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THE EFFECTS OF PROBLEM-BASED LEARNING WITH THINKING MAPS ON FIFTH GRADERS' SCIENCE CRITICAL THINKING

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Abstract. *This research was conducted to evaluate the effects of Problem-based Learning (PBL) with Thinking Maps (TM) teaching method (PBL-TM) on Fifth Graders' science critical thinking. The critical thinking skills evaluated were Comparing and Contrasting, Sequencing, and Identifying Cause and Effect in physical science. A quasi-experimental pre-test and post-test control group design was employed in the research. The sample consisted of 270 Fifth Graders (age 11 years old) from three primary schools in Tawau, Sabah, Malaysia who were all randomly selected and assigned to PBL-TM (n=90), PBL (n=90), and Conventional Problem Solving (CPS) (n=90) teaching groups. The 30-item Test of Science Critical Thinking was used as the pre-test and post-test. The three thinking maps used were Double Bubble Maps, Flow Maps, and Multi-Flow Maps. A MANCOVA was conducted on the post-test scores with students' pre-test scores as the covariates. The result indicated that students in the PBL-TM group significantly outperformed their counterparts in the PBL group who, in turn, significantly outperformed their counterparts in the CPS group in Comparing and Contrasting, Sequencing, and Identifying Cause and Effect. The findings suggest that thinking maps, which were explicitly infused into problem-based learning is effective in promoting critical thinking among Fifth Graders in physical science lessons.*
Key words: *critical thinking, fifth graders, problem-based learning, thinking maps.*

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Introduction

Critical thinking has been identified as one of the key cognitive skills and dispositions in science education. Students who are skilful in critical thinking are considered to be more capable of understanding the scientific process and become more experimental and better at asking questions on the different aspects of the sciences (Tsai, Chen, Chang, & Chang, 2013). The ability to formulate questions is vital for science learners as it is a basis of independent learning and inquiry (Vale, 2013).

Despite the recognition given to the importance of critical thinking in the recently revised Malaysian Primary School Standard Curricula (Curriculum Development Division, 2014), there is a lack of evidence to demonstrate the positive impact of specific learning strategies on promoting subject-specific aspects of critical thinking in primary science lessons. In an affiliated research where no significant differences were revealed in critical thinking between the experimental and control group in primary science lessons (Rashid Alghafri & Ismail, 2014), no details were given as to which learning strategies might have not contributed to students' critical thinking. Tang, Nair and Prachak (2014) examined thinking skills and problem solving skills among Malaysian Fourth, Fifth, and Sixth Graders which focused specifically on general-content-based critical thinking. These observations raised a crucial question: What are the best learning strategies that can help in the development of subject-specific critical thinking among primary students in science lessons?

Learning Environment for Developing Critical Thinking

According to Meyers (1986), the learning environment is made conducive for the development of critical thinking with the presence of four elements: (1) students' interest is stimulated, (2) creation of meaningful discussion, (3) exposure to thoughts and views of others, and (4) fostering of a trusting and supportive atmosphere.

When the principles and processes of PBL are examined, it becomes apparent that the learning strategy actualises those four elements proposed by Meyers. PBL embodies the principle that the starting point of learning is to solve real-world problems (Barrett & Moore, 2012; Savin-Baden, 2004). By presenting students with real-world problems for which students' personal or societal experiences are connected, their interest is aroused (Steinemann, 2003). Once their interest is aroused, they can then be guided to develop their capability to debate and question while solving a given issue or problem. PBL stimulates the diversity of mental processes when students' interpretations differ when debates and questioning take place (Kyriakopoulou & Vosniadou, 2014), thus engaging them in meaningful discussion. Willingness to entertain and understand diverse viewpoints in meaningful discussion enables students to build mental structures necessary for critical thinking (Lai, 2011).

PBL encourages students to work in collaborative groups and share their thoughts and views among group members (Tatar & Oktay, 2011; Droha *et al.,* 2012). Exposure to different viewpoints helps students to realize their own assumptions, as well as to learn to reason from multiple perspectives which indirectly enable students to build mental structures necessary for critical thinking (Abrami *et al.*, 2008). PBL creates a supportive learning community and sustained interaction that explicitly scaffolds learners to learn within social constructivist paradigms, both for the teacher and the student (Cochrane, 2012, p. 125). This PBL philosophy in developing a safe and respectful environment cultivates a trusting and supportive atmosphere. Thus, it can be posited that PBL creates a conducive environment for learning so that students will be able to develop their critical thinking. Indeed, PBL as a component of teaching *for* thinking has been identified as helpful in promoting critical thinking (El - Shaer & Gaber, 2014; Elias & Solomon, 2012; Choi, 2004).

Effects of PBL on Students' Critical Thinking

Despite claims about the positive effect of PBL on students' critical thinking, empirical evidence of the advantages of PBL in Malaysian primary science education is lacking. In a meta-analysis conducted by Najihah and Zaleha (2014) from 2009-2014, there is relatively little research done on the effects of PBL on young learners at the Malaysian primary science level. A review carried out by Masek and Yamin (2011) which included the most recent experimental studies from multiple disciplines between the years 2000 to 2011 showed that research about the effects of PBL on critical thinking were mostly conducted in colleges or universities. Therefore, research is required to examine whether PBL enhances critical thinking in primary school science lessons.

According to Peterson (1997), the success of PBL depends to a large extent on how well students work together to solve problems. Even though group work is an essential component of learning and teaching in PBL, teachers and students continue to experience difficulties related to working with and in groups (Murray-Harvey *et al*., 2013; Pfaff & Huddleston, 2003; Holen, 2000). Peterson (1997) asserted that students in groups who employed a structured problem solving process by utilizing a common set of procedures for thinking, have shown improvements in critical thinking, interpersonal skills, problem solving, and learning. The use of thinking tools as a set of thinking procedures during the PBL process has been proven to increase students' critical-thinking skills (Yeo, 2008; Tseng, Chou, Wang, Ko, Jian, & Weng, 2011).

Thinking Maps are visual representations of thinking that help students see their own learning pathway or the thought processes utilized to solve a problem (Alikhan, 2014). Hyerle and Yeager (2011) found that Thinking Maps help students self-regulate their own learning and be more successful in learning because "Thinking Maps serve as a device for mediating thinking, listening, speaking, reading, writing, problem solving, and acquiring new knowledge". This was also supported by Othman, Ismail, Jaafar, and Samsudin (2014) who noted that thinking maps enhance the skills of, (1) defining concepts, (2) categorizing and organizing information, (3) organizing, (4) comparing the difference, (5) identifying causes and consequences, and (6) analysing and making decisions. These findings raise the question, "To what extent does thinking maps help problem-based learning enhance the ability of primary school students to think critically about science?" Tackling questions such as this, particularly in primary school settings often requires innovative solutions. There is a need to identify an appropriate or integrated teaching approach which allows science teachers to seamlessly examine primary school students' extent of learning and fostering their critical thinking. It is also to ensure that any changes to the curriculum be met with sufficient guidelines about the new teaching methods and how to utilize them in enhancing the critical thinking skills of primary students to their full effect.

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Infusion of Thinking Maps into Problem Based Learning

Costa and Brandt (2001) argue that teaching *about* thinking which focus students' attention on thinking as a subject matter is not enough to help students effectively learn to think. According to them, it is essential to create a classroom climate that stimulates thinking through teaching techniques as what they define as teaching *for* thinking. Swartz and his colleagues propose an infusion approach called *Thinking-Based Learning* (Swartz & Parks, 1994; Swartz *et al.,* 2007), where the thinking skills and the curriculum content are taught simultaneously in a lesson. According to Beyer (1997), a combination of the two components of teaching *about* thinking and teaching *for* thinking makes thinking-based learning more explicit, systematic, clear and focused.

Consequently, this research employed an infusion approach where teaching *about* thinking and teaching *for* thinking are infused into PBL in primary science lesson, namely problem-based learning with thinking maps (PBL-TM). In this teaching method, the students are taught explicitly for more skilful thinking through thinking maps (teaching *about* thinking), and then prompted to use thinking maps to think about the science content they are learning through PBL (teaching *for* thinking). In this research, a thorough infusion was applied, where steps of PBL and thinking Maps were performed simultaneously in each of the science learning process. Thus, this research attempted to examine the effects of PBL-TM on primary students' critical thinking in science.

The Framework for Critical Thinking

The critical thinking framework in this research is based on the *Analysis* thinking framework of Swartz (Swartz & Parks, 1994; Swartz *et al*., 2007) that incorporates specific types of thinking advocated by Ennis (1996) and *analysis* by Bloom taxonomy. Swartz and Parks (1994) consider analysing ideas and arguments as components of *Analysis* (Figure 1). Ennis (1993) further advocates analysing ideas such as comparing and contrasting, classifying, sequencing, and predicting as modes of analysis. Likewise, Bloom correlates this level of thinking process to *Analysis of Relationships* which requires students to illustrate and analyse cause-effect relationships (Krathwohl, 2002). Thinking at the *analysis* level requires a student to diagnose materials, situations, or environments. Students then separate them into their component parts and focus on the relationships among these parts to one another as well as to the total structural organization.

Table 1. Swartz's thinking framework of *Analysis.*

Components of Analysis	Description
Analysing ideas	i. Compare/Contrast ii. Classification/Definition iii. Parts/Whole iv. Sequencing
Analysing Arguments	i. Finding Reasons/Conclusions ii. Uncovering Assumptions

According to Piaget's theory of cognitive development, the developmental stage of the formal operations stage occurs as early as 11 years old and evolves until adulthood. Thus, Fifth Graders at the age of 11 are likely to make the transition from concrete operations stage to formal operational thinking. During the transition stage, children develop the ability to think in a logical way (Inhleder & Piaget, 1958; Pinkney & Shaughnessy, 2013). According to Wolfinger (2000), the ability to formulate hypotheses is one of the most important processes of logical thought or critical thinking. Formulating hypotheses engage student's thinking on causal order, the sequence in which variables are placed. This sequence determines the supposed 'cause' (the independent variable) and 'effect' (the dependent variable).

In the context of the present research, the Fifth Graders acquired the ability to formulate hypotheses and solve problems by producing several possible methods when they attempted to solve science-related activities. Students are required to apply critical thinking skills as required in all Curriculum Standard for Primary Schools (Curriculum Development Division, 2012) such as analysing information by sequencing, categorizing, identifying cause-and-effect relationships, comparing and contrasting, finding the main idea, and drawing conclusions. Thus, assessing critical thinking skills in the *Analysis* component is considered appropriate by considering the cognitive level of Fifth Graders and requirement of primary science curriculum.

The component of *Analysis* is also in tandem with the three types of thinking maps implemented in the 'I-THINK Programme' introduced by the Ministry of Education (Curriculum Development Division, 2012). These three thinking maps are a) Double Bubble map; b) Flow Map; and c) Multi-Flow map. As stated by Hyerle and Yeager (2007), Double Bubble Maps highlights the "Comparing and Contrasting" thinking process; Flow Maps highlight the "Sequencing" thinking process while the Multi-Flow Maps highlight the "Analysing Cause and Effect" thinking process. In relation to this, the critical thinking skills investigated in this research focus only on Comparing and Contrasting, Sequencing, and Identifying Cause and Effect.

Purpose of Research

Past studies indicate that students gain most in their critical thinking when PBL is utilized in their learning process. In connection, a number of studies give evidence that students' critical thinking is cultivated when Thinking Maps (TM) are infused into the learning activities of PBL. Previous research has also shown that TM is most likely to encourage students to go through the process of self-regulation and develop more critical thinking. It appears that TM can be infused into PBL to enhance critical thinking skills such as Comparing and Contrasting, Sequencing, and Identifying Cause and Effect. As yet, little is known on the positive effects of this infusion approach on the subject-specific aspects of critical thinking at the primary school level. Thus, the overall goal of the present research is to find out the extent to which the PBL-TM teaching method would foster students' critical thinking skills such as Comparing and Contrasting, Sequencing, and Identifying Cause and Effect.

In regards to this research, an operational definition of Comparing and Contrasting (CC) refers to the process of finding similarities and differences based on criteria such as characteristics, features, qualities and elements of an object or event; Sequencing (S) refers to skills in organizing objects and information in order based on the quality or quantity or characteristics such as size, length, shape or number; and Identifying Cause and Effect (CE) refers to the process of looking for a cause, or something that makes something else happen, and then look for the effect, or the result of the cause.

This research, therefore, tested the 'Infusion Approach' hypothesis against the 'Non-infusion approach' hypothesis by employing the PBL-TM and PBL intervention method to investigate how far these interventions facilitate students' critical thinking within a PBL-TM and PBL environment. In addition, the research explored the extent to which the PBL-TM and PBL teaching method affected learning compared to the Conventional Problem Solving method (CPS). Thus, three teaching methods were employed in this research: the PBL-TM, PBL and CPS method. Accordingly, the following hypothesis was postulated:

> Students taught via the PBL-TM teaching method will perform significantly better than students taught via the PBL teaching method, who in term will perform significantly better than students taught via CPS teaching method in the critical thinking skills of i) Comparing and Contrasting; ii) Sequencing, and iii) Identifying Cause and Effect.

The purpose of this research was thus to find out the extent to which PBL-TM teaching method could help to promote Fifth Graders' critical thinking skills of i) Comparing and Contrasting; ii) Sequencing, and iii) Identifying Cause and Effect. This research focused on comparisons between two different forms of PBL teaching method, as well as comparisons with non-PBL teaching method in order to determine if other mode of PBL was equally effective in producing desired student outcomes. Consequently, this research was conducted to further investigate if there were any significant differences in student's critical thinking skills between learners who were taught in three different teaching methods.

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Methodology of Research

Research Design

The research employed a quasi-experimental pre-test and post-test control group design to examine the effect of three different teaching methods in the process of teaching and learning on Fifth Graders' critical thinking. The independent variable was the three teaching methods: the PBL-TM and PBL method (Experimental group), and the CPS method (control group). The dependent variables were students' critical thinking skills in Comparing and Contrasting, Sequencing, and Identifying Cause and Effect.

Research Sample

The research population consisted of 4530 Fifth Graders from 59 primary schools in Tawau, Sabah, Malaysia (Tawau District Education Office, 2015). This research was conducted with Fifth Graders in three urban fully government-funded primary schools in Tawau. The three schools were selected based on the similar pre-test mean score gained by its students in the Test of Science Critical Thinking (TSCT). The three urban schools were selected to reduce the demographic differences among the research samples. A total of 270 students were involved, with 90 students selected from each school, with the consent of the school principal and Tawau District Education Office. Students comprised of 141 (52 %) females and 129 (48 %) males aged 11 years old. The three classes in the selected school were randomly assigned to one of the conditions as intact groups: the PBL-TM method, PBL method, or the CPS method. All 270 students participated in the experimental research within the same week, but at different class schedules for a period of nine weeks.

Research Instrument

The effects of the experimental treatments were assessed using a test named the Test of Science Critical Thinking (TSCT) developed by researchers (Mapeala & Siew, 2015). The TSCT consisted of 30 Physical Sciences items, with each 10 questions measuring the critical thinking skills of Comparing and Contrasting, Sequencing, and Identifying Cause and Effect. The 30-item TSCT was found to have relatively high Kuder–Richardson reliability with 0.70, 0.73 and 0.92 for Identifying Cause and Effect, Sequencing, and Comparing and Contrasting, respectively. The content validity index obtained from three expert judgments equalled or exceeded 0.95. In addition, test-retest reliability showed good, statistically significant correlations ($r = 0.76$, $P < 0.01$). The TSCT was also found to have relatively good difficulty index (p) ranged from 0.40 to 0.60 and with good discrimination index (d) ranged within 0.20-1.00.

The TSCT used a double, multiple choice format to present options for answers, and a choice of critical thinking used for each answer. Questions simply asked "Which thinking skills did you use to make this choice?" as an extension of a multiple choice item. Each item required 1.5 minutes to complete and the whole TSCT would take 45 min. The same TSCT was used as pre-test (pre-CC, pre-S, and pre-CE) and post-test (post-CC, post-S, and post-CE) in treatment groups and control group prior to the start of the intervention and after the intervention

The Implementation of the Teaching Methods

PBL-TM

The PBL-TM learning module was developed using Fogarty's (1997) Problem-Based Learning model which was found to have high reliability and validity (Mapeala & Siew, 2016). There were eight steps of Fogarty's (1997) problem-based learning model: (1) Recognizing the problem, (2) Defining the problem, (3) Triggering ideas through questions, (4) Forwarding the hypothesis, (5) Conducting research, (6) Reviewing the best solution, (7) Choosing the best solution, and (8) Presenting the solution.

The PBL-TM learning module consisted of 18 learning activities that studied Energy, one of the Physical Science topics in the Fifth Grade Primary Science Curriculum. Students were prompted to make extensive use of Double Bubble Maps, Flow Maps, or Multi-Flow Maps to think about the energy-related problems given in PBL activities. It was through this process that students would gain benefit from the explicitness of the thinking maps that guide, direct, and stimulate their critical thinking skills. Each learning activity would take about 60 minutes to complete.

The PBL activities were conducted in groups of four to five students. The learning activities were colour printed on A3 size papers. With these papers, all the group members had an equal opportunity to create and expand their own thinking maps using the same activity sheets during the group discussions. In order to establish a meaningful discussion, students shared their thoughts and views with one another, raised questions and entertained viewpoints from peers and facilitators before presenting their thinking maps to the entire class. Students were also urged to show respect towards other students' views and support each other during group discussion. This process enabled students to develop their critical thinking vis-á-vis a trusting and supportive learning environment. Prior to the start of the intervention, the students of the PBL-TM group learned first-hand experience about the three types of TM. They created TM under the facilitation of their teachers. Students were also taught how to behave appropriately in a group discussion. During the intervention, students in their groups created their own TM to solve the given problem.

The problems posed in the module were real-world problems and relevant to the daily lives of the students. One sample of the learning activities related to the problem was: "*Based on the views given by an expert about our excessive dependence on non-renewable sources of energy and its impact on the environment in the article above, discuss with your group members about the similarities and differences of two types of energy pointed out by the expert and present it using an appropriate thinking map*".

Structured questions taken from Swartz and Parks (1998) and Ong (2006) that adhere to Bloom's higher order thinking framework were used to guide students' thinking explicitly as they engaged in the PBL activities. Some examples of the questions were: 'How are they similar or different'; 'What similarities and differences seem significant?' and 'What conclusion can be suggested by the significant similarities and differences?' Students then chose and built a thinking map to explain the best solution to the problem presented in the PBL lessons. Additionally, the Flow Map with sub-sequence proposed by Hyerle and Alper (2011) was also introduced in the activities. Students had to explain briefly the reason the sequence was made by providing reasons or arguments. In order to engage students in critical thinking, the teacher acted as a facilitator to allow for discussion and encourage a freer thought process.

PBL

The teacher of this group continued teaching as the PBL-TM group but the students were not exposed to the Thinking Maps. The students carried out the PBL activities as a group using the learning activities provided in the PBL module. Students were told to solve the given problem using graphic organizers such as mind-maps or concepts maps, which they had been exposed to in some science lessons. Teachers paid little attention to the element of teaching *about* thinking. At the end of the learning sessions, the groups shared their results with the class. Then, the teacher reviewed the day's lesson with the whole class.

CPS

Meanwhile, in the Conventional Problem Solving method (CPS), students solved problems without using the PBL-TM module and thinking maps. Teachers explained the purpose of the learning and then gave a problem to be solved. The given problem and answers to the problem did not necessarily relate to the real life situations. The students tackled the problem individually, and used a textbook or workbook as their main reference.

At the end of the lesson, a post-test was conducted. Students from both the treatment and controlled groups answered the test individually and mean scores were calculated as an indicator of the change of their critical thinking skills.

The Training of Teachers

Teachers who participated in this research were given a two-hour special training and coaching on the implementation of PBL-TM, PBL, and CPS methods prior to the start of the research. Teachers were provided with the complete PBL-TM module which contained information about the concept of PBL, thinking maps, critical thinking skills, and suggested outcomes for each activity. Teachers were also taught how to facilitate the group activities in PBL. The researchers monitored the teachers from time to time through social visits to ensure the consistency and reliability of the implementation. The selection of teachers was based on their willingness and readiness to be involved in the research and who had above 10 years' of experience in teaching science. They were appointed to teach the three classes using the three methods: PBL-TM, PBL, and CPS.

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Data Analysis

Preliminary Analysis

Preliminary analysis was conducted to check whether the prerequisite assumptions of MANOVA / MANCOVA were met. Thus, the assumptions centred to MANOVA / MANCOVA in the statistical analysis were examined for: (a) multivariate normal distribution, (b) equality of group population covariance matrices, (c) linear relationship between covariates and dependent variables, (d) absent of multicollinearity, and (e) homogeneity of dependent variable variance.

Pre-Experimental Research

The purpose of the pre-experimental research was to test the assumption that the respondents across the three teaching groups were equivalent in their prior knowledge of pre-CC, pre-S, and pre-CE. To examine if there were any significant statistical differences among the students' mean scores on pre-CC, pre-S, and pre-CE across the three groups, the one-way multivariate analysis of variance (MANOVA) was conducted. If the overall multivariate test (MANOVA) was not significant, univariate F test (ANOVA) was examined to further identify the presence or non-presence of significant statistical differences between students across the three teaching groups in each of the pre-CC, pre-S and pre-CE.

A multivariate analysis of covariance (MANCOVA) was conducted (with pre-CC, pre-S, and pre-CE as the covariates) to investigate the main effects of the three different teaching methods on students' post-CC, post-S, and post-CE, while controlling the three covariates. By employing the MANCOVA, the extraneous differences among groups can be controlled after removal of the effects of covariates from the dependent variables (Hair, *et al.,* 2010).

If the overall multivariate test (MANCOVA) was significant, univariate F test (ANCOVA) was carried out on post-test mean scores with pre-test mean scores as covariates to further examine if there was a significant statistical main effect of teaching groups on each of post-ccs, post-S, and post-CE.

The assumptions that were used for the MANCOVA/MANOVA and inferential statistics analyses were tested using SPSS for Windows (Version 22). Alpha value was set at 0.05, level of significance. The Wilk's Lambda was used to evaluate the multivariate differences in this research as it is mostly applied in multivariate tests to examine differences between the means of identified groups of subjects on a combination of dependent variables (Everitt & Dunn, 1991). The effect size index (f) was calculated from eta square (η^2). According to Cohen's rough characterization (Cohen 1988, p. 284-288), $0.2 \le f \le 0.4$ is deemed as a small size effect, $0.4 < f \le 0.7$, a medium size effect, and $0.7 < f \le 1.0$, or $1 \le f$ as the large size effect (for interpreting η^2, $0.010 \le \eta^2 \le 0.039$= small, $0.039 < \eta^2 \le 0.11$= medium, and $0.11 < \eta^2 \le 0.20$ = large effect size).

Results of Research

The descriptive statistics of students' pre-test and post-test scores on thinking skills such as Comparing and Contrasting, Sequencing, and Identifying Cause and Effect are summarized in Table 2.

Table 2. Descriptive statistics of the dependent variables.

Dependent Variables	Intervention Group	N	Pre test		Post test	
			Mean	SD	Mean	SD
Comparing and Contrasting	PBL-TM	90	.236	.121	.464	.147
	PBL	90	.226	.114	.366	.127
	CPS	90	.216	.119	.317	.129
	Total	270	.226	.118	.383	.147

Dependent Variables	Intervention Group	N	Pre test		Post test	
			Mean	SD	Mean	SD
Sequencing	PBL-TM	90	.144	.090	.452	.097
	PBL	90	.136	.091	.390	.128
	CPS	90	.140	.102	.282	.115
	Total	270	.140	.094	.374	.133
Identifying Cause and Effect	PBL-TM	90	.133	.100	.438	.111
	PBL	90	.140	.087	.385	.132
	CPS	90	.134	.118	.312	.125
	Total	270	.135	.102	.378	.133

The pre-experimental research results

The results of MANOVA and ANOVA indicated that the participants across the three groups had equivalent pre-test mean scores for Comparing and Contrasting, Sequencing, and Identifying Cause and Effect (Table 3).

Table 3. Summary of multivariate analysis of variance (MANOVA) results and followed-up ANOVA results on pre-test mean scores.

Dependent Variables	Multivariate F	Univariate F
Group Effect	Wilks' Lambda $F(6,530) = .852, p=.530$	
Comparing and Contrasting		$F(2,267) = .641, p=.528$
Sequencing		$F(2,267) = .152, p=.859$
Identifying Cause and Effect		$F(2,267) = .109, p=.897$

Preliminary Analysis

Preliminary analysis indicated adequate conformity to all univariate and multivariate assumptions of MANOVA/MANCOVA for: (a) multivariate normal distribution, (b) equality of group population covariance matrices, (c) linear relationship between covariates and dependent variables, (d) absent of multicollinearity, and (e) homogeneity of dependent variable variance.

Determination of Covariates

The three covariates (pre-CC, pre-S and pre-CE) were predetermined as potential confounding factors prior to conducting the MANCOVA. In order to ensure the variables in the covariate were set to high correlated ones with the dependent variables (Cohen & Cohen, 1983), these potential covariates were correlated with the dependent variables. Pre-CC, Pre-S and Pre-CE had significant correlations with at least one dependent variable (Table 4). Therefore, they remained in the covariate set for the inferential statistics.

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Table 4. Correlation coefficients between covariates and dependent variables.

		Covariates		
		Pre-CC	Pre-S	Pre-CE
Dependent Variables	Post-CC	.149*	-.001	-.006
	Post-S	-.315*	.265*	.250*
	Post-CE	-.068	.274*	.255*

** Correlation is significant at the level 0.01 level (1-tailed)*

The experimental research results

A MANCOVA indicated significant main effects for teaching methods on dependent variables (Wilk's λ =.632, F (6, 524) = 22.527, $p < 0.05$) as shown in Table 5.

Table 5. MANCOVA analysis for group effects.

Wilks' Lambda	F	Hypothesis df	Error df	Sig. of F	Eta Squared $\eta 2$	Effect Size, f
.632	22.527	6	524	< .05	.205	0.5078

Follow-up ANCOVA showed that there were significant main effects of teaching methods on Comparing and Contrasting [$F(2, 264) = 26.302$, $p < .05$, η^2 =.166, f =0.4461], Sequencing [$F(2, 264) = 54.880$, $p < .05$, $\eta^2 = .294$, f = 0.6453], and Identifying Cause and Effect [F (2, 264) = 25.604, $p <. 05$, η^2 =.162, f =0.4397]. A high relationship between the teaching method and dependent variables was obtained, indicating that 16.6% (Comparing and Contrasting), 29.4% (Sequencing), and 16.2% (Identifying Cause and Effect) of the variance obtained was accounted by the teaching methods.

Further testing using the Post hoc Pair-wise test revealed that students in the PBL-TM group significantly outperformed their counterparts in the PBL group ($P_{CC} <. 05$, $P_S =.001$, and $P_{CE}=.009$, respectively), who in turn, significantly outperformed their counterparts in the CPS group ($P_{CC} = .062$, $P_S <. 05$ and $P_{CE} <. 05$, respectively) in Comparing and Contrasting, Sequencing, and Identifying Cause and Effect (Table 5). Therefore, the research hypothesis was supported.

Table 6 shows a large effect size for comparing the PBL-TM and CPS methods in Comparing and Contrasting (1.041), Sequencing (1.616), and Identifying Cause and Effect (1.082), Meanwhile, the analysis showed a moderate to small effect size for the comparison between PBL-TM and PBL in Comparing and Contrasting (0.706), Sequencing (0.554), and Identifying Cause and Effect (0.442). On the other hand, a large to small effect size was observed for comparing the PBL and CPS methods in Sequencing (0.895), Identifying Cause and Effect (0.575), and Comparing and Contrasting (0.367).

Table 6. Summary of post hoc pairwise comparison.

Comparison Group	Mean Difference	Sig.	Effect size	Interpretation
Comparing and Contrasting				
PBL-TM vs PBL	.097	<. 05	0.706	Medium
PBL-TM vs CPS	.143	<. 05	1.041	Large
PBL vs CPS	.047	.062	0.367	Small

Comparison Group	Mean Difference	Sig.	Effect size	Interpretation
		Sequencing		
PBL-TM vs PBL	.062	<. 05	0.537	Medium
PBL-TM vs CPS	.169	<. 05	1.598	Large
PBL vs CPS	.108	<. 05	0.895	Large
		Identifying Cause and Effect		
PBL-TM vs PBL	.052	.011	0.442	Small
PBL-TM vs CPS	.126	<. 05	1.082	Large
PBL vs CPS	.738	<. 05	0.575	Medium

Discussion

Overall, this research finding showed that students taught via the PBL-TM method performed significantly higher than students taught via the PBL method. It was also noted that students taught via the PBL method performed significantly higher than students taught via the CPS method in critical thinking skills of i) Comparing and Contrasting; ii) Sequencing, and iii) Identifying Cause and Effect. A large effect size of more than one (1), and moderate to small effect size for comparing the PBL-TM and CPS method, and the PBL-TM and PBL method respectively indicates that the PBL-TM method is the most effective teaching method amongst the three in promoting thinking skills such as Comparing and Contrasting, Sequencing, and Identifying Cause and Effect among Fifth graders. Overall, students taught via PBL method outperformed those taught via the CPS method with a relatively large to small effect size.

Through the PBL-TM method, students were engaged directly and explicitly to use strategies for more skilful thinking using thinking maps and they were prompted to use thinking maps to think about the physical science problems they were addressing. By putting an emphasis on teaching about critical thinking into physical science instruction, more enhanced effects were gained. This is supported by Swartz *et al*. (2010) who stated that the more explicit the teaching about thinking, the more impact it has on students.

The elements of teaching *about* thinking (TM) and teaching *for* thinking (PBL) were more direct and explicitly infused in the PBL-TM method compared to the PBL and CPS method. Such conditions allowed the PBL-TM group to practice both critical thinking and problem-solving skills more effectively and at the same time learn about the physical science content in groups. When PBL was infused with the utilization of explicit thinking maps with scaffolding by the teacher, an effective learning environment for fostering critical thinking was created. Swartz and McGuinness (2014) also asserted that imposing explicit thinking strategies to an infusion approach together with the scaffolded guidance by the teacher would create a very powerful learning environment for teaching thinking. In addition, a supportive learning environment was provided in the PBL-TM group to stimulate students' interest, initiate meaningful discussion, and expose them to thoughts and views of others with the teacher's guidance. This type of learning environment, according to Meyers (1986) is conducive for the development of critical thinking. As a consequence, students learning with PBL-TM methods were able to outperform their counterparts in the PBL and CPS methods.

On the other hand, students who carried out the PBL activities followed the elements of learning *for* thinking to solve the problem but not the element of learning *about* thinking that encourages thinking. Such a situation could not provide direct and explicit instruction in teaching critical thinking and a deeper mastery of content. Thus, the students did not perform like the students in the PBL-TM group did in skilful thinking. Therefore, the PBL group was unable to develop as much critical thinking skills as students working in the PBL-TM group.

In contrast, the teachers in the CPS group did not expose their students to real-world problems to stimulate the students' interest. No specific attention was given to creating a general feeling of cooperation within the learning groups using thinking maps and PBL. Thus, there were fewer opportunities for students to share their thoughts and views with others as a supportive atmosphere was lacking for meaningful discussion within the groups. The instruction in the CPS method had no inclusion of Meyers (1986)'s conducive learning environment and Swartz and

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his colleagues' Thinking-Based Learning (Swartz & Parks, 1994; Swartz *et al.,* 2007) for the development of critical thinking. Therefore, the students in the CPS group were unable to develop as much critical thinking as students working in the PBL-TM and PBL group.

Comparing and Contrasting skills

The results of the research showed that the PBL-TM method improved the Comparing and Contrasting skills better compared to PBL and CPS method, and PBL method improved Comparing and Contrasting skills better than the CPS method. The Double Bubble Maps used in PBL-TM teaching method were infinitely expandable and had no boundaries (Hyerle & Alper, 2011), thus it helped the students to think more broadly and flexibly about physical science they were learning. Ultimately, as the Double Bubble Maps expanded and integrated with words and symbols on one page of A3 size paper, students were stimulated to illustrate and explain their thought processes boundlessly about the comparison. This directly facilitated the boundless critical thinking among the students.

Double Bubble Map provided a visual framework for students, guiding them through the process of comparing and contrasting. Use of vocabulary such as similar/alike, different, and attribute helped students to internalize these concepts. The PBL-TM method empowers students to suggest patterns and conclusion from the identified significant similarities and differences by creating their own Double Bubble Maps. When students produce Thinking Maps, interaction among the students and their thinking maps occur, which is where the real learning takes place. In line with that, Weis (2011) reported a significant increase in student's ability to compare and contrast in essay writing after instruction with Double Bubble Maps. Students were also found to be able to relate one idea to another and organize their comparisons using a double bubble map.

In addition, the interventions carried out in the PBL-TM group exposed students to structured questions adopted from Swartz and Parks (1998) and Ong (2006) in revealing the similarities and differences between the concepts that were being taught. These structured questions scaffold critical thinking skills through small group discussion. Smith and Szymanski (2013) stated that utilizing questions that adhere to Bloom's higher order thinking could engage students in critical thinking in the classroom. Consequently, PBL-TM provides more opportunities for students to promote Comparing and Contrasting skills compared to the PBL and CPS learning methods.

Sequencing Skills

The results of the research showed that the PBL-TM method improved the skills of Sequencing better compared to the PBL and CPS method, and that the PBL method improved the skills of Sequencing better than the CPS method. The use of Flow Map enabled the PBL-TM group to carry out organizing and logical ordering activities on the objects and information based on the quality or quantity, or their characteristics. These explicit activities facilitated sequential thought processes in PBL-TM group more frequently compared to students in the PBL and CPS method. Williams (2015) also asserted that sequencing skills require a person to focus on discovering some kind of hierarchical and chronological facts, and find out the consequence of actions and decisions, thus it demands rigorous thinking.

Additionally, the Flow Map proposed by Hyerle and Alper (2011) provided a sub-sequence in a visual form for students to briefly explain the features of it, and why the order was made and supported by reasons or arguments. When arguments were presented in diagrammatic form, students were better able to follow extended critical-thinking procedures (Van Gelder, 2005). This activity fit within the analysis and evaluation level of Bloom's Taxonomy. This made the learning activities rich with critical thinking. Khun (2005) supports that arguing can promote the process of metacognition and critical thinking. The PBL-TM group engaged students in frequent arguments that enhanced social interaction and generated more ideas as well as promoted critical thinking for Sequencing.

According to Williams (2011), two important processes in the human brain occur simultaneously, namely the process of building information in sequence and in hierarchy. The use of Flow Map enabled the PBL-TM group to be more capable in analysing and organizing activities in accordance with the sequence and hierarchy that involve more activity of processing information in the human brain. In contrast, students in PBL method tended to analyse such information using general graphic organizers such as mind maps that have defined structures. These severely restrict the space for complete thoughts and ideas (Alikhan, 2014).

Flow Map was also found to be more prone to the process of analysing information in stages through small parts. This action could structure students' critical thinking as a result of the use of the Flow Map. Rosenshine (2002) stated that the effective teaching method for teach something new is to break the cluster of information into smaller parts as it is easily processed by the human brain. As a result, these learning activities help the PBL-TM group to be more capable in sequencing compared to the PBL and CPS groups.

Identifying Cause and Effect

Another finding in this research showed that the PBL-TM method improved the skills of identifying the cause and effect better compared to the PBL and CPS method, and that the PBL method improved the skills of identifying the cause and effect better than the CPS method. The use of Multi-Flow map encouraged the PBL-TM group to analyse the relationship between cause and effect of a phenomenon more explicitly than in the PBL and CPS groups. In connection, Legare (2012) asserts that this kind of activity allows students to become more adept at linking cause and effect and making generalizations in order to understand new information more efficiently. The finding also supports the research of Gillet and Temple (1994), who found that the use of thinking maps such as Multi-Flow maps can improve critical thinking skills such as identifying cause and effect. Alternatively, findings by Mann (2014) show that the Multi-Flow maps not only help students to identify cause and effect but also help to identify the main idea and important information, identify the structure of knowledge, and understand the content of a lesson.

In addition, the 'partial' Multi Flow Map used in the PBL-TM group created two groups of experts to discuss, complete and create a map using their own thoughts on how to solve a given problem. The use of "partial" Multi Flow maps encouraged the students to explain what happens before and after a phenomenon. It could stimulate the students' thought processes in the PBL-TM group to revisit their thinking, which indirectly promotes the process of metacognition skills to make value judgments about positive or negative consequences. According to Daniel (2009), although this metacognition usually occurs in adults, children can also apply this mechanism while carrying out simple tasks.

Problem solving activities using Multi-Flow map also encouraged students to build a hypothesis about the pros and cons of a topic under discussion. This is because students could make in depth analyses about the available information to make judgments on the same situation (Williams, 2011). Learning environments such as this would provide an opportunity for PBL-TM groups to explore and identify comprehensively the relationship between the cause or causes (independent variables) and the effect or consequence (dependent variable). Thus, students were able to see more clearly the relationships between ideas when those relationships were drawn out graphically. According to Wolfinger (2000), this situation is one of the most important processes of critical thinking skills.

As a whole, research findings suggest for a more detailed focus on teaching about critical thinking skills in comparing and contrasting, sequencing, and identifying cause and effect in physical science lessons to help Fifth Graders perform better in problem-based learning.

Conclusions

The present research fills the gap by proposing PBL-TM to foster students' subject-specific critical thinking in primary Physical Science. Overall, Fifth Graders learning with PBL-TM methods were able to use TM as 'strategies' to foster their critical thinking more effectively, compared to PBL and CPS methods. In other words, the more explicit teaching is about thinking, the more impact it has on students. Creating a learning environment that stimulates critical thinking using PBL and normal thinking tools like mind-maps is not a sufficient condition to effectively promote critical thinking within a primary science lesson. Thinking maps that teach about thinking is necessary to help PBL gain maximum effectiveness. This research exhibits that emphasis on teaching about critical thinking in the teaching and learning of primary physical science lessons in PBL (using specific thinking maps like Double Bubble Maps, Flow Maps, and Multi-Flow Maps) would expand students' critical thinking skills in comparing and contrasting, sequencing, and identifying cause and effect.

This research has contributed substantive proof that primary school science teachers need to impart the component of teaching about thinking (TM) and teaching for thinking (PBL) in their science lessons to inculcate critical thinking among students. Interim, this research also supports new research examining the potential effects of an infusion approach using different thinking maps and teaching methods in fostering subject-specific critical thinking among primary school students.

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Although the research findings suggest that primary school students benefited significantly from the PBL-TM infusion method in their critical thinking, its limitation must also be acknowledged. This research involved only 90 students per teaching method, and may not be representative of the Malaysian primary school students' population as a whole. The data in this research were collected after 18 hours of students' learning experiences to analyse its effects quantitatively. Future research will need to employ mixed methods approach with a larger sample size and longer period with extra learning activities compared to the current research to extensively assess the learning effects of infusing TM in a PBL lesson. Further comparison between rural and urban schools would shed light on the extent to which locality influences students' critical thinking in science lessons.

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