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Research Article

Revealing the effect of problem-based learning combined with the use of digital mind map on students' creative thinking

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In the 21st century, the ability to engage in creative thinking is of paramount importance. This study aims to explore the students' creative thinking skills after engaging in learning using Problem-based Learning combined with Digital Mind Mapping [PBL-DMM]. The study was conducted using a quasi-experimental method involving 120 Senior High School students at Solok, West Sumatra, Indonesia. Students' creative thinking skills were assessed through essay tests on pre and post-treatment (pretest-posttest). This study followed a nonequivalent pretest-posttest control group design with two classes for each group. A statistical parametric test of ANCOVA was used to analyze the effect of PBL-DMM on the students' creative thinking. The findings of this study indicate a notable distinction in students' creative thinking abilities when utilizing the PBL-DMM approach, which exhibited a higher level of proficiency than the PBL class. The utilization of digital mind maps in the learning process facilitates the acquisition, organization, and conceptualization of information in a manner that is both extensive and efficient, while simultaneously enabling the formation of naturally occurring groups. Additionally, digital mind maps provide students with convenient and direct access to information, which is conducive to memory retention. Furthermore, they facilitate the analysis of problems. The learning process enables students to hone their cognitive abilities, thereby facilitating the development of a more efficacious creative thinking process and the acquisition of enhanced creative thinking skills. In conclusion, the PBL-DMM learning model represents a potential alternative strategy for enhancing students' creative thinking abilities.

Keywords: Creative thinking; Digital mind map; Problem-based learning

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1. Introduction

The cultivation of creative thinking represents a crucial aspect of contemporary life. This phenomenon is caused by various socio-scientific problems that people face on a daily (Suwono et al., 2021), such as pollution, global warming, energy, and climate change (Godfrey & Tunhuma, 2020; Hallegatte et al., 2018). In the context of education, creative thinking skills refer to the ability of students to comprehend the methodology that has been applied, identify analogous

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applications, and solve problems by considering potential avenues for innovation (Sun et al., 2020). Students' development of creative thinking skills is contingent upon experience, ability to deal with multiple issues, and finding solutions. Creative thinking is a valuable skill that contributes to innovation, problem-solving, adaptability, effective communication, and personal fulfillment (Isaksen, 2023). It carries a crucial role in various aspects of life, enabling individuals to thrive in dynamic and challenging environments (Karunarathne & Calma, 2024).

The development of creative thinking skills is an effective strategy for addressing challenges in the contemporary era (OECD, 2021; P21, 2015). Creative thinking encompasses a person's ability to formulate new ideas (Weiss & Wilhelm, 2022) and deals with problem-solving strategies (Wolcott et al., 2021). A student who thinks creatively does not act in accordance with a pre-established template but rather in accordance with an individual thinking scheme, evinces imagination, and generates ideas (Koshanova et al., 2021). As for the importance of creative thinking, several studies have proposed means to promote students' creative thinking in different fields, for example, in agriculture (Waheed et al., 2020), science, policy and law, economics and business, including education (Al-Samarraie & Hurmuzan, 2018; Jamaluddin et al., 2021; Putra et al., 2024). Furthermore, it is crucial to promote creative thinking among students at every level of education.

Indonesian students' creative thinking skills have been found to be unsatisfactory. Studies (Athifah & Syafriani, 2019; Nurhamidah et al., 2018; Sugiyanto et al., 2018; Yayuk et al., 2020) reveal that students are able to respond to fundamental inquiries and challenges, yet they encounter difficulties in addressing complex problems within the domains of biology, physics, and mathematics. This is due to the fact that the learning experience is centered on memorizing content rather than on the development of skills (Klemm, 2007; Miedijensky et al., 2021). It also represents a significant gap between expectations and reality in the education system. In response to this issue, there is a need for innovative learning strategies that aim to develop students' higher-order thinking skills, including creative thinking (Kwangmuang et al., 2021). Thus, it will better prepare students to navigate the demands of the modern workforce and the challenges of the 21st century.

Problem-based Learning [PBL] has been demonstrated to be effective in developing creative thinking skills (Gallagher, 2015; Kardoyo et al., 2020). It involves students exploring knowledge through observation, literature study, conversation, or experiments without a specific technique for organizing the information they gather. However, one of the biggest problems students face is difficulty in integrating the concepts learned at school and associating them with the new concepts (Debbag et al., 2021). Accordingly, students require tools to arrange the knowledge acquired during learning activities (Putra et al., 2024). Mind mapping enables students to visualize and investigate the relationships between concepts and illustrate inferential links between propositions and arguments (Markiewicz, 2024). However, studies show that mind maps have a detrimental impact on some students due to their perceived inadequacy. Additionally, it may present challenges for students who are more adept at sketching, as it requires the use of drawing and color (Kadagidze, 2016).

The incorporation of technology into the digital mind map process improves its accessibility. Besides, digital mind maps are beneficial for supporting several elements of learning. They can help students solve issues, think critically, retain and recall knowledge, evaluate learning concepts, and think creatively (Kadagidze, 2016). In light of these benefits, a digital mind map can be considered an innovative and alternative teaching tool and a learning technique that integrates digital-native students (Debbag et al., 2021). Furthermore, a combination of PBL and digital mind maps [DMM] offers an innovative approach to problem-solving by allowing students to visualize and systematically arrange their ideas, thereby enhancing creative thinking. Therefore, this study examines the impact of using digital mind maps in problem-based learning on students' creative thinking skills.

2. Conceptual Framework

2.1. Creative Thinking in Science Education

Creative thinking is manifested in a number of indicators, such as fluency, flexibility, elaboration, and originality (Treffinger & Young, 2002; Wang & Li, 2022). Fluency represents the ability to convey their creative ideas (Weiss & Wilhelm, 2022). Flexibility is a cognitive characteristic that enables humans to behave in various situations (Ionescu, 2012). Elaboration involves expanding upon a structure by adding detailed information to enhance its various aspects and create a more comprehensive design (Aldossari, 2021). Originality is the ability of the individual to give original and new responses in terms of their diversity, recency, and rarity (Aldossari, 2021).

The current educational landscape is witnessing a growing emphasis on strategies and efforts aimed at fostering creativity (Liao et al., 2018). For example, Wang and Burdina (2023) applied digital technologies in the educational process to promote students creative thinking. In addition to the traditional presentation of information, the classes for enhancing creativity involve video demonstrations, interactive exercises on the Teams platform, writing thematic posts on social networks, as well as individual and group assignments. Wang and Li (2022) promote digital creative thinking through STEM learning. In the experimental class, students are provided with projects for digital creativity using the capabilities of the Unity AR Foundation and Vuforia augmented reality app creation platforms. Nur et al. (2020) enhance students' creativity using ERCore-Learning (ERCoRe is Eliciting, Restructuring, Confirming, Reflecting), by instructing mind maps during the restructuring and reflecting phase of this learning. Supratman et al. (2020) and Wijayati et al. (2019) use project-based learning to enhance students' creative thinking. Awang and Ramly (2008) also report the effect of Problem-based Learning on innovative thinking.

2.2. Problem-based Learning [PBL] in Science Education

The constructivist learning theory serves as the foundation of problem-based learning (Schmidt et al., 2019), which enables the development of students' creative thinking (Srikan et al., 2021). Problem-based learning is an active learning strategy that originated in medical education (Cavanagh et al., 2019). This learning model is based on the student-centered approach, in which students engage in a collaborative environment, generating solutions to simulated real-life problems. In this learning, group members engage in collaborative discourse, exchanging ideas and information, as well as investigating concepts (Tadjer et al., 2022). Solutions are generated by combining their expertise with fresh information from various sources (Tarhan & Ayyildiz, 2015), including facts, principles, procedures, and concepts. However, PBL does not facilitate the mapping of ideas effectively, necessitating the use of a mind map to map the ideas generated (Arends, 2015).

PBL has the potential to provide more exciting techniques for delivering content, providing education with more significant theoretical and social learning, as well as developing linkages between theory and social context (Servant-Miklos et al., 2019). It improves social accountability by fostering greater learning independence, significance, and applicability (Kwan, 2019). PBL accommodates students to work collaboratively (Suwono et al., 2023) to create high-level thinking and problem-solving through cooperation and the development of information and skills conducive to establishing life-long learning. During the learning process, students are afforded the opportunity to develop their creative thinking abilities, thereby enhancing their creative thinking skills. Students are allowed to construct their understanding and curiosity through active learning activities. In the learning process, the role of the facilitator is to direct students toward achieving higher creative thinking skills (Barbot, 2011; Youngerman & Culver, 2019). The combination of problem-based learning with the use of a digital mind map represents an innovative approach to problem-solving (Baden & Major, 2004). The solutions are developed using existing knowledge and new information from other sources (Tarhan & Ayyildiz, 2015). Previous research has also demonstrated that PBL can positively impact creative thinking skills (Ernawati et al., 2022; Maskur et al., 2020; Simanjuntak et al., 2021).

Also, research has reported the impact of problem-based learning in science classrooms. For example, Suwono et al. (2023) used PBL to promote health literacy in medical schools. Belland et al. (2019) emphasize the impact of PBL on students' beliefs and arguments. Furthermore, technology can be integrated into learning to develop creative thinking skills (Kizilay et al., 2023). For example, electronic mind maps can be employed to facilitate student learning. Mind maps have been demonstrated to assist students in developing their social skills (Polat et al., 2022). Moreover, the utilization of electronic mind maps in Problem-Based Learning in science classes remains a subject of improvement. This study aims to elucidate the impact of PBL with a mind map on creative thinking skills in biology classes.

2.3. Digital Mind Map [DMM] in Learning

Tony Buzan invented and trademarked the mind mapping technique, which has been demonstrated to enhance the efficacy, enjoyment, and engagement of teaching and learning processes (Buzan & Buzan, 2000). Mind mapping has been used in a variety of disciplines, including health and medicine (Edwards & Cooper, 2010), language (Shi & Tsai, 2022), food security (Meivi Sesanelvira et al., 2019), and education (McCrea & Lorenzet, 2018). Empirical studies have demonstrated that mind mapping enhances student learning and positively impacts student achievement (Bawaneh, 2019). Mind mapping enables the visualization and exploration of associations between concepts, displays inferential connections between propositions and contentions, as well as evaluation argument structure validity (Markiewicz, 2024). In conjunction with the exponential growth of information technology, electronic-based learning has undergone significant transformations, including the integration of electronic mind maps in educational settings.

Digital mind maps are visual tools that systematically and creatively organize information in a branching diagram format (Eppler, 2006). In digital form, these mind maps are typically created using software or applications facilitating users to easily add, edit, and connect various ideas, concepts, and information. In this case, DMM offers significant innovation in terms of technique, including minimum need for tools, easy sharing, visual richness, and portability, as well as the ability to create and analyze maps with different outlooks (Papushina et al., 2017). Further, users can leverage features such as drag-and-drop, hyperlinks, and multimedia integration like images and videos to enrich the mind map's content. The advantages of digital mind map over manual versions include flexibility in editing, real-time sharing capabilities with team members or colleagues, and greater storage capacity to accommodate complex projects (Bhattacharya & Mohalik, 2020). These tools are highly useful in various contexts, including project planning, brainstorming, decision-making, and education, as they help visualize relationships between information and expedite the process of understanding and retaining knowledge (Debbag et al., 2021). Alternative free software packages for mind mapping include Coggle (https://coggle.it) and MindMup (https://www.mindmup.com).

3. Method

3.1. Research Design

This study employed a quasi-experimental design, with the pretest-posttest nonequivalent group (Cohen et al., 2018). Quasy-experiment research was carried out to determine the effect of a treatment on the subject. This study involved two groups, namely the group performing the experiment and the control group. The experimental group followed the PBL-DMM learning scenario, while the control group utilized the PBL learning scenario.

3.2. Research Sample

The study sample consisted of 120 tent-grade senior high school students at Solok, West Sumatra, Indonesia. They were divided into four classes, with two classes serving as experimental classes and the other two classes as control classes. Each class consisted of 30 students. All students expressed willingness to join as a research sample in this study. The experimental and control classes were chosen based on the same students' cognitive level. Thus, all classes were evaluated for equivalence using the ANOVA test. The objective of this equivalence test was to prevent bias, ensuring that the student's creative thinking results were attributed to the intervention and not to their fundamental cognitive abilities. It should be noted that the participants of this study had no prior experience with learning to use digital mind maps. Therefore, prior to the intervention, the students were provided with a tutorial on creating digital mind maps using free online platforms such as Coggle and MindMup.

3.3. Research Instrument

This study used an essay test of creative thinking skills, which referred to four indicators, fluency, originality, elaboration, and flexibility, following Treffinger and Young (2002), to assess creative thinking skills. The essay test consisted of 11 learning objectives regarding biodiversity and the classification of living things, viruses, bacteria, fungi, and protists. The test consisted of 11 questions, which include (Q1) biodiversity, (Q2) biodiversity, (Q3) classification, (Q4) classification, (Q5) bacteria, (Q6) bacteria, (Q7) protists, (Q8) protists, (Q9) fungi, Q10) fungi, and (Q11) fungi, as presented in Appendix 1. Questions 1 and 2 assess the fluency indicator, questions 3-5 and 10-11 assess the originality indicator, questions 6 and 7 assess the elaboration indicator, and questions number 8-9 evaluate the flexibility indicator.

Table 1
Creative Thinking Rubric based on Treffinger & Young (2002)

Indicators	*Criteria*	*Score*
Fluency	Students may name or write down four or more other ideas, recommendations, or alternative responses.	4
Originality	Students are able to mention or write down some fascinating and logical thoughts that are relatively new and related to the provided topic.	4
Elaboration	Students are able to express some logical details on existing ideas, making them easier to apply and understand.	4
Flexibility	Students are able to write down some reasonable and meaningful alternate answers to the presented topic from various perspectives.	4

The essay test was equipped with an answer key to check student answers. The answer key describes the correct answer according to the question item. The answer key allows for the evaluation of the correctness of students' answers. The students' responses were scored on a 1-4 scale. A pilot test was conducted on 32 eleventh-grade students from senior secondary schools in Solok to assess the empirical validity and reliability of the instruments. Pearson's correlation was employed to assess the validity of the test. The empirical validity test findings indicate that all questions were valid, with a value of 0.463-0.742, which was more notable than the r table (5%) 0.444. Moreover, the Cronbach's alpha reliability coefficient was 0.782, suggesting that the test is reliable. Students were allotted 60 minutes to complete the pre-test and post-test.

3.4. Research Procedure

The research procedure consisted of several steps, as described in the following.

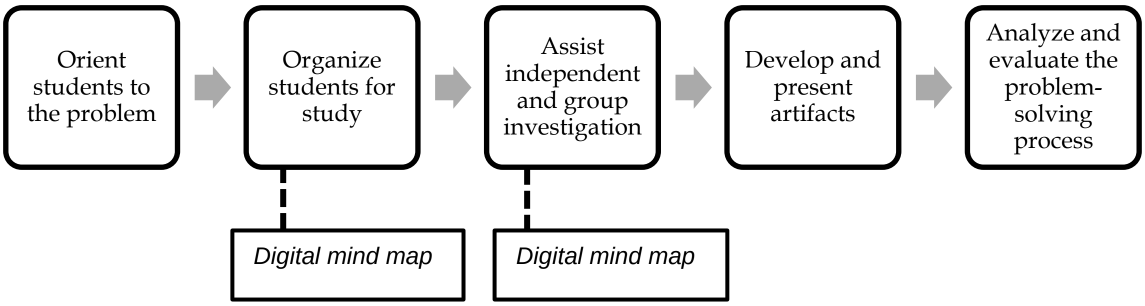
3.4.1. Development and validation

The research commenced by developing a syllabus, lesson plans, handouts, and student worksheets. In addition, an essay test was also designed to assess students' creative thinking skills. The lesson plan followed the curriculum used by the school. The developed lesson plans were further validated by learning and material experts. The results of validity tests by experts ranged between 90-100%, suggesting that all lesson plans are valid and can be used for the learning process.

3.4.2. Learning process and taking the test

This research was conducted from August to December 2022 at Public Senior High School, Solok, West Sumatra, Indonesia. In the early learning phase, students were asked to fill out the pretest in both classes, while the posttest was carried out at the end of the intervention. The implementation of PBL using DMM was performed through five phases, as illustrated in Figure 1.

Figure 1
Phases of Problem-based Learning with digital mind map method; second and third phases of PBL integrated with digital mind map



During the orienting phase of problem-solving, students are given phenomena or issues related to everyday life and tasked to formulate problems. Subsequently, students are tasked with devising solutions to the aforementioned problems and issues. The second phase is the organization of students for study, which allows students to obtain the material concepts that are used to conduct investigations and formulate solutions. These concepts can be obtained from teacher explanations, books, articles, and other sources. Furthermore, in the third phase of assisting independent and group investigation, students conduct group investigations through observation/field trips/laboratory activities, or literature studies. At this phase, the characteristics of collaborative PBL are prominent, thereby students must work together to gather information to formulate creative solutions. The fourth phase is developing and presenting artifacts. This phase provides students with the opportunity to formulate solutions to problems using concepts and results of their investigations. The final phase entails the analysis and evaluation of the problem-solving process. This is conducted in collaboration between students and teachers, whereby the solutions that have been prepared are assessed, with a view to implementing them in order to solve the problem. In phases 2 (organize students for study) and 3 (assist independent and group investigation), a digital mind map was used. This was created using EndrawMind: AI Mind Map & Note application, which is a digital tool that students commonly use.

The learning was carried out for 16 meetings with 3 PBL cycles (repetition of the PBL process). The first cycle focused on material biodiversity and classification of living things, cycle two comprised viral matter and matter, and the third on fungal and protist material.

3.4.3. Cycle 1

In cycle one, students are introduced to the concepts of biodiversity and classification materials. They are presented with case studies illustrating the impact of biodiversity loss in Indonesia and are tasked with developing solutions to address these challenges. To facilitate this process, students are prompted with specific questions that guide them in formulating problem statements. Some students have demonstrated proficiency in articulating problems rather than questions. For instance, they may pose a problem statement such as, "How can we prevent the deforestation of Indonesia's forests?”

3.4.4. Cycle 2

In this cycle, students learn viral and bacterial material. This material incorporates COVID-19 and foot-and-mouth disease in cows as examples to serve as triggers for problem-based learning. These topics highlight relevant viral diseases that can effectively prompt critical thinking and engagement in PBL scenarios. This case study was selected due to the recent global pandemic, with the objective of equipping students with the knowledge and skills to mitigate the spread of infectious diseases and provide care for those infected. Furthermore, a resurgence of foot-and-mouth disease in cows has occurred in the community. Therefore, students will be able to express their creative ideas about preventive and curative handling solutions for hoof-and-mouth disease in livestock. Students are required to formulate problems and formulate creative solutions. For example, students are asked to formulate a solution to the problem of avoiding the contraction of the novel coronavirus, SARS-CoV-2.

3.4.5. Cycle 3

The third cycle of PBL focuses on protist and fungal material. Students are presented with an issue about dengue fever caused by one type of protist and asked to formulate a problem formulation. This issue was selected due to the fact that Indonesia, a tropical country with a humid climate, provides an environment conducive to the proliferation of various mosquito species, including Aedes aegypti, the vector for dengue fever. Students may formulate problem formulations such as, "How might an environmentally friendly mosquito repellent be developed?"

3.5. Data Analysis

The data were gathered from students' creative thinking skills scores on each indicator. Then, the data was converted into interval scale data. The data were subjected to analysis using descriptive and inferential statistics. Descriptive analysis techniques were employed to ascertain the extent of improvement in students' creative thinking skills. Inferential statistical analysis techniques for testing experimental research, such as the ANCOVA test, were preceded by an assumption test, namely a test of data normality using the Kolmogorov-Smirnov test and a test of homogeneity using Levene's test. The ANCOVA technique was selected for hypothesis testing to ascertain whether there were differences between variables. The presence of such differences indicates the impact of the independent variable on the dependent variable. The statistical calculation of the ANCOVA test was conducted using the SPSS program with a significance level of .05.

4. Results

The answers to 10 questions demonstrate students' creative thinking skills. These questions were designed to assess fluency, originality, flexibility, and elaboration. Figure 2 illustrates samples of student answers.

Figure 2
Students' Answer

Fluency indicator
Students are presented with questions designed to assess their ability to think creatively, "based on *the discourse, what ways can be done to maintain biodiversity at the level of genes, types, and ecosystems that exist in nature? Give at least 4 ideas related to it!". Students answered; (1)* not to *expand plantations to forests, (2) maintain flora and fauna habitats, (3) create a fauna shelter so that it does not experience extinction, and (4) appeal to the community to protect the environment.*

Originality indicator.
Students were able to propose original solutions to the problem question, for instance, *"Do you agree with the role of the Sars cov-2 virus as a solution to control the COVID-19 pandemic? Give reasons and explain them according to your own thoughts logically!".* Students propose their idea from their own intellectual insight, for instance, "The role of the Sars Cov-2 virus *is in medicine, the Sars Cov-2 virus is used to make a covid-19 vaccine. The way it works is that the weakened sars cov-2 virus is then injected into the body so that the immune system is accustomed to the covid-19 virus so that it can eradicate the covid-19 virus in the body".*

Flexibility Indicator
Students present the ability to define ideas for the question, "*Do you agree with the steps taken by the taxonomists? Give reasons and explain them according to your own thoughts logically!"* The student's answer is, "*agree, because along with the development of the times technology is growing, so that it can identify something to more specific things. So, in the future, as technology develops, it may be that changes in its identification of something will cause changes."*

Elaboration indicators.
Students are able to present the ability to provide additional information and new details to an idea that makes it more appropriate for addressing the problem at hand and persuading others of the solution. This process of elaboration and clarification can lead to further information and additional details being added, as well as the question, "*What is the role of bacteria in yogurt in an effort to improve digestive problems?".* Students answered the question, "*Bacteria in yogurt are probiotic bacteria that can maintain digestive health because they attack bacteria that cause problems in digestion, and facilitate digestion to avoid diseases in the intestine".*

Students' pretest and post-test answers were assessed using the creative thinking skills rubric and assigned a score between 1-4 (Table 1). The results of students' creative thinking skills from the pretest and posttest are presented in Table 2. This data represents an increase between pretest and posttest scores. In addition, it also shows that student achievement in the experimental class is higher than in the control class.

Table 2
Achievement of Students' Creative Thinking Skills in Control Class and Experimental Class

Variable	*N*	*Pretest*	*Post-test*	*N-gain*	*Category*
PBL-DMM (Experiment)	60	29.01	74.90	0.65	Increased
PBL (Control)	60	25.77	70.36	0.60	Increased

Furthermore, Table 3 presents the students' creative thinking skills achievement for each variable.

Table 3
Achievement of Creative Thinking Skills of Students in Both Classes on Each Indicator

Indicators	*Pre-test*	*Post-test*	*N-gain*
PBL-DMM			
Fluency	58.8	96.67	0.92
Elaboration	34.8	65.83	0.48
Flexibility	11.7	66.81	0.62
Originality	10.83	70.31	0.67
PBL			
Fluency	41.9	92.08	0.86
Elaboration	21.7	61.04	0.50
Flexibility	19.5	63.61	0.55
Originality	20.03	64.69	0.56

As presented in Table 2, the achievement of students’ creative thinking skills in both classes (experiment-control) in each indicator increases. The N-gain score of the fluency indicator in both classes is highest when compared to other indicators. In contrast, the elaboration indicator in both classes obtained the lowest score compared to the other three indicators. Meanwhile, the pretest scores exhibit variability across each indicator, reflecting the initial conditions of students' creative thinking abilities and not serving as covariates. The data were analyzed using quantitative descriptive analysis techniques and parametric statistics to ascertain the impact of the PBL-digital mind map on creative thinking abilities. The results of this study were obtained through the implementation of PBL-DMM and PBL learning in two group classes (experimental class and control class). Normality tests were conducted on the data to determine the distribution of the research data. The dependent variables, which included students' creative thinking skills, were also tested for normality. A summary of the results of the data homogeneity test is presented in Table 4.

Table 4
Homogeneity Test Summary

Data	*F*	*df1*	*df2*	*p*
Pretest	2.953	1	118	.088
Post-test	0.867	1	118	.354

The normality test yielded a significance value on each variable of 0.197 on the pretest and 0.673 on the post-test, greater than an alpha value of .05 ($p > .05$). This signifies that the bound variables are regularly distributed. Furthermore, a homogeneity test was carried out using Levene’s Test to obtain a significance value on each variable that was more significant than the alpha value of .05 ($p > .05$). Furthermore, the result of the ANCOVA test is presented in Table 5.

Table 5
Summary of ANCOVA Test

Source	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*
Corrected Model	1462.109[a]	2	731.054	7.151	.001
Intercept	71082.577	1	71082.577	695.271	<.001
Creative-pretest	836.475	1	836.475	8.182	.005
Class	412.776	1	412.776	4.037	.047
Error	11961.758	117	102.237		
Total	637810.000	120			
Corrected Total	13423.867	119			

Note. a. R Squared = .109 (Adjusted R Squared = .094).

The results of the ANCOVA test on creative thinking skills variables showed that the learning model presents a significance value of .047, smaller than alpha .05 ($p < \alpha$) (see Table 5). The ANCOVA test for the learning model showed significant results. This suggests a difference in creative thinking skills between students who study using the Problem-based learning model combined with the use of a digital mind map and students who learn relying solely on the Problem-Based Learning model. However, post-hoc tests were not conducted in this study, as it only involved two classes, and it was evident that there were differences between the experimental and control groups.

5. Discussion

The results of the data analysis indicate that students who engage in project-based learning through the Digital Mind Map approach exhibit enhanced creative thinking abilities. In the PBL-DMM learning, students can enhance their creative thinking skills by using a digital mind map as it aids them to organise the concepts and information. The research finding aligns with Hidayati et al. (2019), who also asserted that PBL-DMM promotes students' creative thinking. The difference lies in the fact that in the research of Hidayati et al. (2019), students create a DMM before the PBL phase, which directs students to the problem.

Digital mind maps stimulate students to engage actively during the learning process. The positive effect of PBL-DMM on creative thinking skills is influenced by the PBL learning phase, which allows students to develop innovative ideas (Salinitri et al., 2015). Besides, digital mind map has been demonstrated to improve educational success and contribute to meaningful learning (Debbag et al., 2021). Problem-based learning refers to the constructivist learning theory (Schmidt et al., 2019). It focuses on real-life problems that increase student motivation because students feel close to the issues in their daily lives. Thus, the use of a digital mind map in PBL helps students develop their creative thinking skills (Irons & Thomas, 2016).

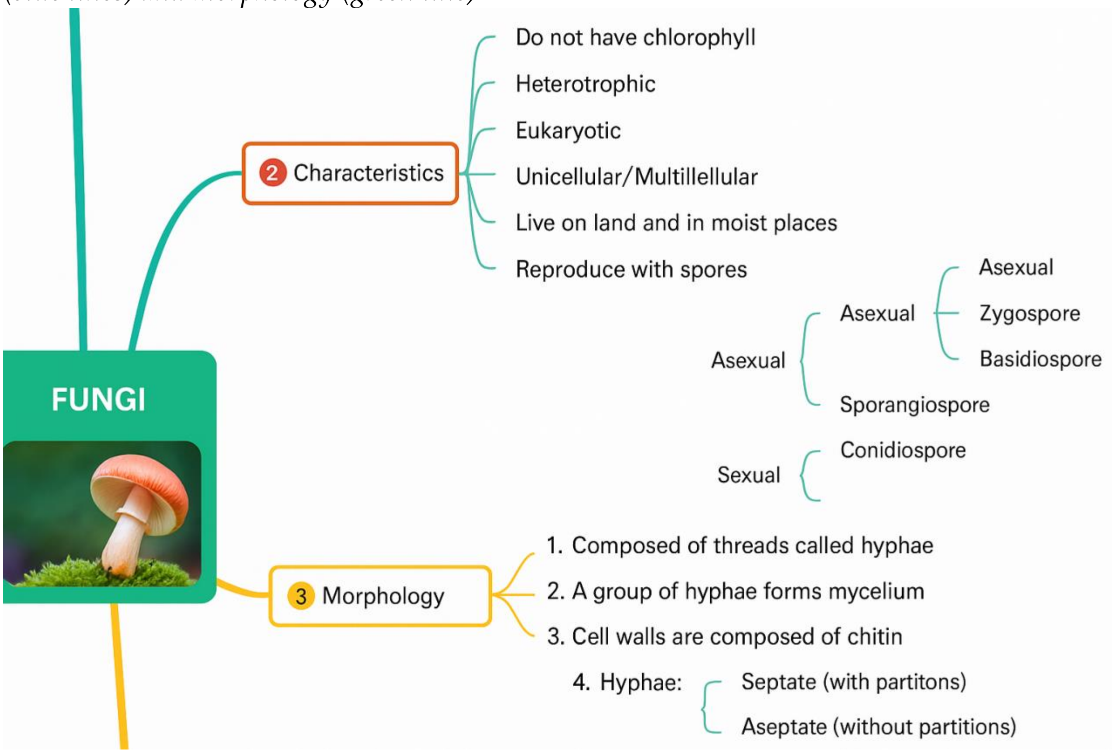
The phases in PBL-DMM learning can stimulate students to engage in creative thinking. The first phase is the student's orientation towards the problem. During the learning process, students are directed to recognize and understand the problems to be solved. Initially, students are not used to identifying problems. However, with time and practice, they gradually became more proficient in this skill. PBL problems are those encountered by students in their daily lives and are complex, requiring collaboration to solve. In the PBL process, students are experienced in facing authentic and meaningful issues (Kwan, 2019). Irons and Thomas (2016) posit that PBL motivates students to analyze problems in everyday life, thereby encouraging them to think about providing solutions or responses to existing problems.

The initial learning phase of PBL aims to assist students develop fluency indicators. Fluency illustrates students' skills in conveying their creative ideas (Weiss & Wilhelm, 2022). The fluency indicator exhibits the highest gain due to the capacity of students to generate a multitude of ideas, a process that is expeditiously facilitated by the digital mind map. Students construct knowledge through a series of phases, beginning with the formation of initial schemas based on available information and culminating in the assimilation and accommodation of new data to create a comprehensive understanding (Zhou & Brown, 2013). The activation of students' potential thinking skills can occur due to the stimulation of the learning process, particularly in challenging environments that enhance the students' potential thinking skills. Individuals can form or build much knowledge from what they learn and understand (Bruning et al., 2004).

The second phase is concerned with the organization of students to facilitate the learning process. In this phase, students are expected to develop knowledge and concepts, as well as their creative thinking processes through a literature review, experiment, interview, or observation activities. Moreover, students are encouraged to explore and deepen the concepts necessary for the development of their creative thinking skills. PBL is predicated on the notion that learning is not merely the memorization of concepts or information; it is also about interacting with one's surroundings through the navigation of real-life challenges (Youngerman & Culver, 2019). In the second phase of PBL, students organize information using a digital mind map. They generate mind maps using several applications. However, in this phase, students are required to choose one application to limit the number of options, thereby emphasizing the importance of choice in the learning process and fostering a sense of autonomy and enjoyment.

The use of a digital mind map enables students to organise concepts, knowledge, and information in a more efficient, systematic, practical, and reusable manner. Digital mind map also helps students to practice their creative thinking skills. As described by Buzan and Buzan (2000), mind mapping represents an innovative and efficacious approach to recording and organizing thoughts, as well as the most straightforward method of entering and retrieving information from the brain. Students employ color lines and illustrations to creatively organize the concepts they learn through digital mind mapping. Figure 3 illustrates the example of outcomes produced by students in the second phase.

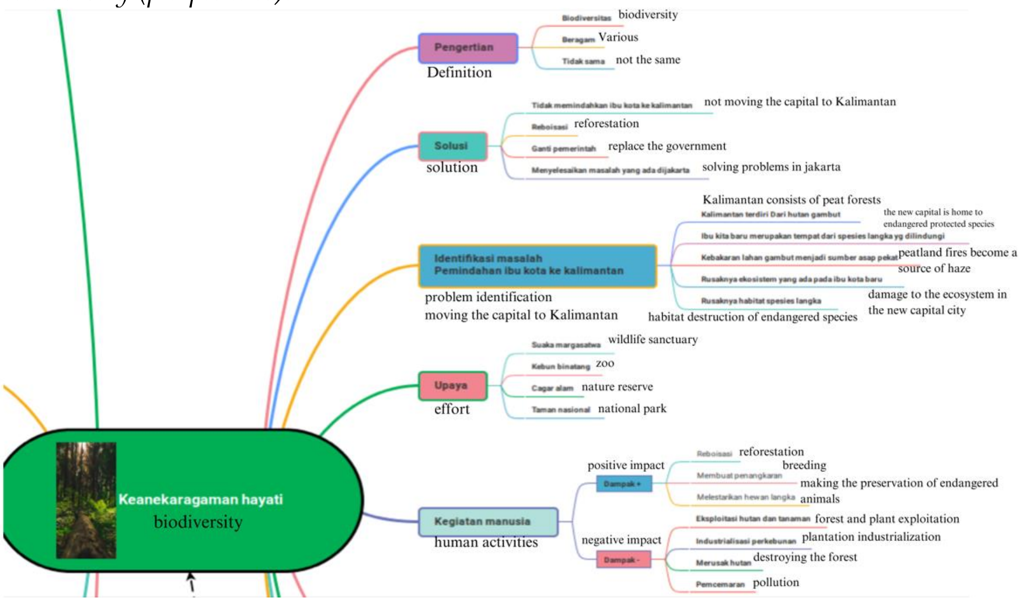
Figure 3
Sample of Students' Digital Mind Map in the Second Phase in Fungi Topic; branches for the characteristics (blue lines) and morphology (green line)



The next phase is to devise a plan and carry out the investigation. In this phase, students carry out problem investigation activities. Digital mind map assistance at this phase serves as a tool to facilitate the organization of information and the development of ideas among students. The creation of a digital mind map in a collaborative setting allows for the discussion of ideas in a cooperative manner. Thus, students demonstrate a greater capacity for creative problem-solving when utilizing a digital mind map, as compared to when they do not. Additionally, mind maps facilitate the formation of associations between ideas and enhance memory retention (Gavens et al., 2020). This method of organizing knowledge in mind maps can assist students in learning meaningfully and autonomously (Burrow, 2018; Chiou, 2008) as it is related to deeper-level processing (Nesbit & Adesope, 2006). The educational strategy of employing a mind map has been demonstrated to facilitate clear thinking, effective problem-solving, creative thinking, and planning (Meivi Sesanelvira et al., 2019). The mind map focuses on mapping the temporary solution's components, as presented in Figure 2. An example of the results of the Mind map made by students in the third phase is presented in Figure 4.

Figure 4

Sample of Students' Digital Mind Map at Third Phase: Students' digital mind map on biodiversity topic; definition (orange line), solutions toward biodiversity problems (blue line), identify the problem (yellow line), strategies to tackle the problems (green line), human activities that cause the threatened the biodiversity (purple line).



In the third phase, students are also instructed to mention or write down some fascinating and logical thoughts that are relatively new and related to the provided topic (originality). Originality can be defined as the individual's ability to provide responses that are original and new in terms of their diversity, recency, and rarity. Originality depends on the value and quality of one's ideas (Aldossari, 2021). This pedagogical approach encourages students to generate novel concepts that are both intriguing and relatively novel with respect to the problems at hand. Youngerman and Culver (2019) also state that through PBL, students can participate in ill-structured real problem-solving. Knowledge construction is carried out through authentic contexts.

The fourth phase is to develop and present the results of problem-solving. In this phase, students formulate solutions to problems and present them to the class. Students present their works through reports, papers, videos, models, and ideas. The study's results using the Problem-based learning model combined with the use of a Digital Mind map indicated that students exhibit an enhanced capacity for flexibility. Flexibility is a cognitive characteristic that enables humans to behave in various situations (Ionescu, 2012). It is a quality that allows individuals to adapt to changing circumstances (Ionescu, 2012). Flexible students can formulate solutions to problems, demonstrating the ability to state solutions to problems firmly and clearly but still consider scientific logic. For instance, when presented with a case by their instructor, they can make a clear argument.

Also, in the fourth phase, students are instructed to express the logical details of existing ideas, thereby facilitating their application and comprehension (elaboration indicator). Elaboration indicators instruct students on how to elucidate specific logical aspects of existing ideas, thereby enhancing the applicability and clarity of their formulations. The edifice exemplifies elaboration, whereby the information provided is utilized to construct a more intricate and comprehensive structure (Aldossari, 2021). In this study, students in the PBL class yield higher elaboration achievements than those in the PBL-DMM class. The intervention is analogous to the fourth step, wherein students are not provided with learning tools such as digital mind maps. Therefore, it can be posited that students in PBL classes may achieve higher levels of elaboration. This demonstrates that the PBL model has been effective in enabling students to develop and hone their creative thinking abilities. The objectives of PBL include: i) assisting students in developing thinking skills and problem-solving abilities; ii) fostering intellectual skills in studying the multifaceted responsibilities of adulthood through their involvement in actual events; and iii) cultivating independence in learning (Burrow, 2018; Youngerman & Culver, 2019). The concluding phase of the PBL-DMM entails analyzing and evaluating the outcomes of the problem.

The last phase of the PBL-DMM entails analysis and evaluation of the results of the problem-solving phase. At this phase, students assess their investigations and the processes they have employed in order to develop a solution to the problems initially presented at the outset of the learning activities. Problem-solving concepts must be effective and efficient in terms of time and resources. An efficacious solution that is ultimately ineffectual or unfeasible is not a valid solution. It is expected that students will develop solutions with as much detail as possible, including the alternative outcomes and the positive and negative consequences of those answers. It is essential that individuals are able to evaluate by connecting empirical facts with theory. This enables them to learn what is currently known or believed, generate testable questions, test hypotheses, and make suitable conclusions (Morris et al., 2012). Additionally, scientific reasoning also necessitates the capacity to analyze data and derive logical inferences from patterns detected. Furthermore, it requires evaluating a person's thinking at each stage of the process (Alshamali & Daher, 2016). Thus, this learning experience enables learners to determine the right solution.

6. Limitations and Future Implications

This study implies that the PBL-DMM model can improve creative thinking skills. The PBL-DMM model in biology learning can be used to teach and develop students’ creative thinking. The development of creative thinking skills is contingent upon students being permitted to construct their understanding and cultivate curiosity through the implementation of student-centered active learning activities. It is anticipated that students who have developed creative thinking skills will become capable of navigating the complexities of modern life, which is characterized by rapid change and uncertainty. It should be noted that the study was not without limitations. The study subjects were limited to students in grade 10th of high school. The research subjects were selected based on the diversity of organisms taught in grade 10th. Secondly, the research was conducted on biology learning. It is possible to improve creative thinking through PBL-DMM in other subjects. Thirdly, the data was collected in the context of the 2013 Indonesian Standard Curriculum. In future research, students' creative thinking skills at different grade levels and courses can be explored.

7. Conclusions

The capacity for creative thinking is a fundamental skill for students to navigate the diverse challenges they encounter in their lives. This skill has been extensively cultivated in educational settings, including those focused on science. One strategy that has been demonstrated to effectively develop creative thinking skills is problem-based learning with digital mind mapping. The research findings indicate that the PBL-DMM is an effective approach for fostering positive student creative thinking skills. A comparison of the pretest and posttest results indicates a gain in students' achievement in creative thinking skills. Although the results of the elaboration achievement were not higher than those of the PBL class, we are confident that the PBL-DMM positively impacted students' creative thinking, as opposed to merely PBL without a digital mind map. The use of digital tools enables students to organize the concepts they have acquired, thereby facilitating the development of more effective creative ideas. These results indicate that the PBL-DMM has a positive impact on students' creative thinking abilities. Furthermore, the integration of technology in the classroom has been demonstrated to enhance student motivation and engagement with the educational process. Problem-based learning (PBL) is based on real-life problems that are relevant to students' lives, which makes them more motivated to solve problems. This research also recommends practicing creative thinking skills in the classroom because these skills are essential for success in the future. Furthermore, suggestions are provided for evaluating the impact of PBL-DMM on students who are used to using it in the classroom to achieve optimal results.

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Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Appendix 1. Creative Thinking Questions

1. Fluency

Q1: Pig hunting has become a habit for some people in West Sumatra. It has even become a hobby until there is a Pig Hunting Sports Association (PORBBI). The union exists in almost all regions in West Sumatra, usually this pig hunting action has been scheduled and many people who come are also from outside the area where the pig hunting is held. Massive pig hunting can cause a new problem, namely the reduced availability of feed for predatory animals such as tigers in the Sumatran forest. *Based on this discourse, what ways can be done so that people do not hunt fauna in nature excessively? Give at least 4 ideas related to it!*

Efforts that can be made are.

- Provide education and socialization on the importance of preserving fauna in Indonesia even though the animals hunted are pests. Excessive hunting of pigs will reduce the number of wild boars thus affecting the tiger food chain.
- Support environmental conservation efforts
- Creating captivity for other economic commodities. It is used to replace the benefits obtained from clay pigs in the forest.
- Provide customary and formal legal sanctions for hunters who violate the rules

2. Fluency

Q2: Indonesia is a country with high biodiversity, one of which is on the island of Sumatra. However, currently the deforestation rate on the island of Sumatra tends to increase from year to year. The main causes of deforestation are caused by oil palm plantations and the pulp and paper industry. Primary forests that have been turned into oil palm plantations and industrial timber plantations in Sumatra cover nearly 1.6 million hectares (4 million acres) and 1.5 million hectares (3.7 million acres). This causes a number of flora and fauna to lose their natural habitat due to the change of heterogeneous forest functions into homogeneous forests. *Based on this discourse, what ways can be done to maintain biodiversity at the level of genes, types, and ecosystems in nature? Give at least 4 ideas related to it!*

Efforts that can be made, i.e.

- Technological innovation
- Technology that can be utilized to reduce and monitor deforestation in Indonesia such as the use of remote sensing and drone technology to map and monitor the current condition of forest cover.
- Efficient land use
- Combining the cultivation of forest crops in agriculture can minimize erosion potential, maximize biomass production, and maximize positive interactions between soil and plants.
- Changing consumption patterns
- It takes changes in consumption patterns individually or collectively to be more efficient in the use of biological natural resources.
- Policy support
- Support is needed by the Government in forest management and protection to eradicate illegal logging, as well as to carry out law enforcement for the perpetrators.

3. Flexibility

Q3: Taxonomists regularly hold conferences to discuss the naming of animals and plants every year. This is done to update the naming system of animals and plants because along with the development of knowledge and the discovery of scientific evidence of kinship. For example, rice (Oryza sativa) used to be included in the Graminae tribe, but now it is included in the Poales tribe.

Based on this discourse, do you agree with the steps taken by these taxonomists? Give reasons and explain them according to your own thoughts logically!

Agree, naming an organism using a scientific name has a function, among others, to make it easier to recognize the characteristics of a group of living things, to distinguish one group of living things from other groups of living things, and to indicate the level of taxon

4. Originality

Q4: The COVID-19 pandemic caused by the Sars cov-2 virus has been ongoing since 2019 and can only be controlled in early 2022. The concept of ending a pandemic is when the human population in an area has reached herd immunity. This concept involves the Sars cov-2 virus itself as a pandemic controller. *Based on this discourse, do you agree with the role of the Sars cov-2 virus as a solution to control the COVID-19 pandemic? Give reasons and explain them according to your own thoughts logically!*

The COVID-19 pandemic subsided after the distribution of various vaccine brands. One way of making this vaccine involves the whole Sars Cov 2 virus itself which is then turned off or attenuated. In other words, vaccines are created and developed by utilizing inactivated viruses. In addition, another technology that can be used is to utilize genetic material, namely the spike protein from COVID-19. These substances will later be used to give instructions to body cells and trigger the formation of antibodies against the virus.

Appendix 1 continued

5. Originality

Q5: The public is again shocked by the emergence of hoof and mouth disease in livestock. Mouth and hoof disease abbreviated as FMD is a contagious animal disease that attacks cloven-hoofed animals both livestock and wild animals such as cows, buffaloes, sheep, goats, pigs, deer / antelope, camels and elephants. This disease inflicts very high economic losses. *Based on this discourse, what efforts can animal farmers make, so that their livestock avoid hoof and mouth disease? Give reasons and explain them according to your own thoughts logically!*

Solutions that can be done by farmers to prevent their livestock from hoof and mouth disease, namely.

- Control community access to livestock and equipment
- Control the incorporation of new animals into the herd
- Monitor and report sick animals
- Dispose of dirt and carcasses properly.

6. Elaboration

Q6: Yogurt is a food product that utilizes Streptococcus thermopilus and Lactobacillus bulgaricus bacteria. These bacteria belong to probiotic bacteria that can maintain the health of the digestive system.

Based on this discourse, how the role of bacteria in yogurt as an effort to improve digestive problems!

Probiotics act as probiotic agents and normal flora so that they can play a role in limiting the growth of pathogenic bacteria. The production of metabolites through carbohydrate digestion by probiotics can inhibit pathogens by lowering intraluminal pH, by inhibiting attachment and translocation of bacteria and producing bacteriocins (antimicrobial peptides). The effect on the complex microbiota helps with intestinal dysbiosis, and reduces bacteria.

7. Elaboration

Q7: Rina is a fisherman's son. One day Rina had diarrhea from eating fish that was not fresh. The fish consumed by Rina almost rotted. This process of food spoilage is caused by aerobic bacteria that multiply. However, Rina does not have a freezer or refrigerator.

Based on this discourse, how do you make the fish obtained by Rina not rot easily? (Connect with the role of rot-causing bacteria in fish)

The bacteria that cause decay in fish are bacteria of the type Clostridium. These bacteria are anaerobic bacteria or bacteria that do not need oxygen in their metabolic processes. The solution that can be done is by drying and salting. High salt concentrations cause conditions in bacteria to be hypotonic while the external environment is hypertonic, as a result of which bacteria will lysis. In addition, a very low concentration of water stops the metabolism of bacteria.

8. Flexibility

Q8: Although Protists have a positive role, these organisms also have a negative role for humans. An example is toxoplasmosis caused by the bacterium Toxoplasma gondii.

Based on this discourse, what possibilities can arise in humans if they have toxoplasma infection? What can you do if you have a toxoplasma infection?

Toxoplasma infection in humans can cause toxoplasmosis. This disease causes complications that can be divided into three, namely.

- Ocular toxoplasmosis. Inflammation and injury to the eyes caused by parasites.
- Congenital toxoplasmosis occurs when the fetus is infected with toxoplasmosis.
- Cerebral toxoplasmosis. If people with immune system disorders are infected by toxoplasmosis, the infection can spread to the brain and can threaten the life of the sufferer.

9. Flexibility

Q9: Fire algae (Pfiesteria) is one type of algae that is dangerous. These algae is what causes the occurrence of red tide events where the color of the sea water becomes reddish. This type of algae can cause damage to the nervous system (neurotoxin).

Based on this discourse, what negative impacts can arise for humans and marine life if there is an overpopulation of fire algae? What can you do to avoid overpopulation of red algae?

Red tide kills many marine lives, changes the community structure of aquatic ecosystems, and can also cause death in humans. Efforts that can be done are to control the growth of fire algae populations in waters so as not to cause negative impacts on the surrounding environment.

Appendix 1 continued

10. Originality

Q10: Take a look at the picture below!

The picture above, is a disease of Tinea unguium caused by a type of fungus.

Based on the picture, what efforts can you make to prevent the occurrence of nail disease in the picture above? Give reasons and explain them according to your own thoughts logically!

- Make sure your feet and hands stay dry, as dry skin and nails are not easily infected with nail fungus.
- Do not cut the nail too short, because it can cause injury to the nail. Also keep the nail cutter clean so that mold does not grow on the tool.
- Use dry socks and change them regularly. Don't wait for it to get damp or wet.
- Choose footwear that is not narrow so that air circulation in the foot area is maintained. For shoes, you can choose shoes made of leather or canvas

11. Originality

Q11: Take a look at the picture below!

Amarita mushroom picture
Source: Greeners.com

Amarita mushroom is one of the poisonous mushrooms. If someone intentionally or unintentionally eats this type of mushroom can cause death. Therefore, this fungus is called a killer fungus. In the United States, the most severe cases of Amanita phalloides mushroom poisoning occurred from November 2015 to October 2016. Most people who are poisoned do not know that the mushroom Amanita phalloides is a poisonous mushroom. *Based on these discourses and images, what efforts can be made to avoid Amarita mushroom poisoning? Give reasons and explain them according to your own thoughts logically!*

Steps that can be taken to avoid toxic fungi are first by recognizing and observing the color and tau of the fungus. Most species of mushrooms that are poisonous are brightly colored and smell unpleasant. In addition to bright colors, poisonous mushrooms are also found brown or dark blackish in color and grow in animal feces. Toxic Fungi is also characterized by milky white discharge.