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CONCEPT MAPPING TO PROMOTE MIDDLE SCHOOL STUDENTS' COHERENT UNDERSTANDING IN SCIENTIFIC INQUIRY: A QUASI-EXPERIMENTAL STUDY BASED ON SCOOTERS UNIT

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Abstract. Inquiry learning is one of the basic pedagogies widely used in science education. In a scientific inquiry activity, learning is sometimes not that efficient and students' understanding of science concepts is always fragmented. Concept mapping is a useful tool for representing and organizing of knowledge structures. Knowledge integration framework (KI) is a well-structured scientific inquiry pattern, suggesting a general instructional pattern that involves eliciting ideas, adding ideas, distinguishing ideas and organizing ideas. This study explores the effects of concept mapping in different knowledge integration processes (eliciting or organizing) during learning *Scooters* on WISE (Web-based Inquiry Science Environment based on KI). Seventy-one 7th grade students from two classes in a middle school from Beijing participated in this study. The result shows that concept mapping in scientific inquiry activities can significantly promote middle school students' coherent understanding of scientific knowledge. Concept mapping in eliciting phase is more likely to promote coherent understanding than in organizing phase. Moreover, Students' prior knowledge has a significant influence on the effects of scientific inquiry activities.

Keywords*:* concept mapping, scientific inquiry, coherent understanding, eliciting, organizing

1 Introduction

With the development of science and technology, enabling students to gain scientific inquiry experience and accumulating scientific inquiry skills have become a universal consensus in international science education community. The Next Generation Science Standards introduced by the United States and the standards of science curriculum in China both put scientific inquiry as a core idea of science education (NGSS Lead States, 2013; Ministry of Education of the People's Republic of China, 2017).

Although has its irreplaceable advantages, in a scientific inquiry class, learning is not that efficient and students' understanding of science concepts is always fragmented (Crismond, 2001). Students cannot use core science principles to improve the design or experiments. Thus, scientific inquiry class has become a craft-making class, lacking effective knowledge construction (Larmer & Mergendoller, 2010). Through class observation, it was found that in some scientific inquiry classes, teachers and students are only concentrated on inquiry process, failing to organize and internalize the embedded scientific knowledge systematically. Ultimately, they fail to form a consistent scientific knowledge system and generate a coherent understanding of science concepts. For example, in a scientific inquiry class, students were asked to explore the transformation between potential energy, kinetic energy, and thermal energy through modeling. However, students didn't form a coherent understanding of energy conservation. Thus, most scientific inquiry instructions didn't achieve the teaching goals that scientific inquiry should connect facts of daily life with scientific knowledge. Therefore, scientific inquiry activities need an effective mechanism to promote the connection between inquiry practice and knowledge construction.

Concept mapping is a useful tool for representation and organization of knowledge structures. Concept mapping can be used to evaluate existing knowledge structures as well as to construct new knowledge structures (Novak, 1985). While learning new knowledge, with the help of concept mapping, students can think more systematically and deeply about the relationship between related concepts as well as the connection between old and new knowledge, and achieve meaningful learning. By reviewing concept maps constructed by students, teachers can find gaps and then refine their instruction. Moreover, the process of concept mapping can reflect how students construct their own knowledge structure so that concept mapping can be used to examine whether students have developed a coherent understanding of the subject knowledge (Novak, 2010). Therefore, concept mapping can be embedded into the process of scientific inquiry as an assessment tool to evaluate the effects of inquiry practice as well as a scaffold to help students construct knowledge so as to help them form a coherent understanding of scientific knowledge.

However, concept mapping in scientific inquiry instruction needs to promote the learner's consistent understanding of scientific knowledge without destroying the advantages of scientific inquiry. Knowledge integration framework (KI) is a well-structured scientific inquiry pattern, suggesting a general instructional pattern that involves eliciting ideas, adding ideas, distinguishing ideas and organizing ideas to improve coherent and accurate understanding (Linn & Eylon, 2011). To create sustainable classroom inquiry instruction, Linn's research team created the Web-based Inquiry Science Environment (WISE) (Linn, Clark, & Slotta, 2010). The projects or curriculums on WISE are designed following knowledge integration framework (Linn & Hsi, 2000). WISE is built around the theories of knowledge integration and constructivism. WISE is a digital learning environment where students can observe, analyse, experiment, and reflect while navigating WISE project and teachers can use online tools embedded on WISE to guild and evaluate students' learning process. Thus, this study developed based on knowledge integration framework on WISE.

This study aimed to enhance knowledge integration processes through concept mapping so as to promote coherent understanding in scientific inquiry instruction based on KI. Concept mapping is a potentially powerful tool to generate, visualize, distinguish and organize connections between ideas (Hamza & Wickman, 2013). This study explores effects of concept mapping in different knowledge integration processes (*eliciting* or *organizing*) on WISE. The study aims to answer two research questions:

- Can concept mapping as ideas eliciting or organizing strategies promote middle school students' coherent understanding in scientific inquiry activities?
- In which phases (*eliciting* or *organizing*), is concept mapping more likely to promote students' coherent understanding?

2 Methods

2.1 Participants

Seventy-one 7th grade students from two classes taught by one teacher in a middle school in Beijing participated in this study. There were 35 students in *eliciting* condition (22 males and 13 females) and 36 students in *organizing* condition (21 males and 15 females). Excluding the students who didn't complete pre-test or post-test, there were 31 effective samples in *eliciting* condition (18males, 13females) and 20 in *organizing* condition (10 males, 10 females).

2.2 Materials

2.2.1 Web-based Inquiry Science Environment (WISE)

The scientific inquiry instruction was carried out based on the Web-based Inquiry Science Environment (WISE, http://wise.bnu.edu.cn). WISE is a research-based digital learning platform that fosters exploration and scientific inquiry designed by Prof. Linn's research team at UC Berkeley. All the projects or curriculums on WISE are designed based on the knowledge integration framework. Students can observe, analyze, experiment, and reflect while navigating WISE projects. Teachers can use online tools provided by WISE to guide and evaluate the learning process.

2.2.2 Curriculum materials

Chinese version of Self-Propelled Vehicles Challenge (Scooters) WISE unit translated and revised from WISE repertory was used as the inquiry curriculum material in this study. The unit can be found at the following web address: http://wise.bnu.edu.cn/project/254#/vle/node1. Table 1 describes the layout of Scooters unit.

Activity number	KI	Description
1	Elicit 1.1-2.8	Students are introduced to self-propelled scooters; students design, build and test their first scooter; students try to explain why scooters can move.
2	Add & Distinguish 3.2-3.15	Students engage in inquiry activities around energy types, energy transformation and energy conservation with computer simulations.
4	Organize 4.1-5.3	Students refine their first scooters. Students reflect on the design process and write project reports.

Table 1: Layout of Scooters WISE unit

In this project, students are introduced to relevant energy concepts (potential energy, kinetic energy and thermal energy) and energy transformation and conservation. The concept map below constructed by the researcher and a science teacher shows the scientific principles of scooters movement (original: figure 1; translated: figure 2).

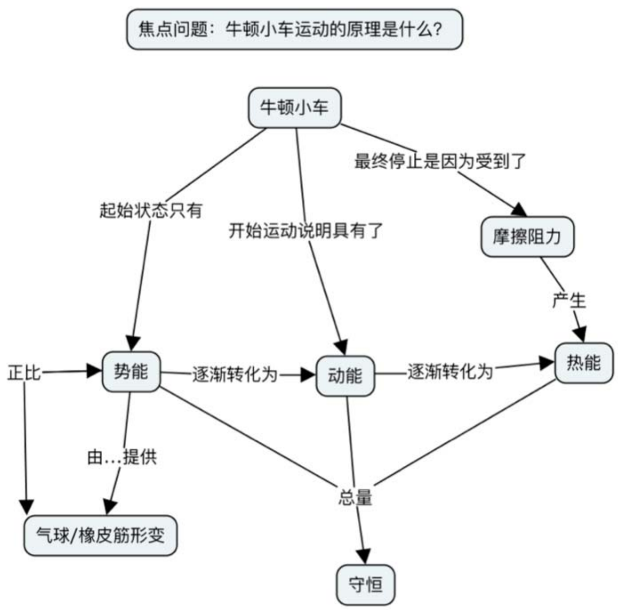

Figure 1. Concept map of energy conservation (original in Chinese)

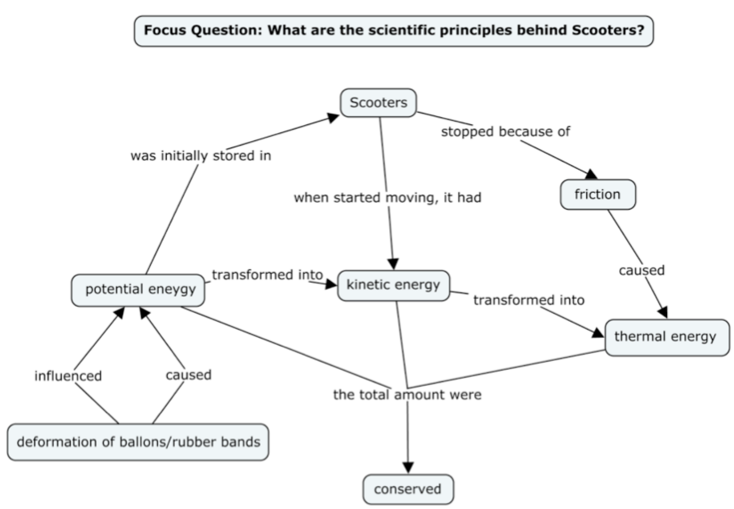

Figure 2. Concept map of energy conservation (translated into English)

2.2.3 Pre-test and post-test

The pre-test and post-test translated and revised from Linn's research team included three multi-part items involving the relationship among different types of energies (Energy Conservation Graphs, Scooter Revision Graphs, Car Performance Comparison) (Applebaum, Vitale, Gerard, & Linn, 2017). The original pre-test can be viewed at this link: http://wise.bnu.edu.cn/project/267#/vle/node.

Energy Conservation Graphs (Conservation). In this item, four graphs describing possible relationships between potential, kinetic, and thermal energy while a scooter is moving are presented to the students. Only graph D is correct. Students should first choose the correct graph and then answer an open response to explain their selection.

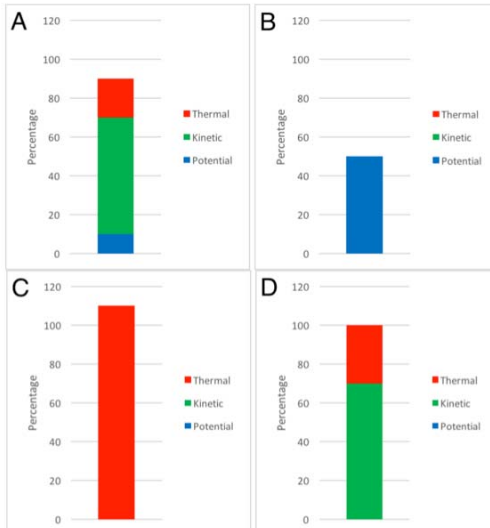

Figure 3. Graphs in *conservation* item

Scooter Revision Graphs (Revision). This item presented students with a stacked bar graph describing the distribution of energy from a scooter after two meters' movement (the graph is similar to figure 3). In addition, this item also presented two students' (Jaden & Jordan) plans for revising their scooters in order to go farther. Jaden wants to reduce friction, while Jordan wants to make the wheels bigger. In this item, students will answer 5 questions. Students should first guess whether the car could travel farther than 2 meters based on the energy graph and explain their reasoning. Then, students should choose who they agree with (Jaden(correct), Jordan, both or neither). After selection, students should indicate which type(s) of energy will NOT change after the revision (potential energy) and explain how the graph will change. Finally, students should explain their selections.

Car Performance Comparison (Comparison). In this item, students are presented with "Liz and Destiny each built a rubber band car. Liz's car had more potential energy, but Destiny's car travelled a farther distance." Students should first list the reasons as much as they can to explain the phenomenon. Then, they should choose one reason and explain how the reason affects the transformation of potential energy towards thermal energy in detail.

2.3 Procedure

The procedure of this study is depicted in figure 4 below. The whole research took 10 class periods.

Concept map training. A 4-class periods-training on concept mapping was first carried out to students in both conditions. The training consists of three tasks to guide learners to generate, critique, and revise concept maps. The goal is that learners can draw concept maps expertly and independently. Scores of the last concept map students constructed were used to measure students' concept mapping abilities.

Pre-test and post-test. Students completed pre-test and post-test on WISE independently in 30 minutes before and after WISE instruction.

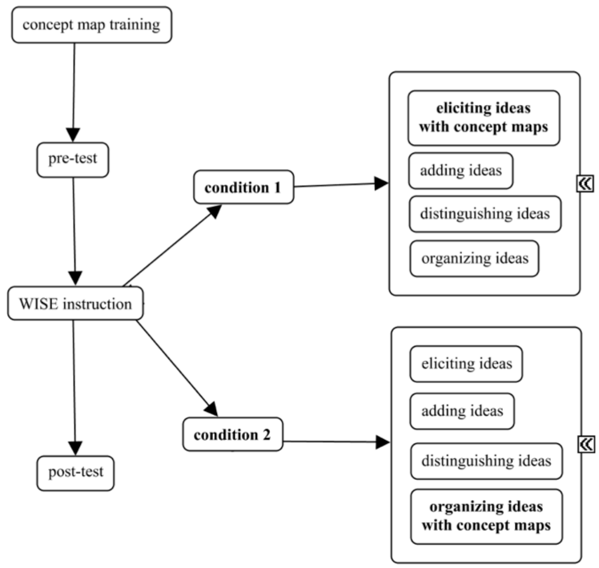

Figure 4. Research procedure

WISE instruction. Students completed the online *Self-Propelled Vehicles Challenge* (Scooters) unit in groups. These groups were typically dyads, while in some cases students worked alone. The whole inquiry instruction took 6 class periods. Students were asked to fill a given concept map (figure 5 & figure 6) about energy transformation and conservation in *eliciting* or *organizing* phase. After the students completed the concept map, they first received a feedback from other groups and revised their maps. Then, the teacher showed a concept map constructed by expert to the students. The students revised their maps based on the map constructed by expert. The construction and revision of concept maps were on paper.

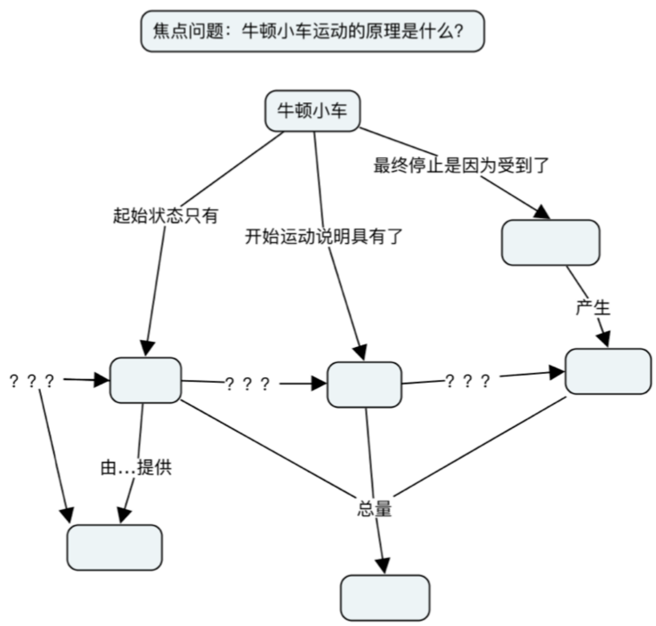

Figure 5. Concept map given to students (original in Chinese)

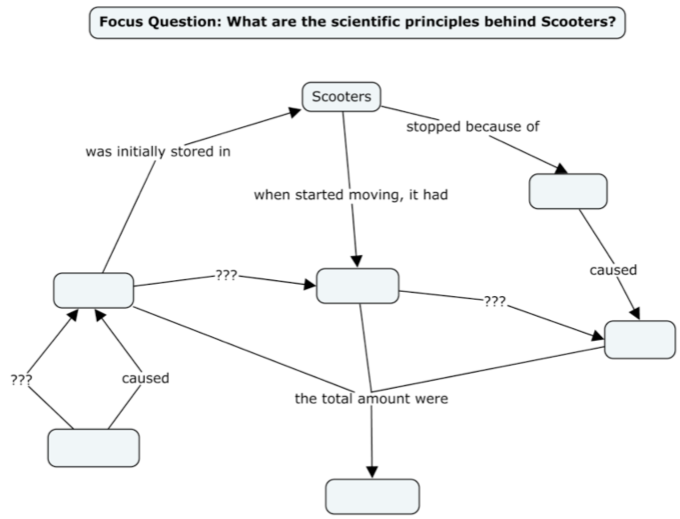

Figure 6. Concept map given to students (translated into English)

2.4 Rubrics and coding

All open response items in pre-test and post-test were coded with a knowledge integration rubric to determine a score that reflected the coherency of the response. All open response items were scored on a 5-point scale (Table 2 for example). All works were scored by two coders. Inter-observer reliability test showed that the scores given by the two coders reached acceptable levels for both pre-test and post-test of two conditions [*eliciting*: n=31, pre-test-icc=0.846, post-test-icc=0.880; *organizing*: n=20, pre-test-icc=0.859, post-icc=0.868]. The scores of concept maps were given by comparing with an expert concept map.

score	Description	Example
0	No answer	…
1	Off task	I don't know.
2	Irrelevant or Non-normative ideas	Everything in the graph changed because if you change one thing on the car it will change everything on the graph.
3	Unelaborated links between ideas, or partial idea	More friction will produce more thermal energy.
4	One scientifically valid link between two ideas	The potential energy didn't change because less friction doesn't have more energy stored.
5	Two or more scientifically valid links between ideas	The potential energy didn't change because potential energy is associated with the deformation of rubber bands only. They didn't change the rubber bands.

Table 2: Knowledge integration rubrics

3 Results and discussion

3.1 Pre-test and Post-test

To determine whether the *Scooters* WISE unit can effectively promote students coherent understanding of energy concepts, a paired t-test showed that there is a significant increase between pre-test and post-test in both *eliciting* and *organizing* condition (see table 3). Thus, concept mapping during *Scooters* inquiry unit can promote students' (in both condition) coherent understanding of energy concepts.

KI		Pre-test		Post-test		Paired t-test		
condition	n	Mean	SD	Mean	SD	Mean(Post-Pre)	SD	P-Value
organizing	20	8.15	3.82	14.58	5.87	6.43	4.00	**0.000**
eliciting	31	8.71	3.42	16.16	6.85	7.45	6.58	**0.000**
total	51	8.49	3.55	15.54	6.47	7.05	5.68	**0.000**

Table 3: Paired t-test

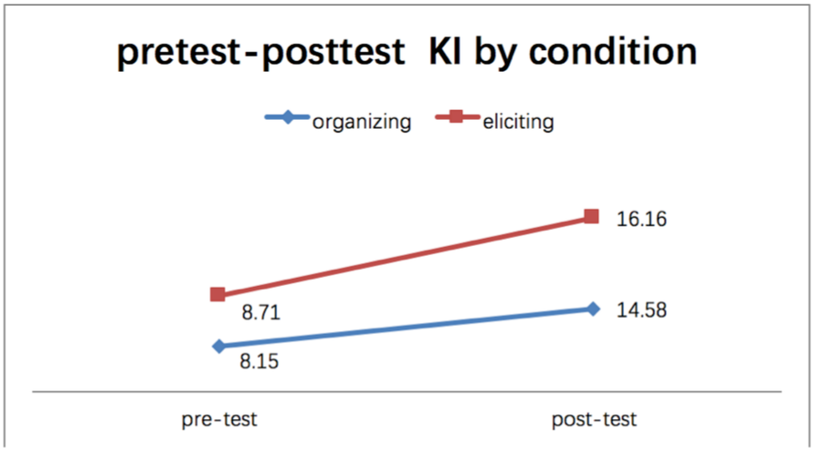

Figure 7. Comparison of pre-test and post-test scores

3.2 Differences of Mean Scores

A t-test performed on the pre-test showed there were no significant differences by condition (t (49) =-0.539, p>0.05).

To determine the effects of the two conditions, a liner mixed effect analysis was conducted using the mean pre-test scores, concept mapping scores as the independent variables, the mean post-test scores as the dependent variable, the condition (*eliciting* or *organizing*) as the grouping variable. The regression results showed that there was a significant positive correlation between pre-test and post-test (SE=0.663, p=0.000<0.001), and concept map scores and post-test (SE=0.020, p=0.000<0.001). Concept mapping in different phases was positively correlated with post-test, but not significant (SE=0.239, p=0.093). The results showed that the pre-test scores and concept mapping scores have a significant impact on the post-test scores. Students in *eliciting* condition received higher scores than *organizing* condition, but the difference was not significant.

Dependent variable: post-test	Estimate	Std.error	t-value	p-value
condition	0.239	0.140	1.712	**0.093**
Pre-test	0.663	0.175	3.783	**0.000**
Cmap	0.020	0.003	6.175	**0.000**
Constant	(0.399)	0.276	(1.445)	0.155

Table 4: Liner mixed effect analysis results

Meanwhile, a related analysis of post-test, pre-test, concept mapping scores and condition (*eliciting* or *organizing*) was conducted (see table 5). Students in *organizing* condition had a higher concept mapping scores but a lower pre-test score. However, comparing the gain scores, there was a significant difference in favor of students in *eliciting* condition. Thus, concept mapping and prior knowledge can promote knowledge integration, but the effect of prior knowledge is more important.

	Post-test	Pre-test	condition	Cmap
Post-test	1	0.48	0.119	0.641
Pre-test	0.48	1	0.077	0.17
condition	0.119	0.077	1	-0.122
Cmap	0.641	0.17	-0.122	1

Table 5: Related analysis results

3.3 Differences of Each Item

The previous analysis showed that there was no significant difference between conditions based on the overall scores. In order to further explore the difference between two conditions, analyses of each item were conducted.

The results of paired t-tests of gains in each item (*conservation*: M = 1.431, t = 5.97, P = 0.000<0.001; *revision*: M = 3.294, t = 6.88, P = 0.000 <0.001; *comparison*: M = 2.324, t = 7.46, P = 0.000 <0.001) showed that concept mapping can significantly promote the understanding of the coherent understanding of scientific knowledge in both conditions. A mixed-effects regression test was conducted on each item which showed that there was a significant positive correlation between the concept mapping scores and post-test scores (*conservation*: β=0.033, t=3.147, P=0.003<0.05; *revision*: β=0.095, t=5.449, P=0.000<0.05; *comparison*: β=0.059, t=4.720, P=0.000<0.05).

In *revision* and *comparison* items, the pre-test scores were significantly positively correlated to the post-test scores (*revision*: β=0.445, t=2.822, P=0.007<0.05; *comparison*: β= 0.603, t=2.534, P=0.015<0.05). For *conservation* item, the correlation between pre-test and post-test scores were not significant (β=0.154, t=0.474, P=0.637 >0.05). In *conservation* item, four graphs that describe possible relations between potential, kinetic, and thermal energy while a scooter is moving were displayed, which is more abstract to students. The difficulty of this item didn't match students' current knowledge level.

In *conservation* and *comparison* items, students in *eliciting* condition got a higher score that *organizing* condition, but the difference was not significant (*conservation*: β=0.474, t=1.039, P=0.304>0.05; *comparison*: β=0.254, t=0.468, P=0.642>0.05). In *revision* item, there was a significant positive correlation between the condition and the post-test scores (β=1.518, t=1.945, P=0.058<0.01), showing that concept mapping in *eliciting* is better than *organizing*. *Revision* item was more concerned with the concepts and relationships. Besides, students' concept map scores have a significant influence on the post-test scores of *revision* item (β=0.095, t=5.449, P=0.000<0.05), which confirmed the revision item was more organized than other items (previous study showed that concept mapping are better for building organized knowledge(Novak, 1989). Therefore, it can be considered that concept mapping in *eliciting* phase has a significant effect on the knowledge integration of more organized scientific concepts and knowledge.

	conservation			revision			comparison		
	β	t	P	β	t	p	β	t	p
Cmap	0.033	3.147	0.003	0.095	5.449	0.000	0.059	4.720	**0.000**
Condition	0.474	1.039	1.039	1.518	1.945	0.058	0.254	0.468	0.642
Pre-test	0.154	0.474	0.637	0.445	2.822	0.007	0.603	2.534	**0.015**

Table 6: Comparison by items

4 Conclusions

This study employed concept mapping to facilitate different knowledge integration processes (eliciting or organizing) and promote coherent understanding in scientific inquiry instruction based on Scooters unit on WISE. The conclusions are as follows:

1. Concept mapping can significantly promote coherent understanding of scientific knowledge in middle school students' scientific inquiry instruction. The result shows that concept mapping in eliciting or organizing knowledge integration phase can both significantly promote students' knowledge integration. In previous study, researchers used concept mapping in adding ideas and disguising ideas based on a biology WISE unit of middle school students, which shows that concept mapping can significantly promote knowledge integration(Schwendimann & Linn, 2016). Therefore, based on the results this research and findings of previous study, it is believed that concept mapping as scaffolds during scientific inquiry activities can promote knowledge integrating and students' coherent understanding of scientific knowledge.

2. Students' prior knowledge has a significant influence on the effect of scientific inquiry activities. Students who have a higher-level prior knowledge achieve a higher knowledge integration level after inquiry practice. Concept mapping can promote knowledge integration, but the effect is dependent on students' concept mapping ability as well as prior knowledge level. The prior knowledge integration level of students has a greater influence on the effect of knowledge integration promotion. Students who have a higher-level prior knowledge achieve a higher knowledge integration level after inquiry practice, which shows that students are more willing to learn the scientific knowledge they already know.

3. Concept mapping in eliciting phase is more likely to promote coherent understanding than in organizing phase. Based on the comparison of post-test scores of both conditions, it was found that concept mapping in eliciting phase is more effective for promoting knowledge integration and coherent understanding, especially for more organized scientific concepts and knowledge.

Future studies will focus on: (1) concept mapping to facilitate knowledge integration based on different WISE projects or off-line inquiry practices; (2) using computer-based concept mapping instead of paper-and-pencil task; (3) comparing the effects of different forms of concept mapping (such as constructing, filling and criticizing concept maps) on knowledge integration in scientific inquiry activities.

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