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The PBL vs. Digital Mind Maps Integrated PBL: Choosing Between the two with a view to Enhance Learners' Critical Thinking

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Critical thinking plays a crucial role in the learning process. Critical thinking should become the focus of learning since it encourages the development of knowledge and includes the act of contemplating subjects, content, and problems. The current study aimed to investigate the effectiveness of Problem-Based Learning (PBL) and Digital Mind Maps-Integrated PBL (DMM-Integrated PBL) in improving students' critical thinking. This quasi-experiment study employed a pretest-posttest control group design, involving 103 university students from the Biology Department of University in Riau, Indonesia, as the sample. The details of each group consist of 31 students in conventional, PBL (37 students), and DMM-Integrated PBL (35 students) classes. The research data was collected using an essay test. The data obtained were analyzed using ANCOVA at a significance level of 5% and an LSD test. Essay test developed based on critical thinking indicators: basic clarification, bases for a decision, inference, advanced clarification, supposition and integration, and strategies and tactics. All the instruments had been validated. The ANCOVA analysis results proved that PBL and DMM-Integrated PBL affected the students' critical thinking. However, the LSD test showed no significant difference between PBL and DMM-Integrated PBL in promoting students' critical thinking. Finally, to promote students' critical thinking, educators are recommended to use PBL or DMM-Integrated PBL in the classroom.

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Introduction

Life in the 21st century demands a type of education that can provide learners with the mastery of various skills to succeed. The 21st century skills include critical thinking, communication, collaboration, creativity, life, and career skills. The learning process should carry out benefits to the students' life, to prepare learners to play prominent roles in society (Fong, Sidhu, & Fook, 2014). The learning process mentioned here is the one that is expected to be able to improve students' critical thinking. Problem-solving requires students to master learning content and engage in critical thinking, data analysis, conclusion, and decision-making processes. Therefore, students need to develop critical thinking skills (Zubaidah et al., 2018).

Critical thinking is the ability to identify and evaluate arguments by applying logical principles (Browne & Keeley, 2010; Facione, 1990; Lin, 2014). To think critically is to think rationally and reflectively to decide what to believe or what to do (Ennis, 2011; Kong et al., 2014; Von Colln-Appling & Giuliano, 2017). It also includes the act of contemplating subjects, content, and problems through analyses, assessment, and reconstruction of ideas to create logical movements (Papp et al.,2014). Critical thinking combines an individual's intellectual ability and attitudes (Yıldırım & Özkahraman,2011) to identify, make a plan, and execute the plan. The quality of an argument constitutes a crucial feature of critical thinking (Lin, 2014). However, according to Halpern (2003), critical thinking is more focused on cognitive skills.

Learners need to think critically to adapt to the changing era (Alper, 2010). Critical thinking should become the focus of learning since it encourages the development of knowledge (Klimovienė, Urbonienė, & Barzdžiukienė, 2006). Through activities such as involving intellectual skills to discuss complex issues (Wang & Woo, 2010) and predict the actions (Butler, Pentoney, & Bong,2017). In particular, university students require critical thinking skills to succeed at college, workplace, and society (Aksu, & Koruklu, 2015; Dwyer, 2017; Gojkov, Stojanović, & Rajić, 2014; McCormick, Clark, & Raines, 2015).

Numerous studies have discussed the definitions of critical thinking. Some approach the term from a more philosophical point of view (Fisher, 2001), while others attempt to explain the term from psychological aspects (Facione, 1990; Halpern, 2010). The philosophical definition of critical thinking emphasizes one's ability to challenge an assumption, evaluate an argument and information, and draw a correct inference (Fisher, 2001). On the other hand, psychologically, critical thinking refers to a broad range of thinking, including problem-solving, decision-making, hypothesis testing, etc. (Halpern, 2010). Critical thinking is defined as the ability to provide judgment to regulate self through interpretation, analysis, and conclusion drawing based on the evidence (Facione, 1990).

Critical thinking involves contextual tasks and problems (Bailin, 1999). Critical thinking is categorized as higher-order thinking consisting of six main indicators: interpretation, analysis, evaluation, inference, clarity, and self-regulation (Facione, 1990). Critical thinking is a process to provide a simple explanation, determine the basis of making a decision, make an inference, clarify the answer, create an assumption and integration, and organize strategies and tactics (Ennis, 2011). One of the key elements of critical thinking is someone's readiness to negotiate with a strong belief because that belief can be a barrier to other people's open-mindedness (Butler, Pentoney, & Bong, 2017). Critical thinkers should be open-minded. They should be able to analyze their own thoughts, ask important questions, collect, and assess information relevant to the thinking (Özkahraman & Yıldırım, 2011).

Colleges or universities as an educational institution aim to prepare the graduates to become a member of a society equipped with excellent academic and professional abilities through critical thinking, and problem solving. Plenty of studies have suggested that Indonesian university students' critical thinking needs improvement (Dwijananti & Yulianti, 2010; Suparni, 2014). That phenomenon may result from several conditions, including the characteristics of the most passive students (Klimovienė et al., 2006) and the characteristics of the university inputs, which were probably lacking in critical thinking, too (Mahanal et al., 2016). Thus, the students' inadequacy to master critical thinking skills should be addressed immediately (Quitadamo, Faiola, Johnson, & Kurtz, 2008).

Due to the central role of critical thinking in learning and the students' inadequacy in mastering these skills, it is necessary to establish a solution to better the students' critical thinking. One of the reasonable efforts that can be made is to implement active learning strategies in the classroom (Kim et al., 2013). Active learning strategies are a series of actions that involve learners in an investigation to collect evidence and apply knowledge in strengthening an argument (Vong & Kaewurai,2016). One of which is Problem Based Learning (PBL).

PBL is a student-centered learning model that contains active learning strategies (Kong et al., 2014; Savery 2006). PBL also encourages students to use real-world issues as a context to learn how to think critically, solve a problem, acquire essential knowledge and concepts (Carriger, 2015; EL-Shaer & Gaber,2014) and learn or practice a range of graduate attributes (Tan, Koppi, & Field, 2016). Therefore, PBL can be implemented to guide the students to achieve the learning objective. By the end of the lesson, the students will solve the problem (Applin et al., 2011; Arends, 2012). The students will become the center of the learning process and thus have more initiative to ask questions, clarify, analyze, and solve problems (EL-Shaer & Gaber, 2014; Hu, Xing& Tu, 2018).

Generally, PBL in the classroom can be implemented through some stages, including problems analysis, independent study, and presentation of the analysis results (Arends, 2012; Hmelo-Silver, 2004). All the steps in PBL are based on an individual's participation in a learning process to enrich their knowledge. The underlying theories of PBL also include contextual theory, discovery theory, information analysis, cooperative learning, and constructivism theory (Hmelo-Silver, 2004; Savery 2006). Some constructivism principles that are relevant to PBL are (1) involving learners' active participation in a problem-solving process, (2) using real-world issues, (3) presenting the problems appropriately, (4) assigning teachers as the facilitator of students' independent study (Hmelo-Silver, 2004; Tseng, Chang, & Lou, 2012).

Several studies have suggested the effectiveness of PBL in improving learners' critical thinking (Gorghiu et al., 2015; Kek & Huijser, 2011; Kong et al., 2014; Mahmoud & Mohamed,2017; Niwa et al, 2016). Integration of PBL with mind maps is also believed to improve students' learning achievement (Hariyadi, Corebima, & Zubaidah, 2018). As mind maps provide a simple overview of complex information, students can understand the concepts' connections (Cuthell & Preston, 2008). Mind maps can help students study better, but they can also develop higher-order thinking in students (Farrand, Hussain, & Hennessy, 2002; Zubaidah et al.,2017).

Mind maps can be established in a digital form (Laampere, Matsak, & Kippar, 2006). This type of mind map is commonly known as a digital mind map (DMM). DMM is a technology-based application that allows an individual to explore and represent ideas and learn cognition distribution (Faste & Lin, 2012). DMM offers more than learning in a mere physical class. Instead, it provides learners with efficient and dynamic learning to develop and organize their ideas using higher-order thinking skills. This technological information tool allows unlimited access to any knowledge so that students can apply their ideas and innovate (Qi, 2018; Wei, He, & Huang, 2018) and provide a good influence on the teacher's way of thinking and develop various other skills (Yilmaz, 2021).

DMM appears as a set of digital hierarchical graphs with color, number, font, and image choices. Each idea creates branches, including subcategories, and examples are drawn logically from ideas (Papushina et al., 2017; Simonova, 2015). Mind maps can help students explore ideas. They can also motivate students to get involved in a process where a higher level of cognition is needed (Noonan, 2012; Rosciano, 2015). DMM is an information technology-based application that can explore and represent concepts (Faste & Lin, 2012; Jbeili, 2013). Unlike paper-based mind maps, DMM is more time-friendly due to its features that ease the process of correcting errors (Jbeili, 2013). DMM also allows learners to explore as many ideas as possible on the map to build their knowledge (Spencer, Anderson, & Ellis, 2013).

The integration of PBL and DMM can hopefully provide a significant opportunity for students with different learning styles and characteristics to use various learning strategies (Jbeili, 2013) and graphic representation in a brainstorming activity (Buzan, 2011). Papushina, Maksimenkova, and Kolomiets (2017) explain that connecting images with concepts involves a lot of creativity. The consistent interface and the hide-and-show feature of DMM can help students concentrate on a specific idea and avoid visual chaos. Students can store various information as files that can be easily picked up. Digital learning has been proven to motivate learners by creating a more fun learning atmosphere (Qi, 2018; Osman & Kaur,2014). The use of multimedia (video, audio, and animation) has been suggested to improve learners' understanding despite their different learning styles (Papushina et al., 2017). The present study aimed to investigate the effects of PBL and DMM-Integrated PBL on students' critical thinking. Research hypothesis in this direction is shaped as follows: there are differences in student critical thinking between PBL and DMM-Integrated PBL.

Methods

Research Design

This experimental research employed a pretest-posttest control group design. The independent variables were the learning models, and the dependent variables were critical thinking level.

Research Sample

The current research was conducted at Universitas Islam Riau, Indonesia. The research population consisted of all biology students. Based on the result of a 30-item multiple-choice test administered before the study, three groups of students with the same academic abilities were selected. Each of the groups consisted of conventional classes (31 students), PBL (37 students), and DMM Integrated PBL (35 students). The number of samples is 103 students.

Research Instruments and Procedures

The current research used a syllabus, lesson plans, students' worksheets, and a test as the instruments on the topic of the circulatory system, excretory system and respiratory system. The students' critical thinking was evaluated using an 18-item essay test developed based on critical thinking indicators suggested by Ennis (2011): basic clarification, bases for a decision, inference, advanced clarification, supposition and integration, and strategies and tactics. This test is used to measure students' critical thinking skills. The test used has been tested for reliability with a score of 0.837 and the validity test also shows that this test is valid.

All the instruments had been validated before they were used in the field. Each instrument's validity score was recorded as follows: 95.42 (valid) for the lesson plans and 94.58 (valid) for the students' worksheets. The instrument's validity score is obtained through a validation sheet that has been filled in by the validator by giving a score to the instrument used. A Pearson product-moment test was performed to test the reliability of critical thinking. The results suggested that tests were reliable, with a score of 0.837 for critical thinking.

The learning process was carried out in a semester (sixteen weeks). During the process, the participants were divided into a small group of three or four. Each of the treatment groups experienced different kinds of learning. The conventional group of students mostly held a discussion and attended the lecturer's presentation who played a dominant role in the classroom. Meanwhile, in the PBL classroom, learning was executed in five stages: (1) the students worked on a problem stated on the worksheet, (2) the students were required to search information relevant to the problems, (3) the students were engaged in a discussion and a collaborative activity to solve the problem, (4) the students wrote a report and shared the results to other classroom members, (5) at the end of the session, the lecturer provided some feedback and together with the students concluded the lesson.

Unlike the PBL and conventional groups of students, the DMM-Integrated PBL students had to (1) organize a digital mind map (DMM) to review their background knowledge and connect it with the concepts they were going to learn, (2) formulate problems, (3) work in a group to prepare references that could support their solutions to the problems, (4) discuss the most appropriate solutions and add more details to the DMM where necessary, (5) write a report and present the findings to the peers, (6) analyze and evaluate the problem-solving process.

Data Analysis

Some prerequisite tests were conducted on the research data to test the normality (Kolmogorov-Smirnov test) and the homogeneity (Levene - test) of the data with a level of significance $p > 0.05$. The normality test result on the students' critical thinking showed that the data were distributed normally with p-values of 0.097. The data had also been proven homogeneous with a p-value>α (α = 0.05). Students' answers to the critical thinking test were scored according to the scoring guidelines. As an example. Score 4, if formulate the question correctly, identify criteria to properly consider possible answers, complete the explanation or answer with examples. Score 3, if formulate the question correctly, identify criteria to properly consider possible answers and unable to complete explanation with examples. Score 2, if formulating the question correctly but the criteria used to provide an explanation are not appropriate. Score 1, when formulating a question but it is not correct and unable to consider possible answers and is not accompanied by examples. Score 0, if unable to formulate questions. The research hypotheses were then examined using ANCOVA at a significance level of 5%. The covariates in this study are pretest values. Pretest was used to control variables that cannot be controlled by the researcher. If the results were significant, the data were further analyzed using the LSD (Least Significance Different) test.

Result

The students' critical thinking score was calculated based on the results of the students' post-test result. There were six aspects evaluated in critical thinking. The comparison of scores obtained by the conventional, PBL, and DMM-Integrated PBL was presented in Figure 1.

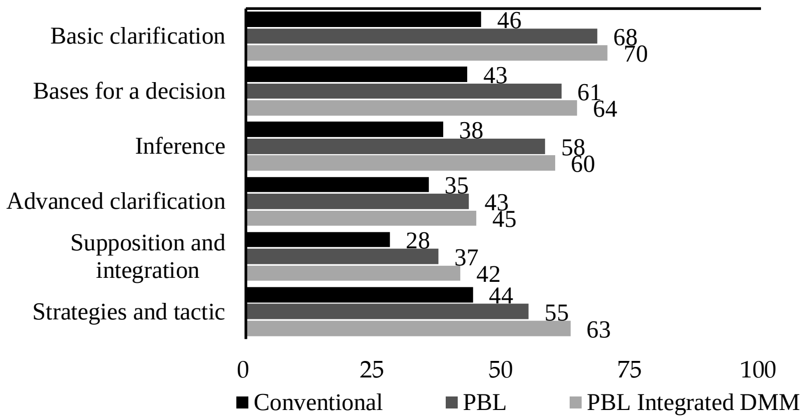


Figure 1. Students' critical thinking scores

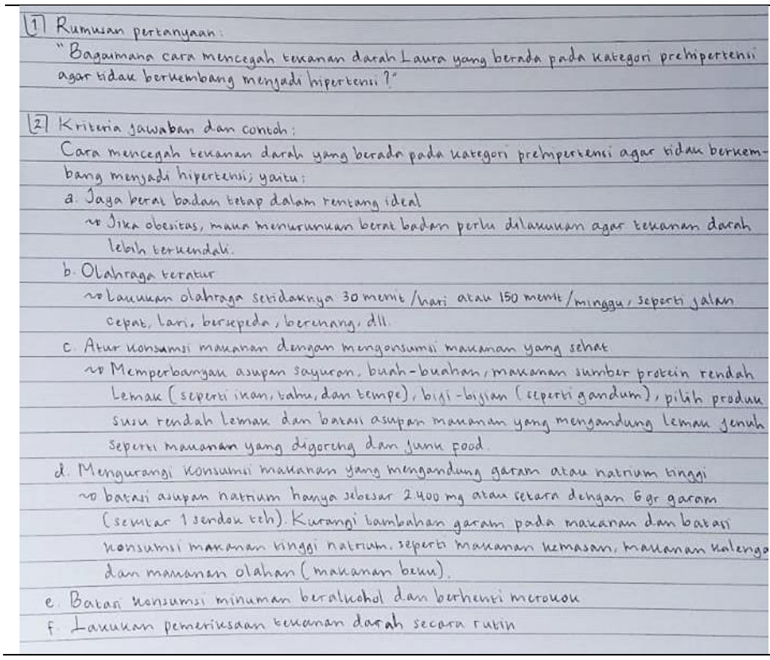
Figure 1 suggested that the highest score of critical thinking was observed in the DMM-Integrated PBL class, followed by the PBL and conventional classes. The critical thinking aspect that ranked first was basic clarification. This finding indicated that the students were able to formulate problems relevant to the contexts presented to them. The above procedure can occur because students are able to formulate problems based on the situation (for example, high blood pressure or hypertension symptoms). The example of student answers can be seen in Table 1.

Table 1. The example of student answers

Question:

Laura is a new student with a variety of activities. This busyness keeps her from having regular exercise, and she has no choice except to consume fast food. Laura felt unwell these few days and checked herself into a doctor. After examination, it was found that Laura's blood pressure was 132/84 mmHg, and she gained rapid weight, approximately 8 kg. The doctor said that Laura's blood pressure was at a pre-hypertension level and could develop into hypertension. Formulate one question based on the conditions above! Then determine the possible answers accompanied by examples!

Answer


1) Rumusan pertanyaan:
"Bagaimana cara mencegah tekanan darah Laura yang berada pada kategori prehipertensi agar tidak berkembang menjadi hipertensi?"
2) Kriteria jawaban dan contoh:
Cara mencegah tekanan darah yang berada pada kategori prehipertensi agar tidak berkembang menjadi hipertensi; yaitu:
a. Jaga berat badan tetap dalam rentang ideal
→ Jika obesitas, maka menurunkan berat badan perlu dilakukan agar tekanan darah lebih terkendali.
b. Olahraga teratur
→ Lakukan olahraga setidaknya 30 menit/hari atau 150 menit/minggu, seperti jalan cepat, lari, bersepeda, berenang, dll.
c. Atur konsumsi makanan dengan mengonsumsi makanan yang sehat
→ Memperbanyak asupan sayuran, buah-buahan, makanan sumber protein rendah lemak (seperti ikan, tahu, dan tempe), biji-bijian (seperti gandum), pilih produk susu rendah lemak dan batasi asupan makanan yang mengandung lemak jenuh seperti makanan yang digoreng dan junk food.
d. Mengurangi konsumsi makanan yang mengandung garam atau natrium tinggi
→ batasi asupan natrium hanya sebesar 2.400 mg atau setara dengan 6 gr garam (sekitar 1 sendok teh). Kurangi tambahan garam pada makanan dan batasi konsumsi makanan tinggi natrium, seperti makanan kemasan, makanan kalengan dan makanan olahan (makanan beku).
e. Batasi konsumsi minuman beralkohol dan berhenti merokok
f. Lakukan pemeriksaan tekanan darah secara rutin

1. Question Formulation:
How to prevent Laura's blood pressure in the pre-hypertension category so as not to develop into hypertension?
2. Answer Criteria:
Laura should make several efforts to keep her blood pressure within normal limits, such as: maintaining weight within the ideal range; doing regular exercise; consuming healthy foods such as vegetables, fruits, low-fat protein sources; reducing the consumption of foods containing high sodium; and doing regular blood pressure checks.

The results of the ANCOVA analysis were depicted in Table 2.

Table 2. The results of the ANCOVA analysis on students' critical thinking

Source	Type III Sum	df	Mean Square	F	Sig.
Corrected Model	9479.243[a]	3	3159.748	68.601	.000
Intercept	3476.244	1	3476.244	75.472	.000
Xcritical thinking	5186.712	1	5186.712	112.608	.000
Class	4571.256	2	2285.628	49.623	.000
Error	3316.306	72	46.060		
Total	223326.075	76			
Corrected Total	12795.548	75			

a. R Squared = .741 (Adjusted R Squared = .730)

Table 2 indicated a significant difference between the learning models in enhancing students' critical thinking (F-calculated = 49.623 and p-value = 0.000). As p-value<α (α=0.05). The significance of each treatment's effects on the students' critical thinking was examined using the LSD test. The results of the test were depicted in Table 3. The results of the LSD test showed no statistically significant difference in critical thinking between DMM-Integrated PBL and PBL groups. However, Table 3 indicated that students' conventional group achieved significantly lower than the other two groups in critical thinking.

Table 3. The Results of the LSD test on students' critical thinking

Class	Pretest	Posttest	Diff	Score Increase	Average Score	Notation
Conventional	26.45	41.04	14.58	55.13%	40.65	a
PBL	25.98	55.81	29.84	114.86%	55.94	b
PBLDMM	25.93	58.90	32.97	127.18%	59.08	b

Discussion and Conclusion

The critical thinking aspect that ranked first was basic clarification. At the basic clarification stage, the students could create multiple interpretations through goals formulation, data selection and examination, and the representation of final conceptualization (Fonseca & Arezes, 2017). Meanwhile, the last place was occupied by supposition and integration. This finding showed that the students could not support their decisions with appropriate reasons or judgment based on relevant theories and facts. Most of the students were unable to decide what a patient might have after they were given the symptoms of pancreatic cancer (e.g., pain on the right side of the abdomen and white stool after consuming high-fat food). That phenomenon is because they could not construct their knowledge based on the theories and facts. Similarly, the study conducted by Amrous and Nejmaoui (2016) proved that students' critical thinking skills, in general, did not yet cover the ability to construct and evaluate arguments. Therefore, their supposition and integration skills were lacking because they failed to consider other logical reasons to support the decision (Ennis, 2011).

Each of the treatment groups in this study achieved differently in critical thinking. The different types of learning processes they experienced might contribute to the result. The students in the conventional group were mostly passive because of the lecturer's dominant role. Student-centered learning process makes students better their achievements including attitudes compared to traditional learning. One example of student-centered learning is problem-based learning (Emanet & Kezer, 2020). They could not think critically since they found some difficulties in seeing the relevance of the presented topics. When learners are only required to receive information from the lecturer, they are trained to be good at memorizing content instead of mastering the ability to diagnose a problem, think about the solution, and create a culture of innovation (Imran, Shamsi, Singh, Goel, Sharma & Panesar, 2015; Şen & Sari, 2018). In contrast, the students in the PBL and DMM-Integrated PBL were more skillful in formulating problems. The students asked many higher-order level questions that could promote their critical thinking (Chikiwa & Schäfer, 2018; Hidayati, Zubaidah, Suarsini, & Praherdhiono, 2020).

PBL was more effective than conventional learning in promoting students' critical thinking (Gorghiu et al., 2015; Niwa et al., 2016). Unlike conventional learning, the PBL process allows students to discuss real problems and try to figure out the solutions in groups. Learners, in this case, are faced with cognitive conflicts. Thus, they are imposed to a situation where they have to interact with their environment and learn from experiences to construct new knowledge (Hmelo-Silver, 2004; Savery, 2006). Also, they need guidance from the teacher as a facilitator (Van Blankenstein, Dolmans, Van der Vleuten, & Schmidt, 2011; Wijnen, Loyens, & Schaap, 2016). PBL can be initiated by learners' hesitation on an ill-structured problem, thus encouraging the students to analyze, synthesize, and manipulate it. The ill-structured problem, in other words, has raised the students' curiosity to solve it (Carriger, 2015). In PBL, students are empowered to do research, integrate theories and practices, and apply knowledge and skills to discover a solution to a problem (Kong et al., 2014)

Both PBL and DMM-Integrated PBL contain authentic problems that require students' higher-order thinking to figure out a solution to a problem (Hu, Xing & Tu, 2018; Savery 2006). In contrast, conventional learning is more dominated by lecturer's explanations and presentations on a particular topic. The PBL and DMM-Integrated PBL students have the same opportunity to explore their ideas and challenge themselves to think critically. During the process, the students are actively engaged in a brainstorming activity, discussion sessions, and reflection because cooperative learning positively affects students' critical thinking skills (Erdogan, 2019).

Also, through PBL and DMM-Integrated PBL, the students are guided to decide or find a solution in this case (Shishigu, Hailu & Anibo, 2018). Making a decision is critical thinking (Ennis, 2011; Papp et al.,2014; Von Colln-Appling& Giuliano, 2017). Therefore, PBL and DMM-Integrated PBL are effective in improving students' critical thinking.

Statistically, there was no significant difference found between PBL and DMM-Integrated PBL in critical thinking. Both classes follow similar stages of learning. The students in both groups are required to study independently. They need to collect information from various sources to figure out which solutions suit the problems. Every student comes to the classroom with different findings and then is required to share the information with other students in a discussion (Hmelo-Silver, 2004; Wijnen, Loyens, & Schaap, 2016).

PBL and DMM-Integrated PBL has been proven to improve students' critical thinking. The development of students' critical thinking should become one of the main focuses of 21st-century education. To succeed in the workplace and to be accepted in society, students also need to possess creative thinking (Ersoy & Başer, 2014; Fuad et al., 2017; Yusnaeni, Corebima, Susilo, & Zubaidah, 2017) and good attitudes (Bachtiar et al.,2018).

The study results indicated that PBL and DMM-Integrated PBL affected students' critical thinking. Integrated PBL are better at promoting students' critical thinking compared to conventional learning. Therefore, it is recommended to implement these learning models in the classrooms. That is to prove why there was no significant difference found between Problem Based Learning (PBL) and Digital Mind Map (DMM)-Integrated PBL groups in enhancing students' critical thinking.

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