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The Effects of Integrating Computer-based Concept Mapping for Physics Learning in Junior High School

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It generally is accepted that concept mapping has a noticeable impact on learning. But literatures show the use of concept mapping is not benefit all learners. The present study explored the effects of incorporating computer-based concept mapping in physics instruction. A total of 61 9th-grade students participated in this study. By using a quasi-experimental research approach, 31 students were assigned to a group that received computer-based concept mapping assisting instruction (CBCM), and 30 students were assigned to a constructive activities group that received "Work, Power, and Energy Curriculum" instruction without concept mapping assistance (NCM). Both groups participated for eight weeks, with four sessions per week and 45 minutes per session. A pre test-post test control group design was employed. The findings revealed that the CBCM group students scored higher than the NCM group students on the cognition understanding and higher order thinking subtests. No significant differences were found in the conception memorization subtest. In the retention test, the students in the CBCM group outperformed the students in the NCM group on all subtests. The results of the current study revealed that concept mapping activities effectively promote higher order thinking and knowledge retention.

Keywords: computer-assisted instruction, physics learning, computer-based concept mapping

INTRODUCTION

One important objective of science education is the enhancement of learners' scientific literacy, including but not limited to science conceptual understanding,

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science procedural skills, and problem-solving abilities (*American Association for the Advancement of Science*, 1993). How effectively students solve problems depends on their domain knowledge structure, processing skills, and attitudes. Therefore, learners' conceptual understanding and its application have always been regarded as one of the most important research issues in science education (Budak & Kaygin, 2015; C.-Y. Chang, Yeh, Lin, Chang, & Chen, 2010; Eylon & Linn, 1988).

It generally is accepted that concept mapping has a certain role in the improvement of learning in science classrooms (Derbentseva, Safayeni, & Canas, 2007; Didis, Ozcan, & Azar, 2014). Concept mapping is based on the principle that meaningful learning occurs when individual learners actively construct hierarchically their cognitive structures regarding a specific topic (Novak & Gowin, 1984). Concept mapping presents the hierarchical structure of students' ideas with an emphasis on the relations between concepts and their manifestations; previous theoretical studies have recognized that concept mapping can provide the necessary framework for students to interpret and organize their knowledge (Tsai, Lin, & Yuan, 2001). Kinchin (2001) suggested that the concept map is helpful for students to integrate new knowledge and build on their existing naïve concepts. Halford (1993) emphasized that the practice of constructing concept maps can develop students' representations and organization abilities.

State of the literature

- It generally is accepted that concept mapping has a certain role in the improvement of learning in science classrooms
- The use of concept mapping is not beneficial to all types of targeted scientific literacy skills in individuals
- Concept mapping may especially benefit students' information integration and higher order abilities because concept mapping has been widely regarded as a metacognitive tool for science learning

Contribution of this paper to the literature

- The study addresses an important issue of exploring the effects of incorporating computer-based concept mapping in physics instruction
- Computer-based concept mapping effectively promotes higher order thinking and knowledge retention
- Students reported that they preferred the environment with the concept mapping assisting instruction

However, the use of a concept map may not benefit all learners. In a study of 132 high school students in six 50-minute periods of an electrochemistry course, Brandt et al. (2001) reported that there was no significant effect on learning from concept mapping or the combination of concept mapping with visualization. Pankratius & Keith (1987) also found no significant difference in the achievement tests of ninth-grade physical science students who were taught to construct concept maps and the students who were not. Stensvold & Wilson (1992) observed 180 high school chemistry students and reported that there were no significant differences on the comprehension test between the students who constructed concept maps and the students who did not. Stensvold & Wilson then argued that the lack of differences between the groups can be attributed to the differential interactions of individual student abilities with the instructional technique.

The inconsistent results of these studies show that there is insufficient evidence to determine whether students who use concept mapping have better outcomes than students who do not use concept mapping. The lack of robust findings may be because the use of concept mapping is not beneficial to all types of targeted scientific literacy skills in individuals. We hypothesize that concept mapping may especially benefit students' information integration and higher order abilities because concept mapping has been widely regarded as a metacognitive tool for science learning. For example, concerning basic science literacy acquisition, Brandt (2010) argued that concept mapping can sometimes complicate rather than facilitate knowledge acquisition. Eppler (2006) also suggested that the overall pattern of concept mapping does not necessarily assist memorability. To our best knowledge, previous concept mapping research has rarely investigated its effects on the different goals of science literacy. This study attempted to fill this gap by conducting such an inquiry.

Computer-based concept map instruction for learning and experimentation

The traditional approach to construct a concept map is usually with paper and pencil. It is generally accepted that the paper-and-pencil approach has certain limitations and drawbacks. These limitations include the following: (1) this approach is inconvenient for the interaction or communication between the teacher and students over time, e.g., to provide appropriate feedback to students; (2) it is difficult to revise; and (3) it is complex and difficult to construct, especially when there is a lack of appropriate training and guidance (K. E. Chang, Sung, & Chen, 2001). Compared with paper-based maps, using computers as a concept mapping tool provides timely feedback from the instructor to the respondents. Computer-based concept maps can facilitate the construction and modification of nodes, links and structure (Reader & Hammond, 1994). Moreover, teachers can more efficiently evaluate students' concept maps without the constraints of time and location (Reader & Hammond, 1994; Tsai et al., 2001). More importantly, computers can provide a framework for helping students to construct concept maps.

Integration of computer-based concept mapping and "Work, Power, and Energy" instruction

In Taiwan, the conception of "Work, Power, and Energy" that underlies introductory physics courses is crucial to science education, as described in the Science and Life Technology Curriculum Standards (Grades 1–9) and Physics Curriculum Guidelines (Grades 10–12). Because the processes by which "Work, Power, and Energy" occur are an integral component of science education, it is crucial to design appropriate instructional tools that relate to this topic. However, the principles and phenomena of "Work, Power, and Energy" are abstract and cannot be observed directly; therefore, students often experience cognitive overload, develop misconceptions, and become disoriented when studying this topic. Essentially, the characteristics of the conceptual relations among work, power, and energy are highly structured. A previous study showed that solidifying the structures of students' conceptions facilitates higher order thinking such as problem solving and conceptual applications (Robertson, 1990). Computer-based concept mapping is widely recognized and can serve as a powerful tool for students to construct their mental models more structurally.

For this study, we attempted to develop a computer-based concept mapping tool to assist "Work, Power, and Energy Curriculum" instruction. This tool utilized computer concept mapping-based instruction to improve learners' cognitive structure and learning performance. We assess student performance, including conception memorization, understanding, and application. We hypothesize that the computer-based concept mapping tool may especially benefit the development of students' higher order abilities.

METHODOLOGY

Participants

A total of 61 9th-grade students from a public senior high school that is located in the northern region of Taiwan participated in this study. By using a quasi-experimental research approach, 31 students were assigned to a group that received computer-based concept mapping assisting instruction (CBCM), and 30 students were assigned to a constructive activities group that received instruction without concept mapping assistance (NCM). These two groups did not show significant differences in their prior knowledge ($p > 0.05$).

Design of the instruction

The "Work, Power, and Energy Curriculum" covers five subunits, namely, work and power, kinetic and potential energy, energy conservation, law of the lever and static equilibrium, and simple machines. The course length is seven weeks with four lessons per week and 45 minutes per lesson. In each unit, educators teach by using lectures, questioning, and cooperative discussion.

CBCM and NCM are designed for 5E model constructivist activities. The students in the CBCM group were asked to create a concept map after each unit, whereas the students in the NCB group were asked to take notes and reflect on the content.

To help the students familiarize themselves with the CBCM tools, the CBCM group students first had two lessons to learn how to create concept maps. The course introduced concept maps and how to represent them with pencil and paper, as well as on a computer. The teacher demonstrated the software functions and taught the students concepts regarding depiction, links (lines), linking words, appropriate fonts, and image use. To help the students learn, a scaffolding strategy was adopted to reduce the students' anxiety that may result from unfamiliarity with concept mapping. The concept mapping scaffold included (1) major concept identification, (2) using linking words to describe the relations among the main concepts, (3) sub-concept identification, (4) using linking words to describe the relations among the sub-concepts, and (5) a concept map review. During the course, concept mapping was introduced in three stages. In the teacher demonstration stage, the teacher asked the students to browse the textbook and highlight important passages that the teacher then introduced and provided examples of these passages in ordinary life. During this stage, the teacher used computers to depict concept maps according to the scaffolding. In the teacher guidance stage, the students drew concept maps and the teacher reminded them how to depict the relations among concepts and to preserve logic. After most students finished their concept maps, the teacher chose some of the maps and displayed them with a projector to share and discuss with the students. In the student initiative stage, the students completed concept maps without help from the teacher, and the scaffolding completely faded out. After finishing their concept maps, the students discussed and shared their work with one another.

The NCM course content was similar; however, instead of concept mapping, the NCM group adopted note-taking and reflection. The teacher also employed a scaffolding strategy to teach the students how to take notes. The scaffolding strategy was designed as follows: (1) identify the topic sentences in the article; (2) identify the main point of the article; and (3) create a summary by deletion (identify the main context and delete the redundant, repetitive, or unimportant messages), generalization (use one word or sentence to replace all the items or incorporate related sentences), and rewriting (rephrase the structured summary and modify the sentences with linking words). Similar to CBCM, the NCM strategy was introduced in three stages from teacher guidance to student initiative.

Concept mapping tool

The Florida Institute for Human and Machine Cognition (IHMC, http://cmap.ihmc.us/) developed a concept mapping tool, CmapTools, which features an easy-to-use operation interface, easy annotation (on each concept (node)), and a free server (Derbentseva et al., 2007). Figure 1 shows the simple CmapTools interface. After creating two concepts, students can link these two concepts together. Blank space and lines automatically appear to remind students to enter linking words to finish the proposition. Students can easily use this tool to create concept maps.

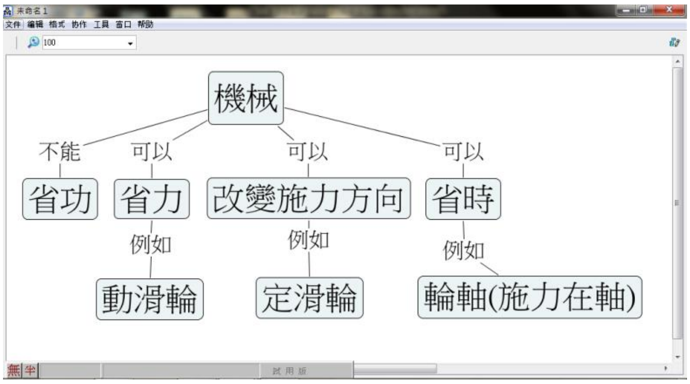


Figure 1. CmapTools operation interface

Because the CmapTools server has been used worldwide, users can share their concept maps and exchange ideas by using this platform. Because of its ease of use, CmapTools is suitable for junior high school students; therefore, this study employed CmapTools to assist in concept mapping.

Learning performance instruments

To measure student learning performance concerning conception memorization, understanding, and application, we constructed and developed the "Work, Power, and Energy" Conception Test (WPECT). The WPECT is a 32-questions multiple-choice test. A panel of specialists, including three university professors and three high school teachers, established the content validity of the WPECT. These specialists checked the degree of alignment of the test items with the important concepts that were introduced in the Work, Power, and Energy Curriculum. The reliability coefficient was estimated to be 0.92 for the present sample of the study by using the Kuder–Richardson formula 20 (KR-20). Table1 illustrates examples of the items of the WPECT.

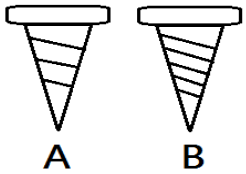
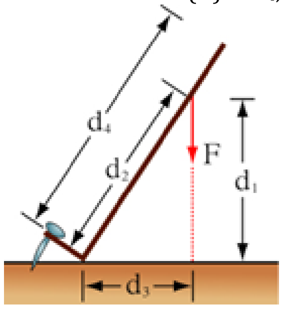
Research design and procedures

A quasi-experimental, two-group pre test-post test design was used in this study. The data collection consisted of four phases. The first two phases were (1) assessing the students' prior knowledge and (2) implementing the Work, Power, and Energy Curriculum for 7 weeks. All subjects were assigned to one of two groups, either CBCM or NCM. (3) In the third phase, the students' learning performances were evaluated by using the WPECT. (4) In the fourth phase, to measure retention of knowledge, all the students' learning performances were evaluated by using the WPECT 4 weeks later. A post-instruction interview was also performed to obtain the students' and teacher's perceptions regarding the instruction. The teacher and all students were interviewed by well-trained instructors immediately following the instruction.

Data analysis

A univariate analysis of covariance (ANCOVA) was conducted (with the pre test as the covariate) to analyze how the students' conceptual understandings were affected by the instruction. The assumptions that were used for the ANCOVA and the inferential statistical analyses were tested by using SPSS version 22.0.

Table 1. Examples of the contents of the "Work, Power, and Energy" Conception Test

Category	**Number of items**	**Example**
Conception Memorization	7	Regarding work and power, which of the following is correct? (A) A unit of power can be joule/second. (B) Work is the ratio of force and displacement. (C) The joule is the unit of power. (D) Watt represents the unit of work. 
Conception Understanding	6	Which of the screws below saves more force? Which saves more work? (A) A saves force, and B saves more work. (B) B saves more force, and A saves more work. (C) A saves more force. Neither saves work. (D) B saves more force. Neither saves work.
Conception Application	19	Mi removes a nail with a nail puller. The size and direction of the applied force F is shown in the figure. Mi has two problems to solve: (1) What is the moment of her applied force? (2) What is the direction of the nail's resisting moment? Please help Mi find the correct answer from the following descriptions. (A) F×d_1, clockwise (B) F×d_2, counterclockwise (C) F×d_3, counterclockwise (D) F×d_4, clockwise  John conducted an experiment with four bowling balls and recorded their volumes, densities, and velocities in the following table. Which of the comparisons of their kinetic energies is correct? (A) D>B=C>A (B) B=C>D>A (C) D>B>C>A (D) A>B>C>D

Ball	volume (cm^3)	density (g/cm^3)	velocity (m/s)
A	6	2	1
B	8	1	2
C	1	8	2
D	1	2	3

RESULTS

The Effects of the computer-based concept mapping Instruction on the Post Test

As shown in Table 2, the ANCOVA analysis showed that there was no significant main effect for conception memorization, $F(1, 58) = 0.09$, $p = 0.76$. However, a significant main effect was observed between the two groups of students for the conception understanding and conception application subtests, namely, $F(1, 58) = 5.93$, p=0.02 for conception understanding and F(1, 58)= 3.72, p=0.001 for conception application. The pair-wise test revealed that the CBCM group outperformed the NCM group in the conception understanding and conception application scores (see Tables 3).

The Effects of the computer-based concept mapping Instruction on the Retention Test

Furthermore, the current study revealed that the participants in the CBCM group retained more knowledge than the participants in the NCM group. As shown in Table 4, the ANCOVA analysis showed that there were significant main effects in the two

Table 2. ANCOVA results of posttest corrected according to pre test

	Source of variance	SS	Df	MS	F	P
Conception Memorizing performance	groups	.12	1	.12	.09	.76
	Pre test	155.47	1	155.47	120.52	<.001
	Residual	74.82	58	1.29		
Conception Understanding performance	groups	9.08	1	9.08	5.92	.018
	Pre test	107.36	1	107.36	70.08	<.001
	Residual	88.85	58			
Conception Application performance	groups	43.50	1	43.50	13.72	<.001
	Pre test	598.30	1	598.30	188.73	<.001
	Residual	183.86	58	3.17		

Table 3. Pair-wise comparisons of the CBCM and NCM groups concerning the adjustments performance on the post test

		M_{adj}	SE	Pair-wise comparison
Conception Understanding performance	CBCM	3.67	0.22	$P = 0.018$
	NCM	2.90	0.22	
Conception Application performance	CBCM	8.77	0.32	P<0.001
	NCM	7.07	0.33	

CBCM: computer-based concept mapping assisting instruction
NCM: instruction without concept mapping assistance

Table 4. ANCOVA results of retention test corrected according to pre test

	Source of variance	SS	Df	MS	F	P
Conception Memorizing performance	groups	21.17	1	21.17	13.22	.001
	Pre test	181.33	1	181.33	113.21	<.001
	Residual	92.90	58	1.60		
Conception Understanding performance	groups	10.25	1	10.25	7.81	=.007
	Pre test	159.74	1	159.74	121.71	<.001
	Residual	76.12	58	1.31		
Conception Application performance	groups	96.38	1	96.38	18.92	<.001
	Pre test	649.38	1	649.38	127.45	<.001
	Residual	295.52	58	5.09		

Table 5. Pair-wise comparisons of the CBCM and NCM groups concerning the adjustments performance on the retention test

		M_{adj}	SE	Pair-wise comparison
Conception Memorizing performance	CBCM	4.61	0.23	P = 0.001
	NCM	3.43	0.23	
Conception Understanding performance	CBCM	3.88	0.21	P = 0.007
	NCM	3.06	0.21	
Conception Application performance	CBCM	9.34	0.41	P < 0.001
	NCM	6.82	0.41	

groups of students concerning their conception memorization, understanding, and application, namely, (F (1, 58)= 13.22, p = 0.001 for conception memorization, F(1, 58) = 7.81, p = 0.007 for conception understanding, and F(1, 58) = 18.92, p = 0.001 for conception application. Pair-wise tests revealed that the CBCM group outperformed the NCM group on the retention test in conception memorization, understanding and application (Table 5).

The results obtained in the interview

The teacher and students' interview data were transcribed and content analysis was used to analyze the narrative data (Table 6 and 7). In the post-instruction interview, more than 71% of the students in the CBCM group reported that they

Table 6. Examples of students' responses to the interview

	CBCM	NCM
I preferred the environment with the concept mapping(CBCM group)/ note-taking(NCM group) assisting instruction	71%	57%
The teacher knows where I have learning difficulties.	68%	30%
I like the interaction with the teacher during the course.	81%	60%
This course is creative.	35%	30%
After this course, I am confident that I can apply what I learned to real life.	42%	33%
I can learn and deliberate on each concept in detail in class.	45%	27%

Table 7. Examples of teachers' response to interview

My role in the classroom was like a facilitator.
Teachers should pay attention to students' learning anxiety during their concept mapping work. Drawing a concept map may be difficult for some students, and these students may feel anxious and frustrated when they cannot finish their concept map.
The concept mapping software had a positive impact on physics learning
I think the cooperative concept construction is worth further study.

preferred the environment with the concept mapping assisting instruction. Only 57% of the students in the NCM group clearly indicated that they preferred the learning environment that the teacher constructed. Compared with the NCM group of 8 students (27%), fourteen students (45%) in the CBCM group reported that they could learn and deliberate on each concept in detail in class. More than 68% of the students in the CBCM group and 30% of the students in the NCM group reported that they perceived that the teacher understood how well the students currently comprehended a specific concept.

DISCUSSION

The present study compared the relative effectiveness of computer-based concept mapping assisting with no computer-based concept mapping assisting instruction in the "Work, Power, and Energy Curriculum" instruction. We focused on exploring the impacts of the instructions on student conception memorization, understanding, and application. The findings revealed that on the post test, the CBCM group scored better than the NCM group in the cognition understanding and higher order thinking subtests. No significant differences were found on the conception memorization subtest. On the retention test, the CBCM group outperformed the NCM group on all subtests.

Many studies provide evidence that a concept map is a useful tool to improve learning (Derbentseva et al., 2007; Didis et al., 2014). Some explanations can account for the beneficial effects of concept mapping tools. First, constructing concept maps may facilitate cognitive representations of the information in both verbal and visuospatial cognitive strategies. The connections between verbal and visuospatial codes provide additional retrieval paths for both types of information. Moreover, the concept mapping strategy is more likely to trigger metacognitive engagement. The metacognitive process may promote deeper understanding and the development of higher order cognitive abilities than instructions that do not involve a concept mapping strategy.

The previous studies that have explored the effect of concept mapping to assist learning appear to mainly compare concept mapping with traditional ways (e.g., text only or didactic instruction); however, these studies have rarely compared a concept mapping strategy with other constructive strategies. The findings of the current study revealed a trend that scientific conception learning can be better enhanced when students receive computer-based concept mapping to assist physics instruction (CBCM) than when they write summaries and outlines (NCM).

This study also found that concept mapping effectively promotes knowledge retention. The CBCM group outperformed the NCM group on all subtests of the post test and retention test, except for the concept memorization subtest of the post test. This finding may help us to better understand the effects of concept mapping on cognitive abilities. Previous studies concerning the effects of concept mapping on learning performance have yielded inconsistent results. We suggest that the previous inconsistent effects may have been because of several factors. First, a concept mapping strategy is likely to trigger higher order cognitive engagement. Second, a concept mapping strategy may be more effective than other strategies for knowledge retention.

Nesbit et al. conducted a meta-analysis in 2006 to review the learning effects of concepts maps. Nesbit et al. reported that concept mapping is beneficial to learning outcomes, both for a multiple-choice test and an open-ended test. Notably, the study showed that the performances on the multiple-choice test were associated with a lower mean effect size, and the performances on the open-ended test were associated with a high mean effect size. Studies have indicated that multiple-choice formats may be appropriate with questions that assess the memorization of key points and definitions. In contrast, open-ended questions that elicit constructed responses and give students a higher degree of freedom in reasoning may be a better foundation to evaluate higher-order thinking (Chang, & Barufaldi, 2010; Ilhan, Sozbilir, Sekerci, & Yildirim, 2015; Wang, Chang, & Li, 2008; Yeh et al., 2012). Many studies also note that it is difficult to develop multiple-choice test items to assess higher cognitive skills (Chang et al., 2010; Hsiao et al., 2014; Wang et al., 2008). These studies support the finding of the post test outcome of the current study, where the concept mapping strategy was more likely to promote higher order abilities.

The previous research that has reported inconsistent effects of the concept mapping strategy have tended to use an immediate post-instruction outcome construct to evaluate learner achievement (Brandt et al., 2001; Stensvold & Wilson, 1992). The studies involving concept mapping have rarely investigated its effects on long-term retention. The results of the current study revealed that a concept mapping strategy is beneficial to knowledge retention. Concept mapping is consistent with the principles of instruction that arise from constructivism. During the learning process, learners actively construct a cognitive structure (map) regarding a specific topic by themselves. Novak (1990) described this process as "meaningful learning" and argued that it is the foundation of human constructivism. Therefore, the construction of a concept map, which likely serves as a scaffold, is intended to develop more refined, integrated, and structured knowledge frameworks (Poehler & Prediger, 2015). We speculate that the refinement concept structure has a profound influence on long-term memory formation. Moreover, effective memory retrieval requires a specification of the context in which the target information was encoded (Kolodner, 1983; Tulving & Thomson, 1973). Thus, a more structured knowledge framework may facilitate the construction's retrieval on the retention test.

Table 6 shows the proportion of all students who responded in certain ways during the interview regarding their perceptions and opinions concerning the "Work, Power, and Energy Curriculum". Many students have described that the computer-based concept-mapping tool help them to integrate their knowledge, and make inferences that related to the specific concepts because the concept mapping functioned as a framework for their mental representations, and help them to interact with teacher. Our findings suggested that the computer-based concept-mapping tool is effective for learning.

The teacher (L) in this study shared during an interview the ideas and experiences that informed his views on the computer-assisting concept mapping strategy. Teacher L referred to his role as a facilitator in the classroom. He also advocated the use of the computer-assisted concept mapping for science learning. Teacher L believed that teachers should pay attention to students' learning anxiety during their concept mapping work. Drawing a concept map may be difficult for some students, and these students may feel anxious and frustrated when they cannot finish their concept map. Therefore, educators should first help students to build their confidence, which can be accomplished by beginning with simple concepts, allowing students to draw simple concept maps, and then gradually showing them how to integrate complex concepts. In addition, during this procedure, feedback from the educator and other students had a positive influence on student confidence.

Teacher L believed that the software had a positive impact on learning. The software has a built-in recording function that records the students' actions that the educator can then use to understand the students' thinking processes and misconceptions to guide them in developing the concepts correctly. Students can also review their own process and compare them with other students to better understand concept mapping.

Teacher L also suggested that cooperative concept construction is worth further study. In this study, the students had high learning motivations when learning concept mapping. The educator noted that cooperative concept construction was integrated, and the students were divided into small groups to complete the concept maps together. During this process, sharing and the discussion with peers increased overall learning motivation. However, educators may find that, in this scenario, students with lower grades may be less motivated to participate; thus, feedback should be given frequently.

Implications and Limitations

This study provided evidences that concept mapping effectively promotes higher order cognition and knowledge retention. The results revealed that the concept mapping can be effectively used cover a wide range of physics topics (content general) because systematic approaches and higher order abilities are essential for solving variety of physics situations in the modern world. It would be interesting to conduct a sequence of experiments to observe the effects of concept mapping on physics instruction in general, and the topics taught in specific. For example, concept mapping may especially benefit on assisting applied physics topics (e.g. semiconductor) learning because applied physics is a study which is highly interdisciplinary and intended for particular technological or practical use. The use of concept mapping may provide the necessary framework for students to integrate and organize interdisciplinary knowledge in physics topics learning.

This study has a number of limitations. The small- to middle-sample size in this study not only remind us of the need to generalize results more cautiously in a practical sense, but also to suggest further replicated studies conducted in this research area. In addition, we acknowledge that future studies in different groups, such as in students of different culture origins, are especially important to validate further the effect of the concept mapping tools.

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