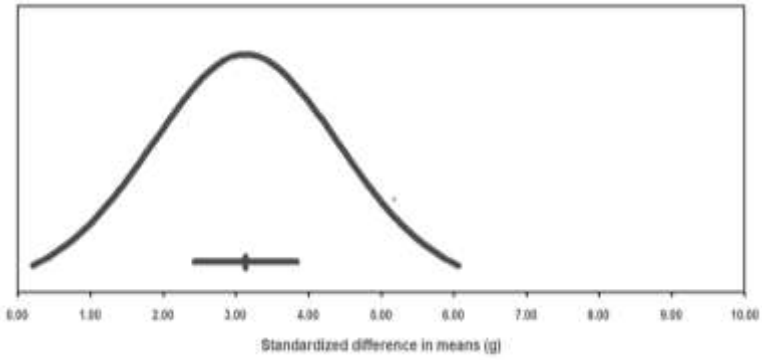

Figure 4
Distribution of mean effects and true effects

As shown in Figure 4, the mean effect size is 3.14 with a 95% confidence interval of 2.42 to 3.85 and the true effect size in 95% of all comparable populations falls in the interval .20 to 6.07. The researchers conducted the Classic Fail-Safe N analysis to validate the obtained effect sizes of BBL on students' conceptual understanding. Table 3 shows the results of the Classic Fail-Safe N analysis.

Table 3
Classic fail-safe N

The Resistance of the Meta-Analysis versus Publication Bias	
Z-value	28.539
p-value	<.001
Alpha value	.05
The alpha value for the Z-value	1.960
N	14
Number of missing studies that would bring *p*-value to > alpha	2955

The Classic Fail-Safe N results show that the 14 empirical studies are valid for meta-analysis and resistant to publication bias ($p < .001$). To invalidate the result of this meta-analysis, 2,955 more studies are needed. In addition, according to Harbord et al. (2009), the funnel plot is not a guaranteed test for publication bias, most especially for meta-analysis with small studies. In addition, based on Janhavi and Anwaya (2017), the Begg-Mazumdar test is fairly powerful for meta-analysis with more than or equal to 75 studies but has low power with less than 25 studies. In this regard, the researchers considered the results of Classic Fail-Safe N and move directly to the moderator analysis to determine the significant difference in effect sizes between groups (grade levels and academic disciplines). Table 4 shows the results of the moderator analysis.

Table 4
The moderator analysis

Moderator Random Effects Model					95% CI				Heterogeneity*		
	k	ES	SE	Variance	Lower	Upper	*Z*	*p*	Q	df (Q)	*p*
Academic level	14	2.969	.344	.119	2.293	3.644	8.618	<.001	1.186	2	.553
Elementary	4	2.630	.467	.218	1.716	3.545	5.636	<.001			
JHS	8	3.355	.521	.271	2.334	4.376	6.441	<.001			
SHS	2	3.825	2.577	6.643	-1.226	8.877	1.484	.138			
Discipline	14	2.978	.348	.121	2.296	3.659	8.565	<.001	1.391	1	.238
English language	8	3.549	.596	.355	2.381	4.717	5.954	<.001			
STEM	6	2.683	.428	.183	1.844	3.522	6.269	<.001			

*Total between was provided under heterogeneity to determine the publication status variable's ability to adequately explain total variance.

Table 4 depicts the results of the moderator analysis to determine the significant difference in the effect sizes between the conceptual understanding of students based on their grade levels and the academic disciplines in which BBL was implemented. Academic levels from elementary to SHS obtained large and positive effect sizes on

improving students' conceptual understanding through BBL. BBL, as applied to SHS, had the largest effect size (*ES* = 3.825) among the other academic levels (elementary and JHS). Additionally, the heterogeneity results (Q < df; and $p > .05$) showed no significant difference demonstrating that the academic levels share common effect sizes. These results indicate that the effects of BBL on students' conceptual understanding do not vary according to educational level. Moreover, BBL as applied to academic disciplines (English language and STEM), had a large and positive effect on improving students' conceptual understanding. The results in Table 5 show that BBL used for the English language as an academic discipline had a larger effect size than STEM. The heterogeneity between these two disciplines ($p > .05$) showed no significant difference signifying that BBL as applied to the English language and STEM may share common effect sizes. These findings suggest that the academic level of students and the discipline wherein BBL was applied were not included among the factors that affect students' conceptual understanding; hence, BBL can be used for various academic levels, most especially in basic education from elementary to SHS level, and for disciplines in English language and STEM.

However, individual studies for elementary ($p < .001$) and JHS ($p < .001$), and academic disciplines in English ($p < .001$) and STEM ($p < .001$) revealed significant differences. These results could be associated with the differences among the various BBL strategies involved in each study. Table 5 shows the various BBL strategies used by studies involved in this meta-analysis.

Table 5
BBL strategies used by included studies in this meta-analysis

Authors	Year	BBL Strategies
Chaengkit & Jansem	2021	- Combination with direct reading and thinking activities - Use of question and answer, online game media, and mind-mapping techniques
Boonramee et al.	2020	- Use of scaffolding for a reading activity, question and answer, mind mapping, games, group discussion, and model making
Alanazi	2020	- 12 brain-based learning principles (Caine & Caine, 1994; 2000) - Making and affirming hypotheses, identifying rules, solving problems, and use of multiple choice questionnaire
Khieosawat et al.	2021	- Use of scaffolding activity, warm-up (stretching) - Presentation of information and content - Practice skills - Repeating concepts through various methods - Teach English after learning brain concepts - Application of knowledge in new situations
Khalil et al.	2019	- Implement cooperative learning (Think-Write Pair-Share and Team-Pair-Solo), brainstorming, reading aloud, discussion, graphic organizers (mind map and Venn diagram), role-play, humor, authentic material (videos, international newspaper), music, and movement activities
Koşar & Bedir	2018	- 12 brain-based learning principles (Caine & Caine, 1994; 2000)
El-Garhy	2017	- Orientation prior to the lesson - Integrating word walls, modeling, Reading-While-Listening techniques
Oghyanous	2017	- Relaxed alertness, Orchestrated immersion, and Active processing (Thomas & Swammy, 2014)
Noureen et al.	2017	- Brain-based learning principles 1, 2, 3, 4, 6, and 12 (Caine & Caine, 1994)
Hussein	2016	- Five stages brain-based teaching model (Preparation, Acquisition, Elaboration, Integration, Evaluation)
Shabatat & Al-Tarawneh	2016	- Use of concept charts (maps), note writing (taking notes), brainstorming, psychoeducational environment (joy, water drinking, collaborative learning, preparation, use of science and computer laboratories, and appropriate light and colors), and Know What Learn (KWL) strategies
Aydin & Yel	2011	- Use of the five-sectioned course plan: 1. Introduction (learning and teaching activities 2. Development (orchestrated immersion, relaxed alertness, and active processing activities) 3. Conclusion (emphasis on the subjects learned) 4. Evaluation (measurement and evaluation activities) 5. Practice and Assignment (learning diaries and activity assignments)
Tüfekçia & Demirel	2009	- Integration of concepts between lessons - Use of examples from students' experiences, resources from the press, the media, and the Internet - Give importance to motivation and students' individual opinions - Integration of activities to develop individual opinions based on BBL - Use of lesson instruments, devices, methods, and comfortable and multi-dimensional communication strategies - Provide and encourage student participation - Collaborative small groups for solving problems - Establish relations between real life and the subjects - Use of creative drama, writing papers, graphics, concept maps, and problem-solving activities
Ozden & Gultekin	2008	- Orchestrated immersion (PowerPoint presentation, cartoons, comic strips, documentary films, and pictures) - Relaxed alertness (working in groups, writing short stories and poems, drawing comic strips, designing projects, and identifying the field of expertise) - Active processing (simulations, group discussions, role plays, dramatization) - Use of classical music listening during the phase of relaxed alertness and active processing

As shown in Table 5, there are various combinations of strategies and techniques involved in implementing BBL. Among these various strategies and techniques are the use of graphic organizers such as concept maps and Venn diagrams, movement activities, music, and games. According to Boonramee et al. (2020), the most liked by the students among the BBL strategies was the integration of model-making activities, which pertains to creating models of their choice. The second is mind mapping, which refers to a summary or outline of the essence of a particular story that was read by students. In addition, most of the studies involved in this meta-analysis made use of the BBL principles established from the studies of Caine and Caine (1994; 2000) and Thomas and Swammy (2014).

DISCUSSION

This meta-analysis involving 442 students from various levels of basic education and academic disciplines demonstrated the effectiveness of BBL in fostering conceptual understanding among students. These results were determined statistically by analyzing 14 empirical studies from 2008 to 2022. The overall effect size of 3.135, as determined by the analysis, is interpreted as having a large and positive effect, establishing BBL as an effective pedagogy in English and STEM education for enhancing conceptual understanding. In addition, this meta-analysis provides a summary of the strategies and methods utilized by studies that implement BBL in basic education and academic disciplines such as English and STEM.

As studies comparing control and experimental groups from 2008 to 2022 are limited, this meta-analysis compared pretests and posttests; hence, the I^2 value indicates that a moderator analysis is warranted. The results of the moderator analysis show that the combined effect sizes of the studies conducted at the elementary, JHS, and SHS were 2.630 (large), 3.355 (large), and 3.825 (large), respectively. These findings suggest that BBL can be effectively utilized and implemented at a variety of educational levels, from elementary to secondary, as the effect sizes are comparable ($p > .05$). Likewise, the combined effect sizes of studies conducted in English and STEM were 3.549 (large) and 2.683 (large), respectively, with comparable effect sizes ($p > .05$). These results signify that BBL can be effectively used in teaching the English language and various STEM disciplines such as Biology, Chemistry, Physics, Math, and Technology.

Individual studies employ various BBL strategies, as determined by the analysis, wherein when compared obtained a significant different results in academic levels (elementary and JHS) and disciplines (English and STEM) ($p < .001$). In particular, the most prevalent are graphic organizers such as concept maps and Venn diagrams, movement activities, music, and games. According to Boonramee et al. (2020), the BBL activity that students enjoyed the most was the incorporation of model-making activities, which involved the creation of models of their choice. The second strategy is mind mapping, which refers to a summary or outline of the essence of a story that students have read. In addition, the majority of the studies included in this meta-analysis employed the BBL principles established by Caine and Caine (1994; 2000) and Thomas and Swammy (2014).

The findings that BBL strategies can have varying effects on academic levels and disciplines have several pedagogical implications. First, educators should consider the specific needs and characteristics of their students when selecting BBL strategies, as some strategies may be more effective than others for particular student groups or subject areas. For example, graphic organizers may be more effective for visual learners and STEM subjects, while movement activities and music may be more effective for kinesthetic learners and language learning. Second, educators should incorporate a variety of BBL strategies into their teaching to address different learning styles and preferences. This can help to engage and motivate students, as well as enhance their learning outcomes. For example, Boonramee et al. (2020) found that students enjoyed model-making activities and mind mapping, which could be incorporated into lessons to increase student engagement and interest in the lesson. Third, educators may use BBL strategies that are based on established principles, such as those developed by Caine and Caine (1994; 2000) and Thomas and Swammy (2014). These principles emphasize the importance of creating a positive learning environment, engaging students in active learning, and promoting critical thinking and problem-solving skills.

Only two studies were identified that considered the health and nutrition of students as part of BBL strategies (Khieosawat et al., 2021; Shabatat & Al-Tarawneh, 2016). On one hand, Khieosawat et al. (2021) examined the use of warm-up or stretching before and between lessons or activities. Exercise improves brain function and cognitive development, and may prevent the onset of neurodegeneration, although the underlying mechanisms remain unknown (Pinto & van Praag, 2022; Stillman et al., 2020). Shabatat and Al-Tarawneh (2016), on the other hand, consider drinking water to be a component of BBL strategies. 75% of brain mass is composed of water; therefore, dehydration may impair cognitive performance (Pivarnik & Palmer, 1994). However, gender, heat stress, and exercise may also affect cognitive performance in addition to the water level in the body (Zhang et al., 2018). In this regard, it is suggested that empirical studies on BBL that promote activities toward improving students' health and nutritional status for better brain functioning other than exercising and drinking water are imperative.

The findings suggest that while some BBL strategies, such as exercise and drinking water, can have a positive impact on students' health and cognitive performance, only a few studies have considered health and nutrition as part of BBL strategies. To fully leverage the potential benefits of BBL, it is suggested that more empirical studies on BBL should promote activities that improve students' health and nutritional status beyond exercise and water consumption. These activities could include nutrition education, sleep hygiene, stress reduction techniques, and other health-promoting interventions that can enhance cognitive function and academic achievement. Implementing these types of activities with other BBL strategies may have significant pedagogical implications for improving student well-being and academic success.

The study by Koşar and Bedir (2018), with the largest effect size of 6.349, utilized the 12 BBL principles of Caine and Caine (2000) as the foundation for their activities. However, the study's specific methodologies were not described in the paper. Similarly, the study with the second-largest effect size of 6.013 (Alanazi, 2020) utilized the 12

BBL principles of Caine and Caine (2020), specifying some of the specific activities used which include the following: making and confirming hypotheses, identifying rules, solving problems, and using multiple choice questionnaires. Alanazi (2020) utilized various instruments such as the Teacher's Guide, the Study Tool, and the Student Guide in addition to the BBL theory. The purpose of the Teacher's Guide was to enable teachers to recognize the fundamental principles of BBL theory and implement BBL methods when teaching science. The Study Tools consist of lesson plans and prelearning and postlearning examinations. The Student Guide aims to assist students in conceptualizing and exploring the lesson. It also includes health and safety protocols and a map of core activities that are consistent with the BBL theory. The use of teachers' guides and students' guides may have various positive effects on students' cognitive performance and motivation (Funa & Ricafort, 2019; Funa et al., 2021), most especially when used along with the BBL principles.

Teachers need to be knowledgeable and trained with the BBL principles and methods to implement them effectively. The use of guides and other support materials can be useful for teachers to teach with BBL. Another implication is that the use of specific activities aligned with BBL principles, such as making and confirming hypotheses, identifying rules, and solving problems, can be effective in promoting deeper learning. Alanazi (2020) utilized these activities in their study, and the results showed a significant effect size. Therefore, educators may want to consider using these types of activities in their own teaching to improve students' learning outcomes. By incorporating these strategies, educators can help students develop a deeper understanding of discipline-based concepts and improve their learning outcomes.

CONCLUSION AND RECOMMENDATIONS

In conclusion, this meta-analysis involving 14 research studies with 442 students from various levels of basic education and academic disciplines demonstrated that BBL is an effective pedagogy for enhancing conceptual understanding among students. The study's overall effect size of 3.135, as determined by the analysis, establishes BBL as an effective pedagogy in English and STEM education. This meta-analysis provides a summary of the strategies and methods utilized by studies that implement BBL in basic education and academic disciplines such as English and STEM. The study found that different BBL strategies have varying effects on academic levels and disciplines. The findings have several pedagogical implications, including the importance of selecting BBL strategies based on specific student needs, incorporating a variety of strategies to learning and teaching practices, and using principles established by previous research. Finally, the study suggests that more empirical research on BBL should promote activities that improve students' health and nutritional status beyond exercise and water consumption. In this way, researchers would be able to exclusively establish effects and profoundly discuss BBL strategies. Implementing these types of activities with other BBL strategies could have significant pedagogical implications for improving student well-being and academic success. Overall, the findings of this study support the use of BBL as an effective pedagogy for enhancing conceptual understanding and improving academic outcomes.

LIMITATIONS

The number of studies included in this meta-analysis may be deemed to be small. However, the results can be considered valid because the researchers selected the studies based on the predetermined inclusion and exclusion criteria and analyzed for selection bias using statistical methods. In addition, despite exhausting all available resources, the number of studies obtained for this meta-analysis is so small that statistical tools for publication bias may report false positive results. However, Harbord et al. (2009) concluded that a minimum of ten studies should be analyzed prior to using statistical tools to determine publication bias. Moreover, this study is limited to the results provided by the pooled studies that examined the efficacy of BBL in enhancing students' conceptual understanding. These studies employed a quasi-experimental or pre-experimental design and explicitly reported pretest and posttest results. With the use of pretest and posttest results, a positive effect size is anticipated because an intervention was implemented. As studies comparing control and experimental groups for BBL from 2008 to 2022 are limited, the researchers compared the pretests and posttests instead. Hence, the results and findings of this study is important that it may provide curriculum designers and researchers with useful information for future development and research.

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APPENDIX

List of included research studies on the effectiveness BBL toward students' learning and reading comprehension.

No.	Study identification							Outcome measures					
								Pretest			Posttest		
	Author/s	Year of publication	Country of publication	Databases	Grade level of participants	Focused discipline	Instrument used	sample size	mean	*sd*	sample size	mean	*sd*
1	Chaengkit & Jansem	2021	Thailand	Google Scholar	Grade 12	English Language	Directed Reading Thinking Activity (DR-TA) Brain-Based Learning activities	50	10.28	4.12	50	15.04	3.22
2	Boonramee et al.	2020	Thailand	Google Scholar	Grade 5	English language	lesson plans based on the concepts of scaffolding for reading activity and brain-based learning activities	35	13.11	3.11	35	25.80	6.79
3	Alanazi	2020	Saudi Arabia	ERIC	Grade 7	Chemistry	A 25-item multiple choice test Teacher's guide Study tools Student's guide	26	9.00	1.95	26	21.12	2.02
4	Khieosawat et al.	2019	Thailand	Google Scholar	Grade 6	English Language	Questionnaire on student satisfaction towards brain-based learning management (BBL) together with complementary learning strategies	31	7.58	3.40	31	13.32	3.17
5	Khalil	2019	Egypt	Google Scholar	Grade 8	English Language	Critical writing test	25	8.2	4.13	25	18	4.66
6	Koşar & Bedir	2018	Turkey	Google Scholar	SHS	English Language	Proficiency exam	27	43.23	2.34	27	77.98	7.26
7	El-Garhy	2017	Egypt	Google Scholar	Preparatory students	English Language	An EFL reading fluency skills checklist	32	29.28	7.08	32	58.88	7.09

							An EFL reading fluency test						
8	Oghyanous	2017	Iran	ERIC	JHS	English Language	Flyers Test Self-Efficacy Questionnaire for Children (SEQ-C)	30	58.17	4.41	30	81.37	3.83
9	Noureen et al.	2017	Pakistan	Google Scholar	Grade 7	Math	Academic achievement test	30	11.70	4.001	30	23.80	6.47
10	Hussein	2016	Egypt	Google Scholar	Grade 8	English Language	Critical reading test	40	12.15	4.19	40	29.38	2.29
11	Shabatat & Al-Tarawneh	2016	Jordan	Google Scholar	Grade 9	Chemistry	Teaching-learning program and the test of academic achievement	32	13.16	2.53	32	21.62	3.56
12	Aydin & Yel	2011	Turkey	Google Scholar	Grade 9	Biology	Achievement test	22	31.82	8.67	22	51.36	13.90
13	Tüfekçia & Demirel	2009	Turkey	Google Scholar	Grade 9	Technology	Basic level learning test	40	22	5.12	40	33.28	7.32
14	Ozden & Gultekin	2008	Turkey	Google Scholar	Grade 5	Physics	Achievement test of the unit movement and power	22	48.18	10.83	22	72.38	9.71