Jurnal Pendidikan Malaysia 44(1) Isu Khas (2019): 83-92
DOI: http://dx.doi.org/10.17576/JPEN-2019-44.01SI-07

Impact of Concept Mapping on Students' Critical Thinking Skills in Science

(Impak Pemetaan Konsep terhadap Kemahiran Berfikir Kritis dalam Sains)

Fatin Azhana Abd Aziz* & Lilia Halim

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

ABSTRAK

Kelemahan kemahiran berfikir kritis dalam kalangan murid sekolah merupakan masalah yang masih belum dapat diselesaikan dalam pendidikan sains. Kajian ini bertujuan untuk mengenalpasti keberkesanan pendekatan Pemetaan Konsep Kolaboratif (PKK) dan Pemetaan Konsep Individu (PKI) dalam meningkatkan kemahiran berfikir kritis murid sekolah menengah. Kajian ini menggunakan rekabentuk kajian eksperimen kuasi yang melibatkan 189 murid tingkatan satu sekolah menengah harian di Malaysia. Pembolehubah yang dimanipulasikan dalam kajian ini adalah kaedah pengajaran pemetaan konsep kolaboratif (PKK), pemetaan konsep individu (PKI), dan pengajaran konvensional (PK). Sementara itu, pembolehubah bersandar terdiri daripada kemahiran berfikir kritis murid dalam Sains. Data telah diperolehi melalui ujian diagnostik kemahiran berfikir kritis dan dianalisis dengan menggunakan ujian ANOVA satu hala. Dapatan kajian menunjukkan bahawa tahap kemahiran berfikir kritis murid-murid dalam kumpulan PKK adalah lebih tinggi secara signifikan berbanding dengan kumpulan PKI dan PK. Analisis data juga menunjukkan bahawa tidak terdapat perbezaan tahap kemahiran berfikir kritis secara signifikan antara murid-murid yang berada dalam kumpulan PKI dan PK. Kajian ini menunjukkan bahawa pendekatan PKK adalah efektif dalam meningkatkan kemahiran berfikir kritis dalam sains dalam kalangan murid sekolah menengah dan perlu diaplikasi dalam proses pengajaran dan pembelajaran sains di sekolah menengah.

Kata kunci: Pemetaan konsep secara koloboratif, pemetaan konsep individu, kemahiran berfikir kritis, pendidikan sains, sekolah menengah, 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 revision of the Secondary School Integrated Curriculum (KBSM) in 1988. Later, the revision of the Secondary School Standard Curriculum (KSSM) in 2017 has further reinforced the importance of KBKK in the curriculum when the revised curriculum stated that its aspiration among others are to create critical, creative, innovative and skilful citizens who embark on Science, Technology, Engineering and Mathematics (STEM) necessary to achieve developed nation status (Ministry of Education 2015).

Despite the curriculum revision, students' critical thinking skills in Malaysia is considered low in comparison to other Asian countries, as shown by Malaysia's achievement in International Trends in International Mathematics and Science Study (TIMSS) 2015. Malaysia recorded an average score of 471 points which is below the international average score of 500 points and placed lower than a few other Asian countries (Education Policy Planning and Research Division, Ministry of Education 2016). Very similar to elements of critical thinking skills found in KBKK, TIMSS measures the ability of students to solve problems critically rather than memorizing facts. Composing of items measuring cognitive domains related to knowledge (30%), application (35%) and reasoning (35%), the domains require students to compare, classify, use a model, make connection, interpret information, find solutions and explain. Furthermore, the reasoning domain requires students to analyse, synthesize, develop a hypothesis, design, conclude, generalize, and evaluate.

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

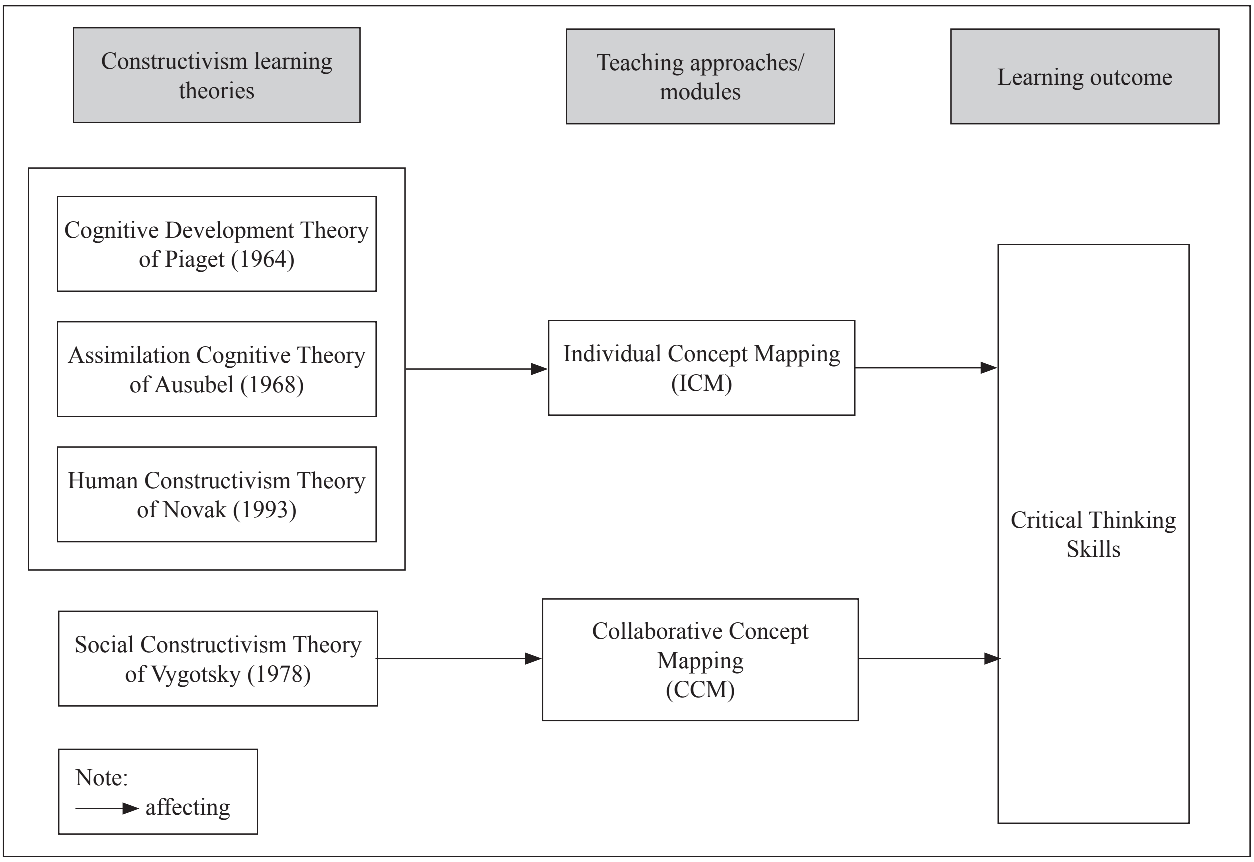

FIGURE 1. Research conceptual framework

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:

Ho_1: There is no significant mean difference in critical thinking skills pre-test score among students who follow the CCM, ICM and CM teaching approaches.

Ho_2: 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). Table1 shows the research design of the study.

TABLE 1. Quasi experimental design

Groups	Pre-test	Intervention	Post-test
First treatment	U_1	X_+	U_2
Second treatment	U_1	X_-	U_2
Control	U_1	X_0	U_2

Note
U1 : Pre-test
U2 : Post-test
X_+ : Collaborative Concept Map (CCM)
X_- : Individual Concept Map (ICM)
X_0 : Conventional method (CM)

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 2. Study samples' profile

Total Num.	Groups	Total	Class	Total	Intervention
189	First treatment	63	First treatment 1	32	CCM
			First treatment 2	31	
	Second treatment	62	Second treatment 1	31	ICM
			Second treatment 2	31	
	Control	64	Control 1	30	CM
			Control 2	34	

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 3. Description of the development of research instrument

Element of Critical Thinking		Mark	Source of questions and marks
1	Identifying	5	a. Form Three Assessment (PT3) formats, Ministry of Education (2014) b. Guidelines to form Higher Order Thinking (HOT) question items, Ministry of Education (2014) c. Standard Document of Curriculum and Assessment of Form 1 (DSKP), Ministry of Education (2015) d. Science Form 1 textbook, Ministry of Education (2016) e. Specifications of Science Curriculum Form 1, Ministry of Education (2011)
2	Compare and contrast	5	
3	Collect and classify	5	
4	Create a sequence	5	
5	Sort according to the preference	5	
6	Analyzing	5	
7	Detecting bias	5	
8	Evaluate	5	
9	Make conclusions	5	
Total		45	

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 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 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 CCM and ICM groups, CCM with ICM [ΔM = 2.966, p = .012 and p <0.05] and CCM with ICM [ΔM = 3.705, p = .001 and p <0.05]. The test also showed that there is no significant mean difference in critical thinking skills between ICM and CM groups, [ΔM = .739, p = .755 and p> 0.05]. Following the analysis, the study indicated that there is a significant difference in critical thinking skills among students in CCM and ICM groups after the intervention were given to the groups, respectively.

The findings suggested that the CCM 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 CCM approach provides multiple learning methods (Basque & Lavoie 2006; Torres & Marriott 2010) that appeals to students. Moreover, there is a

TABLE 4. One-way ANOVA analysis for initial critical thinking skills score of the students in all groups of teaching approaches

	Sum of Square	df	Mean Square	F	Sig. (p)
Between Groups	1.509	2	.754	.209	.812
Within Groups	672.819	186	3.617		
Total	674.328	188			

TABLE 5. One-way ANOVA analysis for final critical thinking skills score of the students in all groups of teaching approaches

	Sum of Square	df	Mean Square	F	Sig. (p)
Between Groups	486.086	2	243.043	7.951	.000
Within Groups	5685.353	186	30.566		
Total	6171.439	188			

TABLE 6. Post Hoc Scheffe test analysis of students between groups of teaching approaches

Dependent Variable: final critical thinking skills						
(I) teaching approaches	(J) teaching approaches	mean difference (I-J)	Std. Error	Sig. (p)	95% Confidence Interval	
					Lower Bound	Upper Bound
1 CCM	2 ICM	2.966*	.989	.012	.53	5.41
	3 CM	3.705*	.981	.001	1.28	6.13
2 ICM		-2.966*	.989	.001	-5.41	-.53
	1 CCM	.739	.985	.755	-1.69	3.17
	3 CM	-3.705*	.981	.001	-6.13	-1.28
		-.739	.985	.755	-3.17	1.69
3 CM	1 CCM	2.966*	.989	.012	.53	5.41
	2 ICM	3.705*	.981	.001	1.28	6.13

*The mean difference is significant at p = 0.05

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.

REFERENCES

Abdul Rahim Abdul Rashid. 1999. *Kemahiran Berfikir Merentasi Kurikulum*. Shah Alam: Penerbit Fajar Bakti Sdn Bhd.

Akbariah Mohd. Mahdzir. 2009. Penerokaan ciri-ciri psikometrik instrumen pentaksiran pemikiran kraitis Malaysia (IPPKM) dan model pemikiran kritis Malaysia. Tesis Dr. Fal, Fakulti Pendidikan, Universiti Kebangsaan Malaysia.

Ali S. R. Alghafri & Hairul Nizam Ismail. 2014. The effects of intergriting creative and critical thinking on school students' thinking. *International Journal of Science and Humanity* 4(6): 518-525.

Anderson, L.W., Krathwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Pintrich, P.R., Raths, J. & Wittrock, M.C. 2001. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Pearson, Allyn & Bacon.

Anderson, L.W. & Krathwohl, D.R. 2001. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Longman.

Ausubel, D.P. 1968. *Educational Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston.

Azizi Yahaya, Noordin Yahaya dan Zurihanmi Zakariya. 2005. *Psikologi Kognitif*. Skudai: Penerbit Universiti Teknologi Malaysia.

Barchok, K.H., Too, J.K. & Ngeno, K.J. 2013. Effect of collaborative concept mapping teaching strategy on students' attitudes towards chemistry in selected secondary schools in kenya. *Asian Journal of Social Sciences & Humanities* 2(2): 1-11.

Basque, J. & Lavoie, M. C. 2006. Collaborative concept mapping in education: Major research trends. In *Concept Maps: Theory, Methodology, Technology - Proceedings of the Second International Conference on Concept Mapping*, edited by San Jose, Costa Rica: Universidad de Costa Rica. Bekelesky G.M. 2015. Critical thinking development in undergraduate Dental Hygiene students. Disertasi Dr. Pendidikan (Ed.D), Grand Canyon University.

Bixler, G. M., Brown, A., Way, D., Ledford, C. & Mahan, J. D. 2015. Collaborative concept mapping and critical thinking in fourth-year medical students. *Clinical Pediatrics* 54(9): 833–839.

Bloom, B.S. & Krathwohl, D. R. 1956. *Taxonomy of Educational Objectives: The Classification of Educational Goals, by a committee of college and university examiners*. Handbook I: Cognitive Domain. NY, NY: Longmans, Green

Boyd, K. 2001. Critical thinking tests and higher education research. Disertasi Ph.D. Georgia State University.

Brookfield, S. D. 1989. *Developing Critical Thinkers: Challenging Adults to Explore Alternative Ways of Thinking and Acting*. San Francisco, Oxford: Jossey-Bass Publishers.

Burton, J. 2010. *WHO Healthy Workplace Framework and Model: Background and Supporting Literature and Practices*. http://www.who.int/occupational_health/healthy_workplace_framework.pdf. [16 April 2015]

Campbell, D. T. & Stanley, J. C. 1963. *Experimental and Quasi-Experimental Designs for Research*. Chicago: Rand Mcnally.

Cañas, A. J., Novak, J. D. & Reiska, P. 2015. How good is my concept map? Am I a good Cmapper? *Knowledge Management & E-Learning (KM&EL)* 7(1): 6-19.

Cañas, A. J., Reiska, P. & Novak, J. D. 2016. Is my concept map large enough? In *Proceedings of the Seventh International Conference on Concept Mapping* (Vol. 1). Berlin: Springer.

Cañas, A. J., Reiska, P. & Möllits, A. 2017. Developing higher-order thinking skills with concept mapping: A case of pedagogic frailty. *Knowledge Management & E-Learning,* 9(3): 348-365.

Cook, T. D. & Campbell, D. T. 1979. *Quiasi-experimentation: Design and Analysis Issues for Field Settings*. Chicago: Rand McNally.

Creswell, J.W. 2008. *Educational Research: Planning, Conducting and Evaluating Quantitative and Qualitative* Research. Edisi ke-3. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Cherry, K. 2008. *Hawthorne Effect*. http://psychology.about.com/od/hindex/g/def_hawthorn.htm. [26 Disember 2015]

Daley, B. J., Shaw, C. R., Balistrieri, T., Glasenapp, K., & Piacentine, L. 1999. Concept maps: A strategy to teach and evaluate critical thinking. *Journal of Continuing Education in Nursing* 27(1): 17-27.

Dewey, J. 1933. *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process*. Boston: D.C. Heath & Company.

Dick, W. 1996. The Dick and Carey model: will it survive the decade? *Educational Technology Research and Development* 44(3): 55-63. doi: http://dx.doi.org/10.1007/BF02300425.

Education Policy Planning and Research Division, Ministry of Education. 2016. Laporan TIMSS 2015-Trends in International Mathematics and

Science Study. Kuala Lumpur. Perpustakaan Negara Malaysia. ISBN 978-983-3444-96-0

Effah Bte Moh @ Hj Abdullah, Othman Bin Lebar, Abd. Aziz B. Abd. Shukor, & Mohd. Uzi Bin Dollah. 2013. Kesan model konstruk pengetahuan berstruktur (KPB) terhadap anjakan sikap terhadap pembelajaran biologi pelajar. *Jurnal Pendidikan Sains & Matematik Malaysia* 3(2).Elder, L. & Paul. R. 2008. *The Thinker's Guide to Intellectual Standards. Foundation for Critical Thinking*. Dillon Beach, California.

Elder, L. & Paul. R. 2009a. *The thinker's guide to analytic thinking. Foundation for Critical Thinking*. Dillon Beach, California.

Elder, L. & Paul. R. 2009b. *The aspiring thinker's guide to critical thinking. Foundation for Critical Thinking*. Dillon Beach, California.

Fan Yan. 2015. Mapping students' ideas about chemical reactions at different educational levels. Disertasi Ph.D. University of Arizona.

Facione, P. A, 2011.*Think Critically*. Pearson Education: Englewood Cliffs, NJ.

Ghani, I. B. A., Yahaya, N. A., Ibrahim, N. H., Hasan, M. N., & Surif, J. 2017. Effects of concept mapping in laboratory learning activities to generate students' higher order thinking skills in electrolysis. *Advanced Science Letters* 23(4): 2779-2782.

Gokhale, A. A. 1995. Collaborative learning enhances critical thinking. *Journal of Technology Education* 7(1): 1-5.

Gray, N. 2014. Development of a concept exploration based teaching Methodology for undergraduate chemistry education. Disertasi Ph.D, Graduate Faculty, University of Alabama.

Green, M. A. 2010. Evaluation of concept mapping as a strategy to enhance critical thinking. Science Master Thesis. Graduate School, Ball State University.

Harris, D. 2008. A comparative study of the effect of collaborative problem-solving in Massively Multiplayer Online Game (MMOG) on individual achievement. Disertasi Ph.D. University of San Francisco.

Hawkins, D., Elder, L. & Paul, R. 2006. *The Thinker's Guide to Clinical Reasoning*. Foundation for Critical Thinking, Dillon Beach, California.

Higgins, S., Mercier, E., Burd, L. & Joyce-Gibbons, A. 2012. Multi-touch tables and collaborative learning. *British Journal of Educational Technology* 43(6): 1041–1054

Johanssen, D. H., Reeves, T., Hong, N., Harvey, D. & Peters, K. 1997. Concept mapping as cognitive learning and assessment tools. *Journal of Interactive Learning Research* 8(1): 289-308.

Johnson. 2007. *Contextual Teaching and Learning: Exciting Make Teaching and Learning Activities and Meaningful*. Bandung, Indonesia: Mizan Learning Center.

Kamisah Osman,Wahidin & Subahan Mohd Meerah. 2013. Concept mapping in Chemistry lessons: Tools for inculcating thinking skills in chemistry learning. *Journal of Baltic Science Education* 12(5): 666-681.

Khajavi, Y. & Ketabi, S. 2011. Influencing EFL learners' reading comprehension and self-efficacy beliefs: The effect of concept mapping strategy. *Porta Linguarum* 17(1): 9-27.

Kinchin, I. M. 2014. Concept mapping as a learning tool in higher education: A critical analysis of recent reviews. *The Journal of Continuing Higher Education* 62(1): 39-49.

Khajavi, Y. & Ketabi, S. 2011. Influencing EFL learners' reading comprehension and selfefficacy beliefs: The effect of concept mapping strategy. *Porta Linguarum* 17(1): 9-27.

Lawson, A.E. 2001. Using the learning cycle to teach biology concepts and reasoning patterns. *Journal of Biological Education* 35(4): 165-168.

Leach, B.T. & Good, D.W. 2011. Critical Thinking Skills as Related to University Students Gender and Academic Discipline. *International Journal of Humanities and Social Science* 1(21): 100-106.

Marin, L.M. & Halpern, D. F. 2011. Pedagogy for developing critical thinking in adolescents: Explicit instruction produces greatest gains. *Thinking Skills and Creativity* 6(1): 1-13.

McInerney, M. & Fink, L., D. 2003. Team-based learning enhances long-term retention and critical thinking in an undergraduate microbial physiology course. *Microbiology Education* 4(5): 3-12.

Ministry of Education. 2011. *Spesifikasi Kurikulum Sains Tingkatan 1*. Putrajaya.

Ministry of Education. 2012. *Membudayakan Kemahiran Berfikir*. Putrajaya.

Ministry of Education. 2013. *Pentaksiran Kemahiran Berfikir Aras Tinggi*. Putrajaya.

Ministry of Education. 2014. *Kenyataan akhbar Kementerian Pendidikan Malaysia berkaitan Pentaksiran Tingkatan 3 tahun 2014*. http://www.Ministry of Education.gov.my/v/pemberitahuan-view?id=4547 [18 Disember 2015].

Ministry of Education. 2015. *Dokumen Standard Kurikulum dan Pentaksiran Sains Tingkatan 1*. Putrajaya.

Ministry of Education. 2016. *Sains Tingkatan 1*. Shah Alam, Selangor: Karangkraf Network Snd. Bhd.

Ministry of Housing and Local Government. 2001. Rangka Rancangan Jangka Panjang Ketiga (RRJP3) 2001-2010. Kuala Lumpur: Percetakkan Nasional Malaysia Berhad.

Nirmala, T. & Shakuntala B. S. 2011). Concept mapping – An effective tool to promote critical thinking skills among nurses. *Nitte University Journal of Health Science* 1(04): 21-26.

Novak, J. 1990. Concept mapping: A useful tool for Science education. *Journal of Research in Science Teaching* 27(10): 937-949.

Novak, J. 1993. How do we learn our lesson?. *Journal of Research in Science Teaching* 60(3): 50-55.

Novak, J.D. & Cañas, A.J. 2004. Building on new constructivist ideas and CmapTools to create a new model for education. *Proceedings of the First International Conference on Concept Mapping*, 469-476.

Novak, J. D. & Cañas, A. J. 2008. The Theory Underlying Concept Maps and How to Construct and Use Them. Technical Report IHMC CmapTools 2006-01 Rev 01-2008. Florida Institute for Human and Machine Cognition.

Novak, J. D. & Gowin, D. B. 1984. *Learning How to Learn*. New York and Cambridge, UK: Cambridge University Press.

Pallant, J. 2011. *SPSS Survival Manual*. Edisi ke-4. Crows Nest NSW, Australia: Allen & Unwin.

Piaget, J. 1964. in Piaget, J. 1994. Cognitive Development in children: Piaget Development and Learning. *Journal Research in Science Teaching* 1(2): 176-186.

Quitadamo I.J. 2002. Critical thinking in higher education: The influence of teaching styles and peer collaboration on science and math learning. Ph.D. Dissertation, Washington State University.

Richbourg, J.A. 2015. Concept Mapping as a Tool for Enhancing Self-Paced Learning in a Distance Scenario. Ph.D. Dissertation, Walden University.

Roop, K.M. 2002. Effect of Concept Mapping as a Learning Strategy on Certificate Practical Nursing Students' Academic Achievement and Critical Thinking Development. Ed.D. Dissertation, Wilmington College.

Rosen, Y. & Tager, M. 2014. Making student thinking visible through a concept map in computer-based assessment of critical thinking. *Journal of Educational Computing Research* 50(2): 249-270.

Sadiah Bharom. 2008. Kesan paduan kitar pembelajaran dan pemetaan konsep terhadap konsepsi pelajar tentang pembahagian sel. Ph.D. Dissertation, Universiti Sains Malaysia.

Sarimah Kamrin & Shaharom Noordin. 2008. Tahap penguasaan pemikiran kritis murid sains tingkatan 4. *Jurnal Pendidikan Universiti Teknologi Malaysia* 13(10): 58-72.

Scriven, M. & Paul, R. W. 2004. Defining critical thinking. A statement for the national council for excellence in critical thinking instruction. Foundation for Critical Thinking. Santa Rosa, California.

Shadish, W.R., Cook, T.D. & Campbell, D.T. 2002. *Experimental and Quasi-experimental Designs for Generalized Causal Inference*. Boston, NY: Houghton Mifflin Company.

Simon, N.A. 2013. Simulated and virtual science laboratory experiments: improving critical

Sternberg, R. J. & Sternberg, K. 2012. *Cognitive Psychology*. Ed. ke-6. Belmont, California: Wadsworth. thinking and higher-order learning skills. Ph.D. Dissertation, Northcentral University.

Styron, R.A. 2014. Critical Thinking and Collaboration: A Strategy to Enhance Student Learning. *Systemics, Cybernetics and Informatics*12(7): 25-30.

Torres, P.L. & Marriott R.C.V. 2010. Handbook of Research on Collaborative Learning Using Concept Mapping. Hershey, New York: Information Science Reference (an imprint of IGI Global).

Vacek J. 2009. Using a conceptual approach with concept mapping to promote critical thinking. *Journal of Nursing Education* 48(1): 45-8.

Vygotsky, L.S. 1978. *Mind and Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Walker, S. E. 2003. Active learning strategies to promote critical thinking. *Journal of Athletic Training* 38(3): 263-267.

Wheeler, L. A. & Collins, S. K. R. 2003. The influence of concept mapping on critical thinking in baccalaureate nursing students. *Journal of Professional Nursing* 19(6): 339–346. doi: 10.1016/S8755-7223(03)00134-0.

Fatin Azhana Abd Aziz
Fakulti Pendidikan
Universiti Kebangsaan Malaysia
Emel: fatinazhana@yahoo.com

Lilia Halim
Fakulti Pendidikan
Universiti Kebangsaan Malaysia
Emel: lilia@ukm.edu.my

*Author for correspondence, email:
fatinazhana@ yahoo.com

Submitted: 8 April 2019
Reviewed: 15 May 2019
Accepted: 3 July 2019
Published: 20 September 2019