Impact of Concept Mapping on Students’ Critical Thinking Skills in Science
(Impak Pemetaan Konsep terhadap Kemahiran Berfikir Kritis dalam Sains)

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ABSTRACT

The lack of students’ critical thinking skills has been a persistent problem in science education. This study aimed to identify the effectiveness of Collaborative Concept Mapping (CCM) and Individual Concept Mapping (ICM) in improving students’ critical thinking skills in science subjects. This study employed quasi-experimental research design that involved 189 form one students from public secondary schools in Malaysia. The manipulated variable in this study is teaching approaches, which includes Collaborative Concept Mapping (CCM), Individual Concept Mapping (ICM) and conventional method (CM). Meanwhile, the dependent variable is students’ critical thinking skills in Science. Data was collected using critical thinking skills diagnostic tests and analysed using one-way ANOVA test. The study showed that the level of critical thinking skills is significantly higher among students in CCM group in comparison to students in ICM and CM groups while there is no significant difference in students’ level of critical thinking skills in ICM and CM groups. This study indicated that CCM approach is effective in improving students’ critical thinking skills in Science, and thus should be integrated into Science classroom learning in secondary schools.

Keywords: Collaborative concept mapping, individual concept mapping, critical thinking skills, Science education, secondary school, Malaysia

INTRODUCTION

The development of thinking skills among students and community is a means to produce citizens who are critical, creative, competent and responsible to the country (Ministry of Education 2015; Marin & Halpern 2011; Sarimah & Shaharom 2008; Ministry of Housing and Local Government 2001). Education is deemed incomplete without prioritizing the development of thinking skills. Hence, a good
education system must invest in efforts to create a society that is capable of thinking and possessing universal standard intellect (Abdul Rahim 1999; Elder & Paul 2008; Sarimah & Shaharom 2008; Scriven & Paul 2004), which is the basis for educated minds (Boyd 2001; Brookfield 1989; Elder & Paul 2008, 2009a, 2009b; Facione 2011; Ghani et al. 2017; Cañas et al. 2017).

Individuals who have acquired and mastered critical thinking skills will be more confident in identifying and solving problems. Using this view, critical thinking could be defined as cognitive action to process information by systematically evaluating ideas through analysing and considering the ideas using various perspectives before accepting them (Bloom & Krathwohl 1956; Abdul Rahim 1999; Anderson et al. 2001; Anderson & Krathwohl 2001; Azizi et al. 2015; Sternberg & Sternberg 2012). Following the view, it is imperative for students to acquire and master critical thinking skills before they could acquire and master creative thinking skills (Anderson et al. 2001; Anderson & Krathwohl 2001; Marin & Halpern 2011; Ghani et al. 2017; Cañas et al. 2017). In the context of Malaysia, thinking skills are known as Critical and Creative Thinking Skills (KBKK) and have been introduced in the national education system during

The Ministry of Education in Malaysia has further outlined three approaches to teach thinking skills in Science education, i.e., ways to think, manner of thinking and about thinking. These approaches are seen as methods to apply critical thinking skills in Science classroom learning and would help students to acquire and apply critical thinking skills. However, existing studies indicated that the teaching of thinking skills is still poorly implemented during Science classroom learning (Ali & Hairul Nizam 2014; Ghani et al. 2017). Moreover, existing studies have suggested that there is a lack of thinking skills among students in schools (Ali & Hairul Nizam 2014; Ghani et al. 2017). Accordingly, there is a need to increase students’ critical thinking skills in schools (Sarimah & Shaharom 2008; Simon 2013; Ali & Hairul Nizam 2014; Ghani et al. 2017) such as by designing and implementing teaching strategies that apply the constructivism theory (Lawson 2001; Sadiah Baharom 2008; Sarimah Kamrin & Shaharom Noordin 2008; Effah Moh et al. 2013; Cañas et al. 2017). The concept mapping approach is one of teaching approaches that are founded based on constructivism theory (Novak & Govin 1984; Novak & Cañas 2004 & 2008; Harris 2008; Bixler et al. 2015; Ghani et al. 2017; Cañas et al. 2017) and thus suitable to be applied within the latest science teaching and learning processes.

LITERATURE REVIEW

Concept mapping approach is a general method that can be used to help any individual or group to describe their ideas about some topic in a pictorial form. The approach is structured and facilitated, which utilizes specific steps to articulate its ideas and to understand the ideas more clearly (Trochim 2006). Similar to the teaching and application of critical thinking skills, concept mapping approach requires students to engage in systematic procedures (Dewey 1933; Novak & Govin 1984; Anderson et al., 2001; Anderson & Krathwohl 2001; Novak & Cañas 2004; 2008; Cañas et al. 2017). Literature suggested that concept mapping approach supports Science learning (Novak 1990; Ali & Hairul Nizam 2014: Cañas et al. 2017; Ghani et al. 2017) and
improves students’ critical thinking skills in Science (Cañas et al. 2017; Ghani et al. 2017). Concept mapping approach could be implemented either in collaborative or individual forms. Collaborative Concept Mapping (CCM) helps students to actively build knowledge or conceptual framework and trains students to use critical thinking skills by helping students to structure a large number of new information into the students’ existing knowledge or conceptual framework, as the students exchange their ideas with other members in a collaborative learning environment (Quitadamo 2000; Harris 2008; Barchok et al. 2013). According to Gokhale (1995), students’ conversation in the collaborative group could stimulate students’ thinking and develop their critical thinking skills. On the other hand, Individual Concept Mapping (ICM) provides an opportunity for students to take their own or individual time to build their knowledge or conceptual framework and to choose and employ suitable knowledge or conceptual framework to understanding their learning topics, and identify and their own abilities and weaknesses (Khajavi & Ketabi 2011). However, very few studies have tested the effectiveness of concept mapping approach in improving students’ critical thinking skills (Cañas et al. 2017). Past studies have employed concept mapping approach to help students to understand concepts within a particular science topic (Roop 2002; Harris 2008; Sadiah Baharoom 2008; Gray 2014; Fan Yan 2015; Richbourg 2015). Furthermore, most studies on concept mapping and and critical thinking skills have been found in areas other than Science education (Vacek 2009; Nirmala & Shakuntala 2011; Bekelesky 2015). Therefore, this study aimed to identify the effectiveness of concept mapping approaches, namely Collaborative Concept Mapping (CCM) and Individual Concept Mapping (ICM), in improving students’ critical thinking skills in Science classroom.

**CONCEPTUAL FRAMEWORK**

This study is based on Cognitive Development Theory (Piaget 1964), Assimilation Cognitive Theory (Ausubel 1968), and Human Constructivism Theory (Novak 1993) as illustrated in Figure 1. The Cognitive Development Theory and Assimilation Cognitive Theory explain how knowledge structures

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**FIGURE 1.** Research conceptual framework
are formed through the mapping of concepts and how understanding of the concepts is giving students the opportunity to acquire critical thinking skills. Additionally, the Human Constructivism Theory (Novak 1993) explains how the meaning was formed by students within the framework of knowledge. The meaning has been organized systematically in each node of students’ concept mapping and allows students to make appropriate judgments on new or existing problems related to students’ life. Solving the life related problems requires students to master elements of critical thinking skills that enables them to evaluate and make decisions and conclusions.

This study is also based on the Social Constructivism Theory (Vygotsky 1978) which emphasizes the importance of the relationship between individuals in the social environment. According to Vygotsky, social interaction between one individual to other individuals is important in the development of students’ cognitive skills. Vygotsky argues that the learning process will be more effective if students learn collaboratively in which they are guided by other students who are more capable than themselves, as well as with the help of teachers. This theory supports CCM approach that assumes students learn collaboratively in a collaborative group while constructing the group’s concept map.

Based in the conceptual framework illustrated in Figure 1, this study developed the following research question: To what extend Collaborative Concept Map (CCM) and Individual Concept Map (ICM) teaching modules effect student’s critical thinking skills in Science?

Following the research question, the study developed the following null hypotheses:

**H₀₁:** There is no significant mean difference in critical thinking skills pre-test score among students who follow the CCM, ICM and CM teaching approaches.

**H₀₂:** There is no significant mean difference in critical thinking skills post-test score among students who follow the CCM, ICM and CM teaching approaches.

### METHODOLOGY

### RESEARCH DESIGN

This study is a quasi-experimental study and employed a Reversed-Treatment Control Group design (Shadish et al. 2002). Table 1 shows the research design of the study.

This design was chosen because it has the advantage of increasing the internal validity of the study. In this study, the second treatment group acts as a “reverse effect” (Shadish et al. 2002) which may occur due to the absence of collaborative components in concept mapping interventions. “Reverse effects” may occur when any parts of the intervention component are eliminated which would cause any interventions not to work as expected. The first treatment group is designed to study the effect of concept mapping with collaborative components on the level of students’ critical thinking skills in Science, while the second treatment group is designed to study the effect of concept mapping with individual components on the level of students’ critical thinking skills in Science. Accordingly, the second treatment group acts as a “reverse effect” detector (Shadish et al. 2002) and aims to control the effect of “Hawthorne” that may exist when implementing a new intervention (Cook & Campbell 1979; Cherry 2008; Burton 2010).

### SAMPLES

The population of the study was a form one students of 13 years old in public secondary schools in a district of Klang in the state of Selangor. Samples of the study involved 189 students in two public secondary schools in Klang. Table 2 shows the sample distribution according to types of groups and interventions. To avoid any interruptions, samples were taken from six existing classrooms in the respective schools because this study was conducted during regular school hours (Campbell & Stanley 1963). However, the treatment and control groups were selected at random.

### TABLE 1. Quasi experimental design

<table>
<thead>
<tr>
<th>Groups</th>
<th>Pre-test</th>
<th>Intervention</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>First treatment</td>
<td>U₁</td>
<td>Xₚ</td>
<td>U₂</td>
</tr>
<tr>
<td>Second treatment</td>
<td>U₁</td>
<td>Xₚ</td>
<td>U₂</td>
</tr>
<tr>
<td>Control</td>
<td>U₁</td>
<td>X₀</td>
<td>U₂</td>
</tr>
</tbody>
</table>

*Note*

U₁ : Pre-test
U₂ : Post-test
Xₚ : Collaborative Concept Map (CCM)
X₀ : Individual Concept Map (ICM)
X₀ : Conventional method (CM)
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INSTRUMENT

Data was collected through critical thinking diagnostic tests that provide pre-test and post-test score of students’ critical thinking skills. The test is a Science test that embodied elements of critical thinking skills. The format of the test is based on the PT3 requirement and are based on the Standard Document of Curriculum and Assessment of Form 1 (DSKP) (Ministry of Education 2015) which consist of multi-form objective questions, limited respond questions and open respond questions (Ministry of Education 2014). The open respond questions are the higher order thinking (HOT) questions which asking the students to analysis data, give ideas based on the correct concepts, valuing and reasoning the choice they choose and detected biased on the stated opinion or concepts. In addition, these items are taken from form one science textbooks and reference books, and collection of actual exam questions based on the Form Three Assessment (PT3) format developed by Ministry of Education (2014). Researcher also used booklets available on the guide to form higher order thinking (HOT) questions by Ministry of Education (2014) and booklets on High-Level Thinking Skills Assessment by Ministry of Education (2013).

As illustrated in Table 3, all of these sources have been used together with the Test Specification Table (TST) to ensure content validity of pre-test, post-test and the scoring rubric. The face validity of pre-test, post-test and the scoring rubric has been established through the analysis of data obtained from questionnaire responded by four experts in Science education field (N=4). The validity of the tests was established based on the percentage value of agreement, whether the criteria set is “excellent” (90% - 100%), “good” (75% - 89%), “moderate” (60% - 74%), and “weak” <60%) (Saelens et al. 2006; Singh et al. 2011). The findings showed that validity value of the pre- and post- test is 97.7%, while the validity value of the scoring rubric is 100%. Based on criteria set by Saelens et al. (2006) and Singh et al. (2011), the findings showed that the tests and rubric have an excellent validity, and thus are able to measure the level of the students’ critical thinking skills in Science. The test was administered for CCM, CIM and CM groups before (pre –test) and after (post- test) the respective intervention was completed.

TABLE 2. Study samples’ profile

<table>
<thead>
<tr>
<th>Total Num.</th>
<th>Groups</th>
<th>Total</th>
<th>Class</th>
<th>Total</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>189</td>
<td>First treatment</td>
<td>63</td>
<td>First treatment 1</td>
<td>32</td>
<td>CCM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>First treatment 2</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Second treatment</td>
<td>62</td>
<td>Second treatment 1</td>
<td>31</td>
<td>ICM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Second treatment 2</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>64</td>
<td>Control 1</td>
<td>30</td>
<td>CM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control 2</td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3. Description of the development of research instrument

<table>
<thead>
<tr>
<th>Element of Critical Thinking</th>
<th>Mark</th>
<th>Source of questions and marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Identifying</td>
<td>5</td>
<td>a. Form Three Assessment (PT3) formats, Ministry of Education (2014)</td>
</tr>
<tr>
<td>2 Compare and contrast</td>
<td>5</td>
<td>b. Guidelines to form Higher Order Thinking (HOT) question items, Ministry of Education (2014)</td>
</tr>
<tr>
<td>4 Create a sequence</td>
<td>5</td>
<td>d. Science Form 1 textbook, Ministry of Education (2016)</td>
</tr>
<tr>
<td>5 Sort according to the preference</td>
<td>5</td>
<td>e. Specifications of Science Curriculum Form 1, Ministry of Education (2011)</td>
</tr>
<tr>
<td>6 Analyzing</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>7 Detecting bias</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>8 Evaluate</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9 Make conclusions</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>
DATA ANALYSIS

Researchers have provided a scoring guideline known as Science Critical Thinking Skills Rubric to ensure consistency of the science test assessment by teachers. The scoring rubric provides analytic and holistic scoring methods for the test and is based on the Standard Document of Curriculum and Assessment of Form 1 (Ministry of Education 2015). Analytic scoring method is the method whereby each correct answer is given points or scores according to their respective weighting. For example, a correct answer for the first question was scored two marks, while a correct answer for the second question is scored one mark. On the other hand, the holistic scoring method is a scoring method of observing every correct key point in answers given by students. Each correct key point is scored one mark. Students will score full marks if they provide correct answers and key points. Holistic scoring method are usually applied to open-ended items such as questions that require students to provide opinions or views and discuss the opinions and views. The study also employed one-way ANOVA test to determine whether there is a significant mean difference in critical thinking skills score among students in CMM, ICM and CM groups.

FINDINGS AND DISCUSSION

The findings showed that there is no significance difference in initial critical thinking skills among students in CMM, ICM and CM groups before the students were being exposed to any intervention. One-way ANOVA test analysis showed in Table 4 indicated that there is no significant mean difference in the pre-test and post-test critical thinking skills score among students in CCM, ICM and CM groups, where \[ F (2, 186) = .209, \ p = .812 \text{ and } p > 0.05 \]. However, the findings indicated that there is a significant critical thinking skill among students in CCM, ICM and CM groups after respective treatments were given to the students. As shown in Table 5, one-way ANOVA test analysis suggested that there was a significant difference in the final critical thinking skills score between the three groups \[ F (2, 186) = 7.951, \ p = .000 \text{ and } p < 0.05 \] after the respective treatments were given to the students.

The study further employed Post-Hoc Scheffe test (Pallant 2011) to test for multiple comparisons between CCCM, ICM and CM groups. As illustrated in Table 6, the analysis showed that there is a significant mean difference of critical thinking skills between CCCM and ICM groups, CCCM with ICM \[ \Delta M = 2.966, \ p = .012 \text{ and } p < 0.05 \] and CCM with ICM \[ \Delta M = 3.705, \ p = .001 \text{ and } p < 0.05 \]. The test also showed that there is no significant mean difference in critical thinking skills between ICM and CM groups, \[ \Delta M = .739, \ p = .755 \text{ and } p > 0.05 \]. Following the analysis, the study indicated that there is a significant difference in critical thinking skills among students in CCCM and ICM groups after the intervention were given to the groups, respectively.

The findings suggested that the CCCM approach is effective in increasing students’ critical thinking skills in comparison to the ICM and CM approaches. The combination of concept mapping learning and collaborative learning methods found in CCCM approach provides multiple learning methods (Basque & Lavoie 2006; Torres & Marriott 2010) that appeals to students. Moreover, there is a

<table>
<thead>
<tr>
<th>TABLE 4. One-way ANOVA analysis for initial critical thinking skills score of the students in all groups of teaching approaches</th>
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</thead>
<tbody>
<tr>
<td>Sum of Square</td>
</tr>
<tr>
<td>Between Groups</td>
</tr>
<tr>
<td>Within Groups</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 5. One-way ANOVA analysis for final critical thinking skills score of the students in all groups of teaching approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of Square</td>
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<tr>
<td>Between Groups</td>
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<td>Total</td>
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sharing session of information/ideas/concepts between students in a CCM group that provides the opportunity for students to think, converse and exchange ideas between members in a collaborative group. For example, if there are four students in a collaborative group, each student would receive information/ideas/concepts three times more than if they were to study individually. In other words, students in the CCM group receive more information/ideas/concepts as a stimulus to think, in which the students would process the received information more often compare that students in ICM and CM groups. Accordingly, such sharing sessions would stimulate students to think and ultimately foster their critical thinking skills as agreed by Gokhale (1995), Bixler et al. (2015), Ghani et al. (2017) and Cañas et al. (2017).

In this relation, literature also suggested that concept mapping (Novak & Cañas 2004, 2008; Harris 2008; Sadiah Baharoom 2008; Kinchin et al. 2014 Cañas et al. 2015; Cañas et al. 2016; Cañas et al. (2017) is a suitable approach to process ‘vast’ and ‘abundant’ information. Concept map has been widely recognized as a tool for managing thoughts (Wheeler & Collins 2003; Novak & Cañas 2004 & 2008; Green 2010; Rosen & Tager 2014; Bixler et al. 2015; Cañas et al. 2016; Cañas et al. 2017; Ghani et al. 2017). Previous studies found that when students receive an abundant of information through the sharing sessions of a collaborative group, students tend to employ cognitive skills such as critical thinking skills to meet the demand of the interactive learning (Walker 2003; Cañas 2004, 2008; Cañas et al. 2012; Kinchin 2014; Chang et al. 2016; Ghani et al. 2017). The study showed that CCM students are actively building their concept map throughout an interactive process in which students are trained to apply critical thinking skills. As indicated by literature, students who practice and train their critical thinking skills will relatively acquire the skills more easily (Novak & Gowin 1984; Novak & Cañas 2004 & 2008; Bixler et al 2015; Cañas et al. 2017).

Although the study found that there is no significant difference in the post-test critical thinking skills score among students in ICM and CM groups, the study indicated that students in ICM group scored higher in the post-test. These findings might be due to the situation that the teachers in the ICM class are more ready to evaluate and reflect on the students’ learning guided by the students’ concept maps in comparison to teachers in CM groups class, as indicated by Johanssen et al. (1997), Novak & Cañas (2004 & 2008) and Cañas et al. (2017). In this study, teachers are more likely to identify the level of knowledge attained by students just by looking at the development of Science concepts on the concept map developed by the students in ICM group (Novak & Cañas 2004 & 2008; Cañas et al. 2017).

CONCLUSION

The aim of the study was to identify the effectiveness of CCM and ICM in improving students’ critical thinking skills in Science. The study found that the concept mapping approach, particularly CCM approach, was effective in helping secondary students to acquire and foster critical thinking skills across Science subject. Accordingly, the study suggested that if students are given appropriate supports to develop concept map collaboratively,
the collaborative concept mapping approach would help students to learn Science and acquire critical thinking skills. Thus, CCM could be used as a complementary approach in science classroom to foster students’ critical thinking skills in science. More future research should be conducted to investigate the details of concept map and how the concept map impact students’ acquisition of critical thinking skills across science subjects.

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