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Abstract

This meta-analysis examined 12 empirical studies, published from 2013 to 2023, to determine the effectiveness of DBL in enhancing scientific creativity. The sample size involved 1211 students. Based on the analysis using random-effect model, DBL has a positive and strong significant effect (ES=1.181) to scientific creativity. Moderator analysis uncovered significant difference in the effect sizes when clustered according to the academic level and geographic location, while the STEM discipline and the implementation period demonstrated otherwise. It is further revealed that engineering design (g=1.546) registered the largest effect size in comparison with design thinking (g=0.896) and STEAM design (g=0.696) models. Moreover, originality, elaboration, fluency, and flexibility are the most frequently used dimensions in assessing scientific creativity. In conclusion, the findings established the effectiveness of DBL in enhancing scientific creativity among STEM students. Hence, teachers must be equipped of the technical know-how of integrating design process in teaching STEM subjects.

Introduction

Creativity is an essential human capital in a society affected by technology automation. Creativity served as a one of the foundations of social and economic progress across nations (Sorgo, 2012). It is used as an input to economic productivity and provide support system for global competitiveness. Furthermore, creativity along with analytical thinking skills and flexibility are known as highly demanded skills in the year 2025 based on the Future of Jobs Report 2023 of World Economic Forum (Zahidi, 2020). This provided evidence that creativity, as a consistent top skill, is essential for future society that is information-based and technology driven (Schwab & Zahidi, 2020). This confronted the current educational system to reform the schooling to deliver quality education responsive to the new generation with high creativity to become globally competitive and meet the global standards (Daud et al., 2012).Scientific creativity is a context-specific form of creativity that involves novel, original, and adaptive ideas in natural and social science. It was first explained by J. P. Guilford (1956) as "divergent production," leading to multiple solutions to problems, rather than convergent production. Guilford emphasized the importance of envisioning multiple solutions and characterized creativity by sensitivity to problems, fluency, originality, analysis, synthesizing, and redefining things. Torrance (1965), noted for being the Father of Modern Creativity, defined creativity as the process of sensing problems or gaps in information, identifying difficulties, and seeking solutions through trial and error or forming hypotheses. These definitions align with the nature of the scientific process and have significantly influenced subsequent scholarly works on scientific creativity.

STEM education assumed a crucial role in the development of creativity among 21st century learners. It provides conducive avenue to nurture the creativity (Daud et al., 2012). Science subjects is a creativity-fostering learning environments that supports interaction among various factors including domain-specific knowledge, divergent thinking, imagination and visualization, and a social dimension (Cakir et al., 2019;Hadzigeorgiou et al, 2012; Ozturk & Susuz, 2023; Rocena & Joaquin, 2021). Furthermore, the innate characteristics of science allowing learners to receive various data and apply scientific process, in reference with its theoretical perspective, is aligned with the nature of creative process (Mukhopadhyay & Sen, 2013). In this setting, nurturing creativity in science education became a focal figure to the creativity researches in science learning domains. Conradty et al. (2020) elaborated that there are numerous science education curricula which goes beyond conventional learning goals, which gradually emphasize creativity in science classroom, placing creativity as a fundamental skill in the 21st century.

In view of this, design-based learning (DBL) emerged to be an effective instructional strategy to address the learning outcomes of the students in STEM-related fields such as in the science, mathematics, and engineering contexts. Design-based education is a more creative and innovative approach that leads towards better learning engagement and outcomes. It underscores the incorporation of design artefact into the classroom to encourage creativity and problem-solving skills and to support students with learning content acquisition engagement in real-life, and cross-curricular challenges (Fortus et al., 2004). DBL tasks have the potential to provide conducive learning contexts for students to demonstrate creativity (Hathcock et al., 2015). Designing an artefact, solution or system to address ill-defined problems actively engaged the students to meaningful learning and prompted students to employ a larger range of thinking. In this manner, the students' abilities are required to justify the designed artefact they built which unlocks their creative potentials and allows for application of learning to happen (Nelson, 1984). In summary, DBL is an effective method in cultivating the creativity of the learners as they engage, think, create, reflect, and evaluate during the design process.

DBL is a learning approach that requires students to use their conceptual and theoretical knowledge to develop an artefact, solution, product, system to address a real-life problem. DBL is inquiry-based in nature (Hathcock et al., 2015) and theoretically grounded on the integration of design thinking and design process in classroom (Zhang et al., 2020). The DBL further combines the crucial elements of project-based learning and problem-solving through the designed product of the students (Kim et al., 2015). DBL facilitate construction of students' scientific understanding and complex problem-solving skills by engaging the students in the design process. In fact, the design process is considered as the focal figure in the implementation of DBL which should be emphasized more than the culminating output produced (Fortus et al., 2004). This suggests that the meaningful experiences gained from the building process is essentially more vital than the actual product of the process. The innate multidisciplinary characteristics of DBL provides avenue for integrating design projects to curricular content. Design projects allow students to join their previous learning with real-world challenges and to create cross-curricular connections (Azizan & Shamsi, 2022).

In spite of the considerable effectiveness of DBL in fostering scientific creativity, there is a limited literature that systematically review the DBL as an educational approach in STEM instruction both at school and classroom level highlighting scientific creativity. In view of these, this paper aims to review the relevant scholarly literature that integrated DBL in STEM education at school and classroom level using a meta-analysis. The present study aims to provide a critical review based on empirical findings regarding the effectiveness of DBL in the teaching and learning of science in terms of improving the creativity of the students about science content. It further seeks to establish the potential of DBL as a pedagogical intervention and learning approach towards improved scientific creativity.

Research Questions

The following specific research questions are framed to guide the procedure of this study:

1. What is the effectiveness of DBL in enhancing the scientific creativity in STEM?
2. Is there a significant difference between the effect sizes of the studies according to the STEM discipline, academic level, implementation period, geographic location of the students exposed to DBL?
3. What are the DBL models and their respective effect sizes employed in the obtained studies?
4. What are the dimensions of scientific creativity examined in the obtained studies?

Method

Research Design

This study employed a meta-analysis method as research design. Meta-analysis aimed to re-analyze, synthesize, and interpret results across similar studies, which are not related to each other in a specific subject or field, given a certain set of criteria (Hedges & Olkin, 1985; Higgins & Green, 2011). The present study adapted the protocols based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) in conducting systematic review.

Data Gathering Procedure

The present meta-analysis included journal articles that were written in English language published from 2013 to 2023. The eligible articles are empirical studies that investigated the quantitative impact of DBL to improve students' scientific creativity in STEM education. The article may not have an explicit reference to DBL in its title or abstract as long as DBL formed part on the theoretical framework of the study. Likewise, the dependent variables set in the selected studies must be scientific creativity. In terms of research designs, only studies that incorporated true- or quasi-experiment method were considered. In addition, the journal articles considered for review contained the sufficient statistical information such as standard deviations, posttest mean values, and the sample sizes. For the exclusion criteria, journal articles that are not situated in the context of STEM education were not considered. Likewise, articles which employed non-experimental and qualitative research were also removed from the review.

The information sources of this study included the ProQuest Central, EBSCO, Google Scholar, and ERIC databases. The search strategy was conducted using the Animo search engine, the official one-stop search for all resources of De La Salle University, Manila, to obtain relevant articles from the identified databases. To initiate search, the following keywords were used singly and in combination: "design process", "design-based learning", "design-based", "creativity", "creative thinking" and "scientific creativity". Figure 1 shows the PRISMA flowchart.

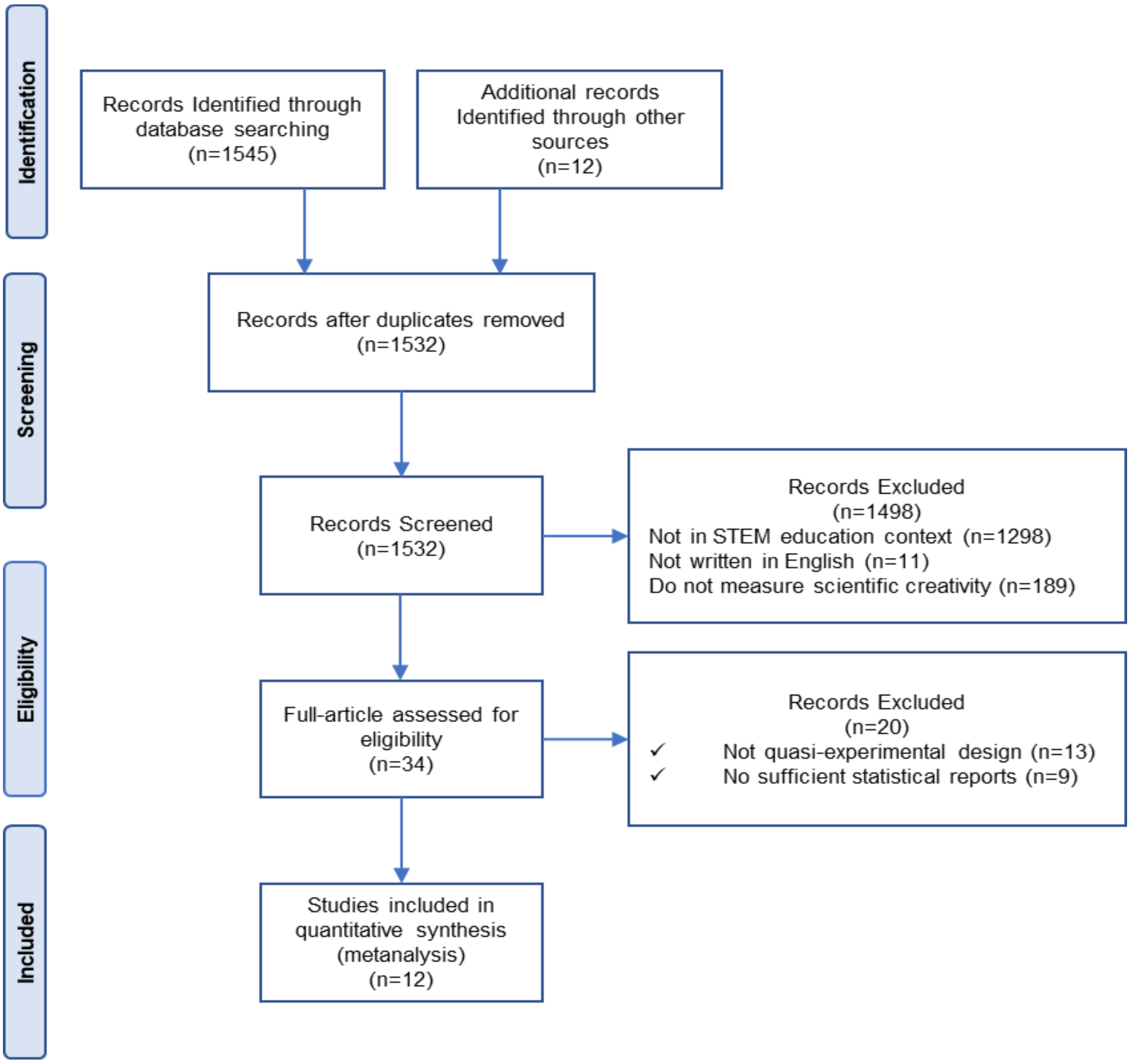

Figure 1. PRISMA Flowchart of the Study

Data Analysis

The statistical analysis was initiated through Comprehensive Meta-analysis Software version 3. The effect sizes of the collected data were computed using Hedge's g, as it provides the size of standardized difference (Williams et al., 2013) between outcomes from experimental and conventional groups (Cooper & Hedges, 1994). It is a more accurate than Cohen's d, correcting bias in small sample studies without affecting larger samples. Moderator analysis was also administered to determine the significant difference in the effectiveness of DBL on scientific creativity providing information about effect sizes (fixed and random), heterogeneity, and forest plots. To interpret the Hedge's g, Cohen (1998) provided the following interpretation guide: small effect ($g \leq 0.2$); medium effect ($0.2 < g \leq 0.5$); and large effect ($g > 0.5$).

Results

This meta-analysis utilized 12 qualified studies that involved a total sample size of 1211 students who were introduced to DBL and non-DBL approaches. The characteristics of the studies examined such as the design-based learning model employed, STEM discipline, academic level, implementation period, country of origin, type of scientific creativity measure, and the designed product were coded. Table 1 shows the frequency and percentage in terms of the moderating variables considered in this study.

Table 1. Distribution according to Moderating Variables of the Study

Moderating Variable	Frequency (k=12)	Percentage
STEM Discipline		0.00
Engineering	2	16.67
Physics	3	25.00
Science	5	41.67
STEM	2	16.67
Academic Level		
Primary	4	33.33
Secondary	4	33.33
Tertiary	4	33.33
Implementation Period		
4-8 Weeks	4	33.33
9-12 Weeks	3	25.00
13-16 Weeks	2	16.67
17-20 Weeks	3	25.00
Geographic Location		
East Asia	3	25.00
South Asia	1	8.33
Southeast Asia	4	33.33
West Asia	4	33.33

Table 1 revealed that DBL is widely employed in teaching scientific creativity in General Science (41.67%) and Physics (25%) followed by Engineering (16.67%) and Pre-school STEM (16.67%). In terms of academic level, the studies are conducted equally across levels with four studies implemented in each level. Moreover, the implementation period of DBL across studies revealed that most of the studies range from 4 to 8 weeks (33.33%) of time interval, followed by 9 to 12 (25%) and 17 to 20 weeks (25%), while the remaining studies were implemented on the duration of 13 to 16 weeks (16.67%). The included studies were all conducted in the continent of Asia. In fact, majority of the studies were implemented in Southeast Asia (33.33%) and West Asia (33.33%). Three of the studies are executed in East Asia (25%) while the remaining one study was done in South Asia (8.33%).

Table 2. Overall Effect Size of DBL in Enhancing Scientific Creativity in STEM

Model	Effect Size in 95% Confidence Interval						Z	p	Heterogeneity			
	k	ES	SE	σ^2	LL	UL			Q	df(Q)	P	I^2
Fixed	12	0.928	0.062	0.004	0.806	1.049	14.953	0.000	110.747	11	0.000	90.067
Random	12	1.181	0.212	0.045	0.765	1.596	5.571	0.000				

Table 2 provides the overall effect size of DBL in enhancing scientific creativity. Based from the heterogeneity analysis, the computed Q-value was found to be 110.747 with 11 degrees of freedom and $p < 0.001$. Using a criterion alpha of 0.100, the null hypothesis stating that the true effect size is the same in all these studies was rejected. This indicates that the distribution of the effect sizes is significantly heterogeneous, suggesting that the appropriate method to synthesize the studies in this meta-analysis is the random-effect method (Borrenstein et al., 2009).

Using the random-effects model, the overall weighted random mean effect size for the studies was computed to be 1.181 with a 95% confidence interval ranging from 0.765 (lower limit) to 1.596 (upper limit). This shows that DBL demonstrates a large effect size and positive impact (Cohen, 1988) in enhancing the scientific creativity of the students. Thus, DBL can be considered as an effective instructional intervention towards improved creative thinking skills of STEM students. Furthermore, since the I2 statistic is 90%, which suggests that some 90% of the variance in observed effects reflects variance in true effects rather than sampling error, a moderation and subgroup analysis can be initiated (Borrenstein, 2020).

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Erol et al. (2022)	1.936	0.292	0.085	1.364	2.507	6.637	0.000
Hsiao et al. (2022)	0.307	0.105	0.011	0.100	0.513	2.912	0.004
Kuo et al. (2022)	1.733	0.363	0.132	1.021	2.445	4.772	0.000
Chang et al. (2022)	0.912	0.320	0.102	0.285	1.539	2.850	0.004
Ayaz & Sarikaya (2021)	1.685	0.299	0.089	1.099	2.271	5.640	0.000
Dogan & Kahraman (2021)	0.840	0.209	0.044	0.429	1.250	4.012	0.000
Wannapiroon & Petsangsri (2020)	1.308	0.281	0.079	0.756	1.859	4.647	0.000
Siew & Ambo (2020)	1.589	0.148	0.022	1.299	1.878	10.756	0.000
Ernawati et al. (2020)	1.017	0.291	0.085	0.447	1.587	3.498	0.000
Parikh et al. (2020)	0.072	0.257	0.066	-0.432	0.576	0.279	0.780
Siew & Ambo (2018)	2.282	0.329	0.108	1.637	2.927	6.932	0.000
Korur et al. (2015)	0.579	0.251	0.063	0.088	1.070	2.311	0.021
Pooled	0.922	0.062	0.004	0.801	1.043	14.974	0.000

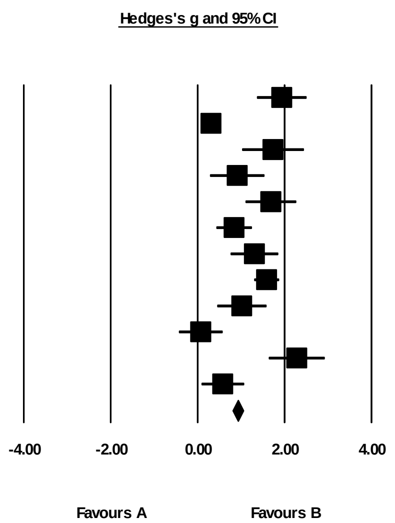

Figure 2. Forest Plot of the Effect Sizes of the 12 studies included in the Meta-analysis

Figure 2 displays the distribution of Hedges' g effect sizes of the studies included in the meta-analysis. The forest plot distribution of effect sizes showed that most of the studies favored the experimental (with DBL) over the conventional (non-DBL) group. This indicates that DBL positively influence the scientific creativity of STEM students. When the studies are examined individually, it can be noted that g=2.282 is the largest effect size displayed by the study of Siew & Ambo (2018), while the study of Parikh et al. (2020) resulted to the smallest effect size of 0.072 among the involved studies. It can also be gleaned from the table that the study of Hsiao et al. (2022) played a major role since it demonstrated a shorter confidence interval. Classic Fail-Safe N analysis was performed to confirm the calculated effect of DBL in the studies, which significantly favor experimental group. Table 3 shows the result of this analysis.

Table 3. Moderator Analysis according to DBL Model, STEM Discipline, Academic Level, Implementation Period, Geographic Location

Moderator Random Effect Model	Effect Size and 95% Confidence Interval						Z	p	Heterogeneity		
	k	ES	SE	σ^2	LL	UL			Q	df (Q)	P
STEM Discipline									2.175	3	0.537
Engineering	2	1.330	0.418	0.175	0.510	2.150	3.179	0.001			
Physics	3	1.093	0.328	0.108	0.450	1.737	3.329	0.001			
Science	5	1.006	0.365	0.133	0.290	1.721	2.755	0.006			
STEM	2	1.637	0.316	0.100	1.017	2.257	5.174	0.000			
Academic Level									9.939	2	0.007
Primary	4	1.472	0.443	0.196	0.604	2.340	3.323	0.001			
Secondary	4	0.642	0.181	0.033	0.288	0.995	3.554	0.000			
Tertiary	4	1.420	0.187	0.035	1.053	1.787	7.588	0.000			
Implementation Period									2.231	3	0.526
4-8 Weeks	4	1.087	0.279	0.078	0.541	1.634	3.900	0.000			
9-12 Weeks	3	1.374	0.572	0.327	0.252	2.495	2.401	0,016			
13-16 Weeks	2	1.505	0.208	0.043	1.098	1.912	7.250	0.000			
17-20 Weeks	3	0.896	0.494	0.244	-0.071	1.864	1.815	0.069			
Geographic Location									19.465	3	0.000
East Asia	3	0.948	0.438	0.192	0.089	1.807	2.163	0.031			
South Asia	1	0.073	0.261	0.068	-0.438	0.583	0.279	0.780			
Southeast Asia	4	1.550	0.222	0.049	1.116	1.984	6.995	0.000			
West Asia	4	1.253	0.320	0.103	0.625	1.880	3.910	0.000			

Publication Bias

Based from the result from Classic fail-safe N, the 12 empirical studies examined for meta-analysis is considered as valid based on the computed p-value ($p < 0.05$), which made the study resistant to publication bias. Similarly, 783 studies are needed in order to invalidate the results of the present study. Using the Begg and Mazumdar Rank Correlation, a Kendall's Tau (0.333), with a p-value of 0.131 ($p > 0.05$) was computed which signifies that no publication bias was detected. Moderator analysis was performed to determine whether effect sizes of the studies vary by the specified variables as shown in Table 4.

Table 4. Effect Sizes of DBL Models Investigated in the Obtained Studies

DBL Model	k	Hedges' g
Design Thinking	3	0.880
Engineering Design	6	1.530
STEAM Design	3	0.688

Heterogeneity analysis uncovered that there is a significant difference in the effect sizes of the included studies when clustered according to the academic level ($Q = 9.939$, $p < 0.05$), and geographic location ($Q = 19.465$, $p < 0.05$). This indicates that the academic level, and geographic location are considered determinants in implementing DBL effectively towards improving the scientific creativity of STEM students. In terms of academic level, the table presented that DBL is most effective when applied in primary level (g=1.472). Similarly, large effect size was also observed in secondary level (g=1.420), while medium effect size was established in secondary level (g=o.642). As regards to the geographic location of the studies, Southeast Asia (g=1.550), West Asia (g=1.253), and East Asia (g=0.948) all exemplified large effect size, while South Asia (g=0.073), insignificant effect size. On the other hand, the STEM discipline ($Q=2.175$, $p > 0.05$) and the implementation period (($Q=2.231$, $p > 0.05$) do not moderate the effect of DBL in scientific creativity as presented in the heterogeneity analysis in Table 3. This indicates that STEM discipline of context and duration of the intervention are not factors affecting the cultivation of creativity. It can also be implied that prolonged exposure to DBL does not guarantee higher creative performance.

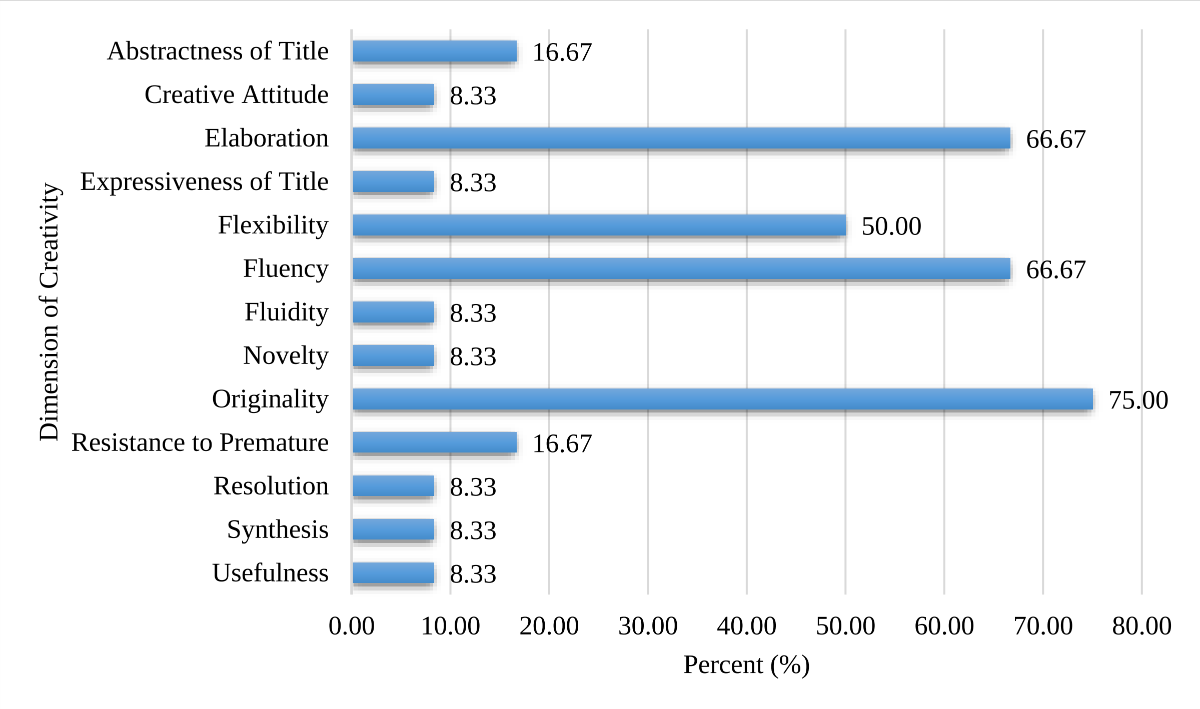

Figure 3. Dimensions of Creativity Examined in the Obtained Studies

There are three DBL models emerged that are commonly employed in STEM education, namely design thinking, engineering design, and STEAM design as revealed in table 6. Based on the table, majority of the studies used engineering design (50%) while the other studies introduced design thinking (25%) and STEAM design (25%) in enhancing scientific creativity. When examined in detailed the different DBL models used across studies, it revealed that engineering design (g=1.546) registered the maximum effect size while STEAM design (g=0.696) displayed the minimum effect size. Meanwhile, design thinking (g=0.896) obtained a considerable large effect size.

Figure 3 presents the dimensions of scientific creativity that were investigated on the obtained studies. The figure clearly shows that four indicators emerged to be the most frequently used indicators to assess scientific creativity. These are originality (75%), elaboration (66.67%), fluency (66.67%), and flexibility (50%). These dimensions of scientific creativity are based from the work of Guilford (1956), Torrance (1990), and Hu and Addey (2002). When the instruments used to assess scientific creativity were examined, it shows that tests developed by Torrance (1965) and Hu & Addey (2002) were among the frequently used as presented in Appendix A. Theoretically, originality pertains to the uniqueness of ideas, elaboration emphasizes the details of ideas, fluency refers to the number of ideas generated, while flexibility underscores the variety of ideas (Torrance, 1965).

Discussion

There is a wide consensus in the academic literature and educational scholars that DBL is an essential pedagogical approach in addressing STEM learning outcomes at K-12 education (Kelly & Knowles, 2016; Ladachart et al., 2022). This placed design process as an essential element to creativity and innovation, which consistently gained tractions in an effort to develop and implement integrated STEM instruction (Li et al., 2019). Previous DBL studies yielded to different effect sizes to scientific creativity in STEM fields across different studies. In view of this, a metanalysis of 12 empirical studies that involved 1221 students from various academic levels in STEM education published from 2013 to 2023 was initiated. This is to establish evidence and confirm the effectiveness of DBL as an effective instructional intervention in enhancing the scientific creativity in STEM education.

This meta-analysis revealed that using DBL has a positive and strong significant effect on the student’s scientific creativity. This is supported by several studies in the literature (Gok & Surmeli, 2022; Hothcock et al., 2014; Pekbay & Kahraman, 2023; Pinasa et al., 2018; Sakon & Petsangsri, 2021; Srikongchan et al., 2020; Syukri et al., 2017) confirming the capacity of DBL to improve scientific creativity. Through the design process, DBL develops students' creativity by providing a learning environment where students can use their imaginations in the projects. It also provides the necessary support system for students to widen and deepen their concepts and ideas about innovations (Azisan & Shamsi, 2022). This also encourages the students to try out ideas and eventually find that there are multiple solutions and perspectives to a given problem or scenario. While many studies proved the effectiveness of DBL in enhancing creativity, other studies reported otherwise (Parikh et al., 2020; Yalcin & Erden, 2021).

The moderator analysis showed that academic level and geographic location significantly affect the effectiveness of DBL in nurturing creativity among students. Primary level students showed the largest effect size, suggesting they are more trainable in creative thinking skills. It raises a question regarding the developmental aspects of creativity and how the application of DBL aligns with the stages of develop of cognitive and creativity of a child. Primary learners' cognitive readiness and openness to diverse learning approaches, and the malleability of their minds are critical to creative development. Young learners are more creative due to their active imagination and exposure to technological innovations (Sloane, 2021). Geographic location also played a significant role in explaining the effect of DBL on students' creativity. South Asian countries have implemented DBL more effectively in their context, attributed to their global competitiveness through the creative economy. The design process was implemented using innovative pedagogical strategies, further strengthening the effectiveness of DBL as an instructional intervention. In this regard, it introduces and interesting matter for future research prompting critical examination of the potential contextual factors associated with different geographical locations that might have an influence in DBL implementation.

The study found that STEM discipline and implementation period do not significantly moderate the relationship between DBL as an instructional intervention and students' scientific creativity as an outcome variable. DBL is a widely used pedagogical approach in implementing STEM education, being inquiry-based nature (Hathcock et al., 2015). grounded in the integration of design thinking and design processes in the classroom (Zhang et al., 2020), and combines project-based learning and problem-solving (Kim et al., 2015). The design process in DBL is similar to the scientific and engineering design processes implemented in STEM fields, making it an effective and efficient education pathway for enhancing students' creativity in STEM education. Furthermore, the duration of the intervention did not affect the effect sizes of DBL on scientific creativity. Extending the implementation period increased the strength of the effect of DBL from 4 to 8 weeks to 13 to 16 weeks. However, prolonging the implementation diminished the influence of DBL. The duration of an intervention depends on the type of intervention and the variable being improved. Scientific creativity is an academic skill, and increased instructional time programs result in better academic and non-academic learning outcomes (Kidron & Lindsay, 2014).

The study revealed that when the effect sizes of studies are examined in terms of the DBL model introduced, it revealed the EDP sustained the largest effect size in comparison with other DBL models. EDP is one of the widely available educational strategies for the implementation of STEM education (Hafiz & Ayop, 2019). The open-ended problem solving that is emphasized throughout the EDP helps students learn from their errors. This procedure develops students' capacity to come up with original responses to problems in any discipline. EDP as a pedagogical strategy further allows students to follow an iterative procedure to apply their mathematical, scientific, and engineering knowledge in order to generate the most operative solution to a given problem (Hafiz & Ayop, 2019). It is claimed that EDP, as an approach to science teaching, is a variation of problem-based learning (Schnittka, 2009). EDP provide an avenue to explore creativity in designing solutions to meet the needed standards (Zeid et al., 2014). On the other hand, it is essential to navigate other factors that delved EDP as the most effective DBL model. In-depth investigation on the specific component of EDP must be considered for more targeted and informed implementation in diverse educational setting.

The study revealed that there are 13 indicators that were used to quantify scientific creativity based from the 12 studies obtained. From the 13 indicators, four are frequently considered is assessing the said scientific creativity. These are originality (75%), elaboration (66.67%), fluency (66.67%), and flexibility (50%). Torrance (1990) recognized fluency, flexibility, elaboration, and original thinking as crucial components of creativity. Based from the Scientific Structure Creativity Model (SCSM) proposed by Hu and Adey (2002), fluency, flexibility, and originality are considered as indicators under trait dimension. It follows that scientific creativity is some ability that involve both cognitive and non-cognitive factors. Furthermore, creativity is thinking of innovative approaches to perform tasks. It also involves producing ideas or behaviors that are considered original. This result is in line in the 4Ps model of creativity (Rhodes, 1961) suggesting that creativity can be viewed using the perspective of a personally-related approach.

Conclusion and Recommendation

The present study initiated a meta-analysis in order to synthesize the results of the studies in the literature emphasizing the impact of DBL in enhancing scientific creativity of STEM students. In line with the aims of the study, 12 studies were included for meta-analysis. The total number of samples involved on the qualified studies are 1221 students from different academic levels and programs. The results of the meta-analysis application revealed that employing DBL as instructional intervention in promoting scientific creativity has a positive and strong significant effect (ES=1.181). This is consistent with the academic literature reporting the positive influence of DBL in students creative thinking skills. Furthermore, the study found out that there is a significant difference in the effect sizes when clustered according to the academic level and geographic location. This indicates that in implementing DBL in STEM classroom the academic level and geographic location must be considered in order to attain better outcomes from the students. On the other hand, moderation analysis further revealed that STEM discipline and the implementation period do not moderate the effect of DBL in scientific creativity. This implies that DBL is found to be effective across STEM disciplines. It also suggests that implementation period does not influence the implementation of DBL in cultivating scientific creativity. In examining the 12 studies, three models of DBL emerged that are being used in enhancing scientific creativity, namely design thinking, engineering design, and STEAM design. The studies revealed that engineering design is the most frequently used model of DBL and most effective design process. Engineering design appeared to be an effective instructional strategy as it integrates a set of processes used by engineers to solve a problem in the design and, teaching and learning process. In terms of assessing the scientific creativity, four dimensions were found to be the most frequently accounted - originality, elaboration, fluency, and flexibility.

The present study encountered limitations to provide a more robust synthesis of the quantitative studies. Based on the inclusion and exclusion criteria, the studies only include studies in the past 10 years and those that are published in the form of research article. This may result to selection bias. Selection bias refers to the propensity of meta-analytic authors to choose particular research. The robustness of the meta-analytic estimate and the focus that academics place on the findings can both be impacted by selection bias (Eisend & Tarrahi, 2014). Likewise, there are only 12 empirical studies that were included in the study. Increasing the number of studies by expanding the selection criteria and databases will provide a more conclusive statement regarding the effectiveness of DBL in fostering scientific creativity. Based from the results and the limitations of the studies, teachers have a crucial role in designing a learning instruction that would enhance the creativity among their students. In this respect, teachers must continue engage in integrating design process on their instructions to allow the students express their ideas freely and encounter ill-defined problem based from real-life scenarios.

On the basis of the salient findings the following are recommended or future lines of research; first, it is recommended to conduct a detailed studies investigating the impact of DBL on students' scientific creativity, in order to confirm the results of the studies. Likewise, long-term impact of DBL models should also be considered to attest the effectiveness in terms of duration. Second, the comparison of DBL models can also be a merit to evaluate the effectiveness of the DBL in implementing STEM education. It can determine the specific elements of each model that contribute to their effectiveness. Third, an in-depth analysis of the dimensions of creativity can be initiated to delve deeper into how each of the dimension contribute to the overall creativity and to determine whether a certain dimension is more critical in specific STEM discipline or academic levels. Fourth, a meta-analysis can also be initiated considering other outcome variable than scientific creativity and recognizing other moderating variables that may have a significant contribution on the implementation of DBL. The specific characteristics of the moderators must also be detailed to uncovers the underlying mechanism in affecting the scientific creativity. Factors such as cultural difference, educational policies, and teaching methodologies may be included in future analysis. Lastly, a systematic review employing meta-synthesis can also be done in order to synthesize qualitative data to form a new interpretation of the research field, since the present study only considered quantitative studies. This would provide venue to show summary of the effectiveness of DBL on the basis of qualitative data from interviews, field observation, and surveys capturing the students' experiences, attitude, and perception, and challenges related to DBL.

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