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RESEARCH REPORT

Using a conflict map as an instructional tool to change student alternative conceptions in simple series electric-circuits*

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Research in science education has revealed that students have alternative conceptions when learning various domains in science. The conflict map uses a series of discrepant events, critical events, relevant scientific conceptions and perceptions to promote student conceptual change. This study was conducted to examine the effects of using a conflict map on eighth graders' conceptual change and ideational networks about simple series electric circuits. Through a quasi-experimental research design, 93 of Taiwan's eighth graders were assigned to a control group, receiving traditional instruction, while 97 eighth graders were assigned to an experimental group, which used a conflict map as an instructional tool. Research data gathered from a two-tier test revealed that the conflict map could help students overcome alternative conceptions about simple series electric circuits. Student interview data, analysed through a flow map method, also showed that the use of conflict map could help students construct greater, richer and more integrated ideational networks about electric circuits.

Introduction

Contemporary science educators widely share a pedagogical view that students' prior knowledge will highly influence subsequent learning (Ausubel *et al.* 1978). In the last 25 years, the most important contribution of science educators may have been to explore and assess students' 'misconceptions' or 'alternative conceptions'. A plethora of research literature documenting student alternative conceptions has showed that these conceptions are content-dependent and they are resistant to alteration through conventional teaching strategies (e.g. Driver and Easley 1978, Driver and Erickson 1983, Tsai 1998a, 1999a, Wandersee *et al.* 1994). However, knowing students' alternative conceptions does not necessarily mean that educators have potential methods to promote student conceptual change. This study described an attempt on using a conflict map to overcome junior high school (eighth grade, 14-year-old) students' alternative conceptions about simple series electric circuits. The idea of using conflict map, as proposed by Tsai (2000a) may provide some insights on helping student conceptual change. Through a quasi-experimental research design, this study examined the effects of using a conflict map on student conceptual change and ideational networks about electric circuits.

* An early version was presented at the annual meeting of the *National Association for Research in Science Teaching*, New Orleans, LA, 28 April–1 May 2000.

Theoretical frameworks

Conceptual change

Since science students generally will have constructed some alternative conceptions about the scientific concepts that are to be taught, students need to modify their existing conceptions into scientifically accepted conceptions during the course of receiving science instruction. This process is called ‘conceptual change’ by science educators (Dole and Sinatra 1998, Duit and Confrey 1996, Tsai 1998a, Posner *et al.* 1982). Although there are numerous perspectives in interpreting student conceptual change in science (e.g. Caravita and Hallden 1994, Chi *et al.* 1994, DiSessa 1998, Hammer 1996a, b, Schwitzgebel 1999, Tyson *et al.* 1997, Vosniadou 1994), the theoretical framework proposed by Posner *et al.* (1982) is the most often-quoted and well-recognized perspective. Posner *et al.* proposed the following four conditions for conceptual change:

1. There must be dissatisfaction with existing (alternative) conceptions.
2. A new conception must be intelligible.
3. A new conception must appear initially plausible.
4. A new conception should be fruitful or open to new areas of inquiry.

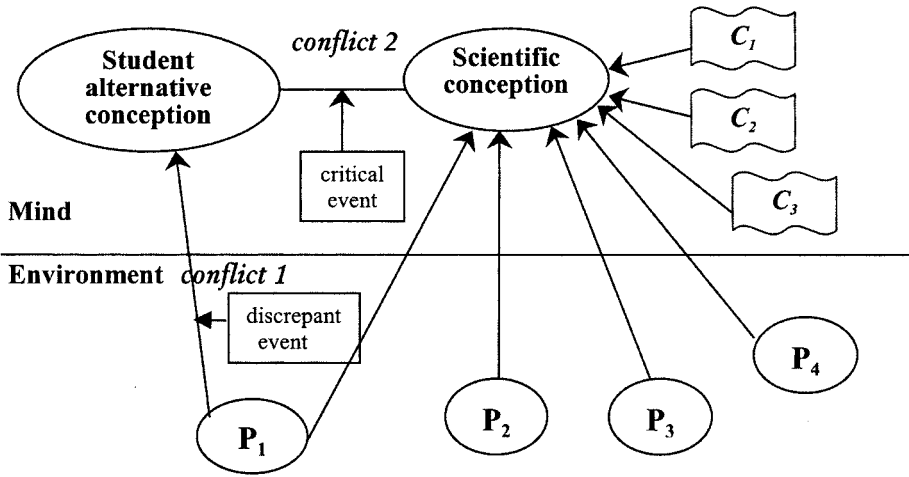
In light of Posner *et al.*'s (1982) model, science educators have become aware of the importance of anomalous data in knowledge acquisition in science. However, the use of anomalous data is no panacea. Chinn and Brewer (1998) concluded that there are eight possible responses to anomalous data:

1. Ignoring the data.
2. Rejecting the data.
3. Professing uncertainty about the validity of the data.
4. Excluding the data from the domain of the current theory.
5. Holding the data in abeyance.
6. Reinterpreting the data.
7. Accepting the data and making peripheral changes to the current theory.
8. Accepting the data and changing the theories.

Among these, seven responses involve discrediting the anomalous data in order to ‘protect’ the original theory. Chinn and Brewer (1993) have also proposed that the characteristics of prior knowledge, the characteristics of the new theory, the nature of the anomalous data and processing strategies, may influence how people respond to anomalous data. In summary, educators agree that conceptual change is a difficult process to be achieved as it may require radical restructuring of one’s existing schema or cognitive structures.

The conflict map

The use of conflict map asserts that students should resolve two conflicts during the process of conceptual change: one between the new perception and students’ alternative conception (conflict 1); the other one between students’ alternative conceptions and scientific concept (conflict 2) (Hashweh 1986). The resolution of conflict 1 does not necessarily resolve conflict 2. Conflict 1 could be resolved through discrepant events and the resolution of conflict 2 could be achieved through using ‘critical events or explanations’ and relevant perceptions and conceptions that



- Notes: P₁: the perception inducing a discrepant event.
 P₂, P₃, P₄: other supporting perceptions.
 C₁, C₂, C₃: relevant scientific conceptions.

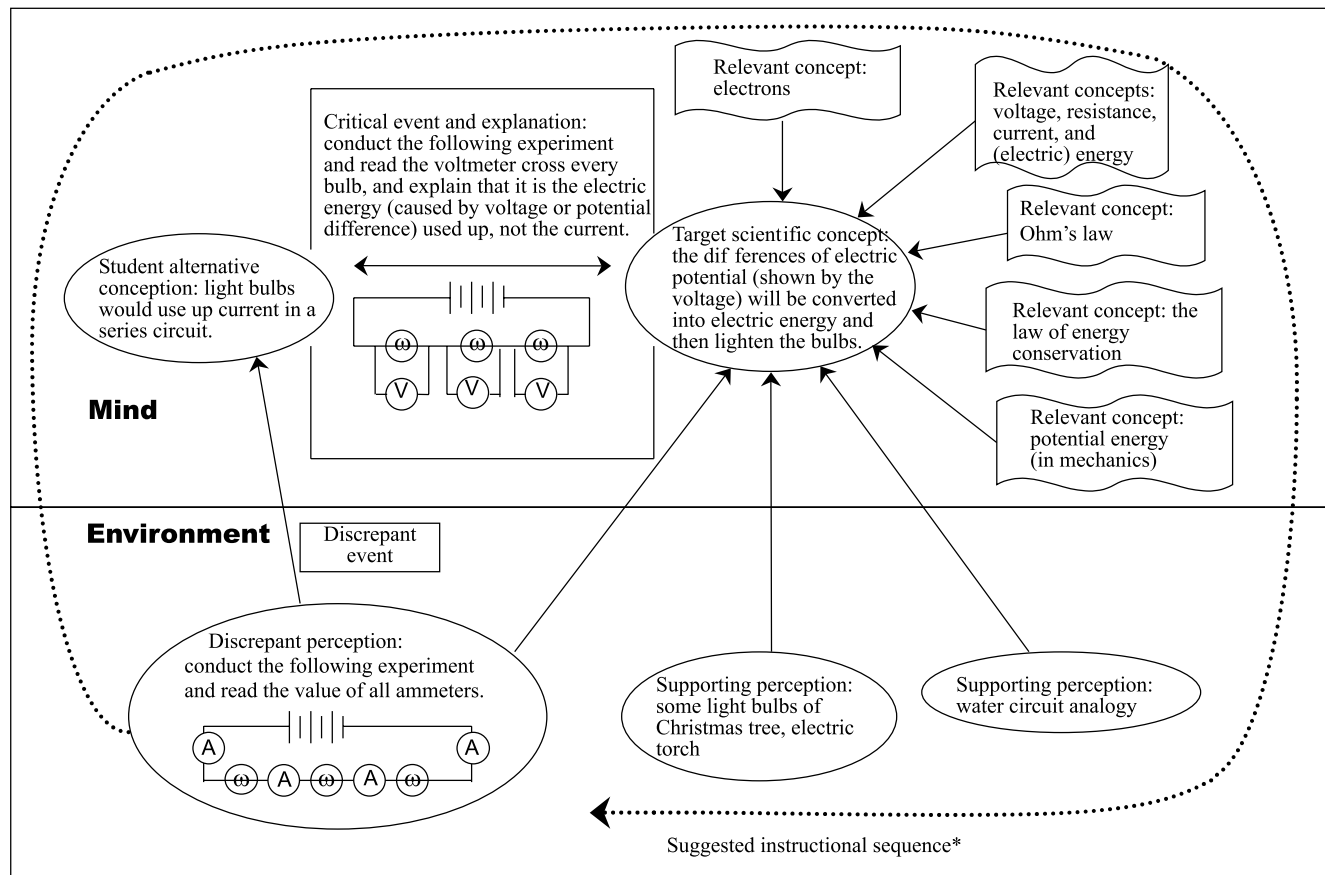
Figure 1. The framework of a conflict map.

explicate the scientific conception (Tsai 2000a). Figure 1 shows the framework of a conflict map.

Figure 2 illustrates a conflict map for changing students' prevalent alternative conception that light bulbs would use up electricity or electric current in a series circuit. The discrepant event is designed to show that the current in the circuit is equal everywhere. However, students would ask: if the current is not being used up, what is lighting the bulbs? The critical event is designed to explain that the differences of electric potential (shown by voltmeters) will be converted into electric energy and then light the bulbs. Ohm's law, the law of energy conservation, the ideas of potential energy (in mechanics), electrons, electric voltage, current and resistance could be considered as other conceptual supports for the target concept. Finally, the water circuit analogy,¹ and the lights of a Christmas tree (part of the light bulbs are in series) and the electric torch, could be viewed as other perceptions to explain the scientific concept that will be taught.

The use of conflict map as an instructional guide

The use of conflict map as an instructional tool is included in lessons within the following sequence: discrepant perception, target scientific concept, critical event and explanation, relevant concepts (e.g. Ohm's law, potential energy, electrons) and finally supporting perceptions (e.g. water circuit analogy). This sequence is consistent with Posner *et al.*'s (1982) conditions of conceptual change. The discrepant event in the conflict map could fulfil Posner *et al.*'s (1982) first condition for conceptual change. The instruction of target scientific concept could fulfil Posner *et al.*'s second condition. The third condition could be possibly achieved



* There is an exception in the teaching sequence that the target scientific concept should be presented earlier than the critical event.

Figure 2. A conflict map about electric circuit (modified from Tsai, 2000a, p. 290).

when the critical event and relevant scientific concepts (i.e., C1, C2, C3 in figure 1) are introduced. Other perceptions (and perhaps, other scientific concepts) that are related to the target scientific concept could possibly help learners achieve the fourth condition (for details, please refer to Tsai 2000a). The use of the conflict map also concurs with the framework proposed by Chinn and Brewer (1993) that conceptual change mainly depends on the characteristics of the anomalous data, prior knowledge, and the new conception as well as students' deep processing strategies. The instruction guided by the conflict map integrates the presentation of anomalous data, prior knowledge, the introduction of the new conception, and the teaching sequence may possibly also help students involve in deep processing.² The ideas of conflict maps are still based upon the paradigm of 'cold' conceptual change, a rational lens with which to view conceptual change (Pintrich *et al.* 1993). However, it is expected that the use of conflict maps could help students seek a stable and desirable equilibration between the conceptual schema they have already assembled and the perceptual information arising from the environment. The clarification as well as the connections among relevant alternative conceptions and scientific ideas are also explored and emphasized. As a result, this study explored not only the effects of using conflict map on students' conceptual change, but also its effects on students' ideational networks about the target scientific concept.

Literature on alternative conceptions involving simple electric circuits

Students' conceptions about simple electric circuits were investigated by Osborne and his colleagues (Osborne 1983, Tasker and Osborne 1985) and four major alternative conceptions were identified. The first one is a 'single-wire' conception that current leaves the battery and recursive wire is unnecessary. The second one, a 'clashing current' model, suggests that current leaves the battery from both terminals and travels toward the bulb, where it is 'used up'. The third conception indicates a unidirectional current consumption model, which is exactly the one presented in figure 2. The fourth conception is a scientifically correct model that the current flows around the circuit transmitting energy. According to the research work of Osborne and his colleagues, the third conception is held by almost an half of eighth graders (14-year-olds) and even ninth graders (15-year-olds); however, the second conception is not frequently observed by students of this age as they may have had some basic ideas about the flow of current in circuits. The research by Shipstone (1985) also showed that more than 60% of 14-year-olds expressed a unidirectional consumption model, and across the ages of 12 to 17, this age reached the highest proportion of students holding such an alternative conception, while the clashing current model was held by only about 10% of the students. Borges and Gilbert (1999) also showed a comparable finding on students of similar age. The 14-year-olds (or eighth graders) may widely share a current consumption view. Consequently, this study, examining the effects of the conflict map instruction on a group of eighth graders, focused on changing students' 'current consumption' alternative conception about electric circuits.

In recent years, science educators have tried various ways to overcome students' 'current consumption' alternative conception, for example, the use of anomalous data (Shepardson and Moje 1999), student-generated analogy (Cosgrove 1995), constructing derivational linkages among various models of electricity (Frederiksen *et al.* 1999) and computer-based simulation (Carlsen and Andre 1992, Ronen and

Eliahu 2000). Although some of them were quite successful, most of them may have required a time-consuming treatment, complicated instructional development, or other computer-based software support. This paper reported a study on using a conflict map as an instructional guide and the format of the instruction could be effectively applied to typical classrooms and to a variety of scientific conceptions in which students have widespread alternative conceptions.

Method

Subjects and research treatment

This study was intended to examine the instructional effects of using the conflict map of simple series electric circuits (shown in figure 2) on student conceptual change and ideational networks. The subjects of this study came from four eighth grade (14-year-old) 'fundamental physical science' classes from a junior high school near Taipei City, Taiwan. By using a quasi-experimental research approach, about at the midterm of students' eighth grade spring semester, two classes were assigned to a traditional teaching group (i.e. control group) and two classes were assigned to a conflict map instruction group (i.e. experimental group). There were 93 students in the traditional group (45 females) and 97 in the experimental group (48 females). These two groups did not show statistical differences in the 'fundamental physical science' course score of their eighth grade fall semester ($p > 0.05$). These two groups (four classes) were taught by the same teacher (their usual science teacher). The teacher was a male teacher with 7 years of junior high school science teaching. Although his teaching style was usually traditional-oriented, he was glad to try some new ways of teaching, if relevant support and guidelines were properly supported. The teacher had acquired some ideas about constructivism when attending some workshops previously. The teacher, except for providing basic information about the subject students (e.g. their previous course grade), did not participate in any research data collection and analysis involved in this study.

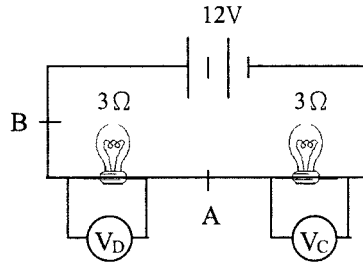
According to the teacher's experience, for students having prior conceptions of current, voltage, resistance and energy, he estimated that it took about three periods (50 minutes per period) to teach the target concept (shown in the conflict map) in a traditional approach (as what he usually did). This time estimation was similar to what actually happened in other classes in Taiwan, based on the author's observations and experiences, and the suggestion provided by the teachers' handbook of national textbooks in Taiwan. Consequently, the teacher, after consulting with the author, proposed a three-period instructional plan for teaching the target concept in a traditional way. To control the time effects, this study created a treatment lesson plan of the same length of time. The treatment basically followed the instructional sequence provided by the conflict map shown in figure 2. Certainly, there were more supporting conceptions and perceptions related to the target scientific conception (e.g. the carrier analogies). The conflict map in figure 2 contained only the activities conducted in the real three-period treatment.

In the first period of the conflict map group, the teacher first reviewed the concepts current, voltage and resistance with students. Then, he drew a series circuit on the blackboard and asked students to predict the current value in any point of the circuit, but did so without offering the correct answer. The students

then worked in small groups to conduct the discrepant event (shown in figure 2) and reported their experimental outcomes together with possible explanations. In the second period, the teacher recalled students' ideas derived from the discrepant event and introduced of the target scientific concept. The students again worked in small groups to conduct the experiment presented in the critical event (shown in figure 2). In the critical event, students experimented with various series circuits consisting different number of bulbs (not only one circuit) and then explored the relationships between the voltage of the battery given and the potential differences across each bulb in the circuits. Finally, the teacher gave a scientific explanation that differences of electric potential (shown by voltmeters) will be converted into electric energy and then light the bulbs. In the third period, the teacher related the target scientific concept to other scientific concepts such as resistance, voltage, energy, Ohm's law, electrons and (electric) potential differences. A discussion about these may have helped students to differentiate these scientific notions. Finally, the teacher used the water circuit analogy³ and other examples (such as electric torch) to explain the target scientific concept.

In the discrepant event ammeters were used, while in the critical event voltmeters were used, and both of them may not have been convincing for the students. However, in the critical event, the students were requested to work on various series circuits involving different number of bulbs and then to understand the relationships between the voltage of the battery given and the potential differences across each bulb in the circuits. The critical event also targets on the research finding by Millar and King (1993) that few students (at age 15) perceived the resistor series circuit as a voltage divider. Millar and King identified this conception as needing to be more strongly and explicitly emphasized in instruction. After conducting the critical event, the teacher gave a scientific explanation and further provided relevant conceptions and perceptions. All of these may have made the discrepant event and the critical event more convincing for students. In sum, the instruction guided by the conflict map involved a series of teaching activities that, as a whole, helped students work on conceptual change, and it did not assert that any single event or activity will induce students' dissatisfaction of existing alternative conception and promote conceptual change.

On the other hand, in the first period of the traditional group, the teacher gave a review of the concepts of current, voltage and resistance. Then, he used the water circuit analogy to illustrate that the current would be uniform in series circuits and the potential differences would be converted to energy and to make the bulbs light. In the second period, students worked in small groups to measure the current in simple series circuits. The teacher explained the experimental results and introduced Ohm's law. In the final period, students practiced four tutorial problems by applying Ohm's law. The first item required students to calculate the resistance of a simple series circuit with current and voltage values provided. The final three problem items were given the values of resistance (caused by bulbs) and battery voltage, and then students were required to determine the current at any point and the potential difference across each bulb. The item in figure 3 is an example.⁴ Hence, it is believed that the main ideas emphasized in both groups were quite similar; that is, the current is uniform in simple series electric circuits; the differences of electric potential across bulbs are converted into electric energy and then light the bulbs; hence, resistor series circuit should be viewed as a voltage divider.



- (a) The current at A and B points, respectively, will be?
 (b) The reading of voltmeters C and D, respectively, will be?

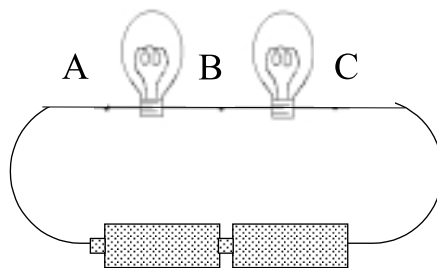
Figure 3. A tutorial problem practiced in the traditional group.

In Taiwan's nationwide curricula, eighth grade is the first time that students receive formal science instruction about electric circuits. This research project was conducted during the period scheduled for teaching the electric circuits. It should be also noted, that prior to the conduct of this study, the students in the two groups had received instruction about the concepts of energy, voltage, current (including the flow of current), and resistance.

Assessing student conceptual change

Two-tier tests are used to investigate students' alternative conceptions (Odom and Barrow 1995, Christianson and Fisher 1999, Voska and Heikkinen 2000, Tsai and Chou 2002). Two weeks before conducting the research treatment, a two-tier test item was administered to all of the subjects to survey student alternative conceptions, shown in figure 4.

The first tier of the test assesses students' descriptive knowledge about the phenomenon, that is the comparison of current of different points in a series circuit. The second tier explores students' reasons for their choice made in the first tier, that



The value of electric current at points A,B,C, will be:

- (a). $A > B > C$, (b). $A = B = C$, (c). $A < B < C$.

The reason for your choice above is:

- (i) The light bulbs will use up both current and electric potential (energy).
 (ii) The light bulbs will not use up current but use up electric potential (energy).
 (iii) The light bulbs will use up current but not electric potential (energy).

Figure 4. A two-tier test assessing alternative conceptions of electric circuits.

is investigating students' explanatory knowledge. The same two-tier test was administered about one week after the research treatment. One science education professor and two junior high school science teachers had validated this test item. Students could have nine possible choices in the two-tier test, with (b)(ii) being the correct answer. Students' responses on the two-tier test were used as a record of their conceptual change.

Exploring student ideational networks about electric circuits

There were two rounds of probing students' ideational networks in this study. One was conducted two weeks after the treatment, while the other one was conducted three months after the treatment. The first round can be viewed as a post-test of student ideational organization (i.e. post Ideational Network Assessment, called *post INA* in this paper), while the second round was intended to examine the effects of using conflict map on student ideational frameworks in terms of long-term observations (i.e. delay Ideational Network Assessment, called *delay INA* in this paper). In each round, twelve students from each class (a total of 24 in each group) were randomly selected for an in-depth interview to explore their ideational networks about electric circuits. The researchers showed a simple electric circuit graph (similar to the figure in the first tier of the two-tier test) to help students recall what they knew about electric circuits. Through interviewing these students with the following questions, they were asked to freely recall or reconstruct what they had learned about electric circuits.

1. Could you tell me what this graph shows?
2. Could you tell me what are the main ideas related to the graph?
3. Could you tell me more about the ideas you have stated?
4. Could you tell me the relationships among the ideas you have already told me?

By such an interview–recall method, coupled with a ‘meta-listening’ technique (i.e. asking each subject to listen to an audio replay of his or her immediately prior elicited recall and possibly to modify his or her original ideas, see Tsai 1998b, 1999b, 2000b, 2001) every selected student's interview narrative was further analysed by a ‘flow map’ method (Anderson and Demetrius 1993, Tsai 2001, Tsai and Huang 2001). The interview recall data were tape-recorded.

A flow map is constructed by diagramming the respondent's verbalization of thought as it unfolds, and it is a convenient way to display the sequential and complex or cross-linkage thought patterns expressed by the respondent. The flow map is assembled by entering the ideas in sequence as they are uttered by the subject. Figure 5 shows a sample of flow map used in this study. The student in the interview recalled ten ideas, shown in a sequential flow. Ideas 8 and 9 were added by the subject after he listened to an audio-replay of his ideas 1 to 7. Since ideas 8–9 were newly added by the subject, the researcher also replayed the ideas of 8–9 to the subject and the subject added the final idea in the interview. Certainly, the researcher replayed the idea 10 to the subject, but he did not add any more ideas. Hence, the meta-listening technique used in this study was repeated until the subject did not produce any additional ideas. In this way, the subject had a chance to listen to all of his or her prior recall ideas elicited in the interview.⁵

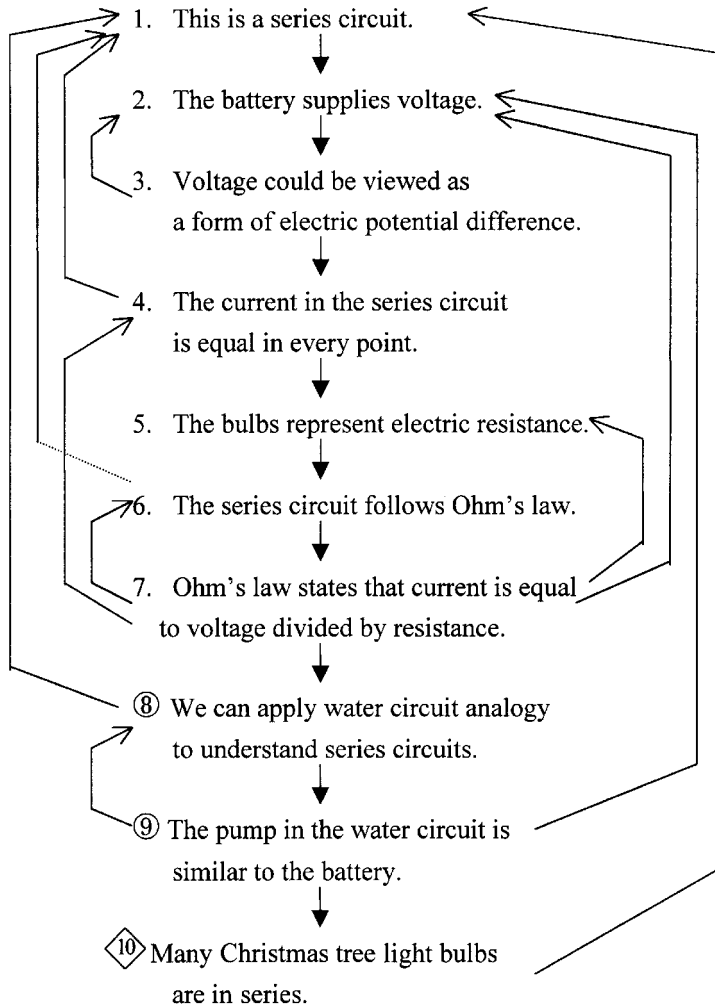


Figure 5. A sample of flow map. Items 8 and 9 were added by the subject after listening to an audio replay of items 1–7. Item 10 was added after listening to an audio replay of items 8–9.

In addition to sequential (linear) linkages, the flow map shows some recurrent linkages for re-visited ideas. For example, statement 7 in figure 5 includes four re-visited (related) concepts: Ohm's law, current, voltage and resistance. The researcher, hence, drew four recurrent (complex) linkages from statement 7 to the earliest steps the subject stated these ideas, that is, statement 6 (about Ohm's law), statement 4 (about current), statement 2 (about voltage) and statement 5 (about resistance).

By employing the flow-map method, this study, both in post INA and delay INA phases, yielded the following major ideational network outcome variables:

1. Size or extent: linear linkages or number of ideas, e.g. 10 in figure 5.
2. Richness: recurrent or cross linkages, e.g. 11 in figure 5.

Table 1. Students' responses on two-tier test.

| Choice | Pre-test ^a | | Post-test ^b | |
|----------|-----------------------|------------------------|------------------------|------------------------|
| | Traditional (#, %) | Conflict map (#, %) | Traditional (#, %) | Conflict map (#, %) |
| (a)(i) | 25 (26.9) | 21 (21.6) | 14 (15.1) | 8 (8.2) |
| (a)(ii) | 5 (5.4) | 10 (10.3) | 3 (3.2) | 3 (3.1) |
| (a)(iii) | 22 (23.7) | 22 (22.7) | 9 (9.7) | 2 (2.1) |
| (b)(i) | 6 (6.5) | 6 (6.2) | 15 (16.1) | 8 (8.2) |
| (b)(ii) | 21 (22.6) | 23 (23.7) | 37 (39.8) | 62 (63.9) |
| (b)(iii) | 4 (4.3) | 5 (5.2) | 11 (11.8) | 8 (8.2) |
| (c)(i) | 4 (4.3) | 5 (5.2) | 1 (1.1) | 2 (2.1) |
| (c)(ii) | 3 (3.2) | 2 (2.1) | 2 (2.2) | 2 (2.1) |
| (c)(iii) | 3 (3.2) | 3 (3.1) | 1 (1.1) | 2 (2.1) |

^a chi-square = 2.44, df = 8, $p > 0.05$, n.s.

^b chi-square = 15.60, df = 8, $p < 0.05$.

3. Integratedness: proportion of recurrent linkages, equal to number of recurrent linkages divided by (number of ideas plus number of recurrent linkages), e.g. $11/(10 + 11)$, 0.52, in figure 5.
4. Correctness (alternative conception): number of alternative conceptions, a lower score on this indicates a higher precision of ideational networks, e.g. 0 in figure 5.

A second independent researcher was asked to analyse 30 randomly selected narrative data (among 96 narrative data for two rounds of ideational network assessment). The inter-coder agreement for sequential statements was 0.90 and for cross linkages was 0.86.

Findings

Students' responses on two-tier tests

A chi-square test was conducted to explore the choice pattern in the pre-test (two-tier test) between the traditional instruction group and the conflict map group. Table 1 revealed that there was no significant difference on choice pattern in the pre-test between these two groups (chi-square = 2.44, $p > 0.05$, df = 8). In each group, the choices of (a)(i), (a)(iii) and (b)(ii) were each selected by about 25% of the students. These results were reasonable since these three choices are logically consistent across the first tier and second tier. The results of (a)(i) and (a)(iii) further confirmed a well-known student alternative conception that light bulbs would use up the current, the target alternative conception identified in this study. The proportion of students (about 50%) was similar to that revealed by Tasker and Osborne (1985) and Shipstone (1985). The post-test showed that the choice pattern between these two groups was significantly different (chi-square = 15.60, $p < 0.05$, df = 8): 63.9% of the conflict map group students answered correctly in the two-tier test (i.e. (b)(ii)), while only 39.8% of traditional group students selected the same

Table 2. Tracking students' responses cross two-tier tests.

| <i>Traditional group</i> | | | <i>Conflict map group</i> | | |
|--------------------------|------------------|------------------------|---------------------------|------------------|------------------------|
| <i>Pre-test</i> | <i>Post-test</i> | <i>(# of students)</i> | <i>Pre-test</i> | <i>Post-test</i> | <i>(# of students)</i> |
| (a)(i) | (a)(i) | 5 | (a)(i) | (a)(i) | 4 |
| | (a)(ii) | 1 | | (a)(ii) | 1 |
| | (a)(iii) | 2 | | (a)(iii) | 1 |
| | (b)(i) | 4 | | (b)(i) | 0 |
| | (b)(ii) | 6 | | (b)(ii) | 14 |
| | (b)(iii) | 5 | | (b)(iii) | 1 |
| | (c)(ii) | 1 | | (c)(ii) | 0 |
| | (c)(iii) | 1 | | (c)(iii) | 0 |
| (a)(ii) | (a)(i) | 1 | (a)(ii) | (a)(i) | 0 |
| | (a)(ii) | 1 | | (a)(ii) | 2 |
| | (a)(iii) | 2 | | (a)(iii) | 0 |
| | (b)(i) | 0 | | (b)(i) | 3 |
| | (b)(ii) | 1 | | (b)(ii) | 4 |
| | (b)(iii) | 0 | | (b)(iii) | 1 |
| (a)(iii) | (a)(i) | 4 | (a)(iii) | (a)(i) | 0 |
| | (a)(iii) | 4 | | (a)(iii) | 0 |
| | (b)(i) | 4 | | (b)(i) | 2 |
| | (b)(ii) | 7 | | (b)(ii) | 17 |
| | (b)(iii) | 3 | | (b)(iii) | 1 |
| | (c)(i) | 0 | | (c)(i) | 1 |
| | (c)(ii) | 0 | | (c)(ii) | 1 |
| (b)(i) | (b)(i) | 3 | (b)(i) | (b)(i) | 2 |
| | (b)(ii) | 3 | | (b)(ii) | 2 |
| | (b)(iii) | 0 | | (b)(iii) | 2 |
| (b)(ii) | (a)(i) | 1 | (b)(ii) | (a)(i) | 2 |
| | (a)(iii) | 1 | | (a)(iii) | 1 |
| | (b)(i) | 3 | | (b)(i) | 0 |
| | (b)(ii) | 16 | | (b)(ii) | 20 |
| (b)(iii) | (b)(ii) | 2 | (b)(iii) | (b)(ii) | 2 |
| | (b)(iii) | 1 | | (b)(iii) | 3 |
| | (c)(i) | 1 | | (c)(i) | 0 |
| (c)(i) | (a)(i) | 1 | (c)(i) | (a)(i) | 2 |
| | (b)(i) | 1 | | (b)(i) | 1 |
| | (b)(ii) | 1 | | (b)(ii) | 1 |
| | (c)(i) | 0 | | (c)(i) | 1 |
| | (c)(ii) | 1 | | (c)(ii) | 0 |
| (c)(ii) | (a)(i) | 2 | (c)(ii) | (a)(i) | 0 |
| | (b)(ii) | 0 | | (b)(ii) | 1 |
| | (b)(iii) | 1 | | (b)(iii) | 0 |
| | (c)(ii) | 0 | | (c)(ii) | 1 |
| (c)(iii) | (a)(ii) | 1 | (c)(iii) | (a)(ii) | 0 |
| | (b)(ii) | 1 | | (b)(ii) | 1 |
| | (b)(iii) | 1 | | (b)(iii) | 0 |
| | (c)(iii) | 0 | | (c)(iii) | 2 |

Note: The first data (a)(i), (a)(i), 5, indicate that five traditional group students who selected (a)(i) in the pre-test finally chose (a)(i) in the post-test. The unlisted choice indicates none selecting the choice.

choice. Still 15.1% of traditional group students chose (a)(i) and 9.7% of the traditional group students chose (a)(iii) as their answer, but few of the conflict map group students selected such choices after the research treatment (8.2% and 2.1% respectively). It is also interesting to find that, in the post-test, about 68% of traditional group students made a correct choice in the first tier (i.e. b), but many of them (about 28%) did not respond correctly to the second tier; that is, they answered (b)(i) and (b)(iii). These two choices seemed not to be logically consistent across the two tiers, and not as many of conflict map group students (about 16%) selected such choices. These findings are somewhat similar to those reported in Voska and Heikkinen's (2000) study that college chemistry students selected correct answers more frequently (the first tier) than they provided correct reasons (the second tier). Students in the traditional group may have memorized the correct factual scientific knowledge (i.e. the first tier) but they did not have further understanding about it (i.e. the second tier).

Table 2 shows a detailed analysis of student responses across two two-tier tests. The table reveals that six students in traditional group choosing (a)(i) in the pre-test finally selected correct answer (i.e. (b)(ii)) in the post-test. However, there were 14 students in the conflict map group following the same path of conceptual change. A similar situation can be found in the pre-test (a)(iii) choice. Seven traditional group students who chose (a)(iii) in the pre-test finally selected correct choice after the treatment. However, 17 students in the conflict map showed the same path of conceptual change resulting from the conflict map instruction. It is found that the increased number of conflict map group students making correct choice in post-test mainly came from those who had originally selected (a)(i) and (a)(iii). The discrepant event and the critical event in the conflict map instruction may have been important in contributing to students' conceptual change; however, it is believed that a careful discussion of relevant conceptions such as energy, voltage, current and electrons may also help students to acquire a better differentiation among these scientific notions, and then to overcome the alternative conception.

Students' ideational networks

In both post INA and delay INA, the comparisons between students' ideational networks in two groups were made by using their eighth grade fall semester score in the 'fundamental physical science' course as a covariate. The ANCOVA (analysis of covariance) results for post INA, shown in table 3, revealed that conflict map group students did not show a larger extent of ideational networks (i.e. number of ideas) than those of traditional group students. However, the richness and integratedness of ideational networks shown by the conflict map group students were better than those of traditional group in post INA ($F = 4.76, p < 0.05$ and $F = 8.45, p < 0.01$ respectively). Conflict map group students seemed not to state statistically fewer alternative conceptions in the flow-map interview than the traditional group students did; but the difference almost reached the significance level of 0.05 ($F = 2.81, p = 0.1$).

The ANCOVA results for delay INA, also listed in table 3, revealed that students in the conflict map group displayed a greater extent and richer texture of ideational networks than those in the traditional group ($F = 6.09, p < 0.05$; $F = 10.27, p < 0.01$, respectively). The delay INA somewhat exhibited the long-term effects of using conflict map on student ideational networks. Although students in

Table 3. Students' ideational network outcomes derived from two flow-map interviews.

| | <i>The post INA (2 weeks after the treatment)</i> | | | | <i>The delay INA (3 months after the treatment)</i> | | | |
|--|---|--|----------------------|----------|---|--|----------------------|----------|
| | <i>Traditional^a (mean, SD)</i> | <i>Conflict map^a (mean, SD)</i> | <i>F^b</i> | <i>p</i> | <i>Traditional^a (mean, SD)</i> | <i>Conflict map^a (mean, SD)</i> | <i>F^b</i> | <i>p</i> |
| Prior science ^c achievement | 76.2 (13.3) | 73.9 (13.0) | 0.38 | 0.54 | 74.8 (13.2) | 73.9 (12.9) | 0.06 | 0.81 |
| Extent | 7.46 (2.59) | 7.38 (2.45) | 0.24 | 0.62 | 6.00 (1.74) | 6.58 (1.95) | 6.09 | 0.02* |
| Richness | 6.79 (2.99) | 7.75 (3.38) | 4.76 | 0.03* | 5.42 (1.69) | 6.50 (2.36) | 10.27 | 0.002** |
| Integratedness | 0.47 (0.05) | 0.50 (0.05) | 8.45 | 0.006** | 0.47 (0.04) | 0.49 (0.04) | 3.72 | 0.06 |
| Alternative conception | 0.79 (0.59) | 0.58 (0.72) | 2.81 | 0.10 | 0.75 (0.68) | 0.58 (0.65) | 1.56 | 0.22 |

^a $n = 24$ for each group.

^b The F value for variables 'extent', 'richness', 'integratedness', and 'alternative conception' is calculated by using student 'prior science achievement' as a covariate (i.e. using ANCOVA method).

^c The prior science achievement score is calculated on the basis of the selected subjects of involving the flow-map interview.

* $p < 0.05$, ** $p < 0.01$.

the conflict map group did not display statistically more integrated knowledge structures than their counterparts, the difference almost reached 0.05 level of significance ($F = 3.72, p = 0.06$). The alternative conception indicator did not show significant difference between both groups, and they showed few alternative conceptions in the flow-map interview (0.67 idea per flow map on average). A plausible interpretation for this may be that the students could have been used to only stating ideas that they were certain about in the interview, similar to a finding by Tsai (2000b). The statistical analysis of INA did not show a difference in student alternative conceptions between these two groups (i.e. the alternative conception indicator); yet, content analysis of students' major ideas shown in ideational networks did show some difference (described later). In sum, as a result of using the conflict map as an instructional guide, students constructed richer and more integrated ideational network in post INA, and students' ideational networks were enhanced in features of extent and richness in delay INA. Educators have proposed that knowledge acquired in rich and well connected ideational networks is more meaningful and more useful for further applications (Ausubel *et al.* 1978, West and Pines 1985). This implies that the instruction guided by the frameworks of the conflict map may help students construct broader and meaningful knowledge structures about the target scientific conception. Earlier studies to examine the effects of an open-ended approach of instruction have demonstrated that it promotes the development of students' ideational networks (Anderson *et al.* 2001, Tsai 2000b). The use of the conflict map, though not always conducted in the inquiry mode of instruction, achieved a similar outcome.

Content analysis of ideational networks

This study further conducted a content analysis of students' ideational networks for both post INA and delay INA. Students with similar ideas shown in the flow maps were grouped together and the frequencies were counted. The major ideas students recalled for both groups were listed in table 4. For example, it was found that all of the selected students in both groups could identify the graph in which the researcher showed to him or her as a series electric circuit in post INA and 18 of them in each group stated an idea that the circuit follows Ohm's law in the post INA interview.

The post INA indicated the following differences. Students in the traditional group emphasized the water circuit analogy about electric circuits, while students in the conflict map group stressed the concepts that the current is equal in the circuit ($n = 21$) and that the voltage the batteries supply is equal to the voltage the bulbs use ($n = 14$). The conflict map instruction seemed to be useful in addressing students' 'current-consuming' alternative conception and then widely accepted the target scientific conception. Similar ideas could be found in delay INA of the conflict map group students. However, the major ideas derived from the delay INA of the traditional group indicated that 11 students (about a half of 24 selected students) had 'used up' alternative conception about electric circuits. A similar proportion of students in the traditional group had the same alternative conception shown in the pre-two-tier test (56% of the students chose (a) as their answer for the first tier). This suggested that students regressed to their original understanding after three months of the traditional instruction, however, the conflict map instruction did not show such regression. This implied

Table 4. The major ideas students recalled in both flow-map interviews.

| <i>The post INA (2 weeks after the treatment)</i> | | | | <i>The delay INA (3 months after the treatment)</i> | | | |
|---|----------|---|----------|---|----------|---|----------|
| <i>Traditional group</i> | | <i>Conflict map group</i> | | <i>Traditional group</i> | | <i>Conflict map group</i> | |
| <i>Idea</i> | <i>n</i> | <i>Idea</i> | <i>n</i> | <i>Idea</i> | <i>n</i> | <i>Idea</i> | <i>n</i> |
| This graph shows a series electric circuit. | 24 | This graph shows a series electric circuit. | 24 | This graph shows a series electric circuit. | 22 | This graph shows a series electric circuit. | 23 |
| The circuit follows Ohm's law. | 18 | The current in the circuit is equal everywhere. | 21 | The circuit follows Ohm's law. | 15 | The current in the circuit is equal everywhere. | 19 |
| We can use water circuit analogy to understand electric circuits. | 18 | The circuit follows Ohm's law. | 18 | Ohm's law indicates that the resistance is equal to voltage divided by current. | 12 | The circuit follows Ohm's law. | 16 |
| Ohm's law indicated that the resistance is equal to voltage divided by current. | 17 | Ohm's law indicated that the resistance is equal to voltage divided by current. | 16 | The unit of current is Ampere. | 11 | The voltage the batteries supply is equal to the voltage the bulbs use. | 14 |
| The pump in the water circuit is similar to the role of battery in electric circuits. | 16 | The voltage the batteries supply is equal to the voltage the bulbs use. | 14 | The current the batteries supply is used up by the bulbs. | 11 | Ohm's law indicates that the resistance is equal to voltage divided by current. | 14 |

that traditional instruction did not successfully challenge students' alternative conception, while in many cases, the scientific concepts might have been acquired through memorization, not real understanding. It is frequently found that the most important application of obtaining scientific knowledge for students is to achieve a high grade in a course or a standard examination. Hence, in research literature, educators have summarized that students often have 'undisturbed' or 'two perspectives' outcomes after (traditional) science instruction (Gilbert *et al.* 1982, Wandersee *et al.* 1994). In terms of the content analysis above, the conflict map instruction showed some evidence that students' alternative conception was properly challenged and that students did not return to their original understanding, even a relatively long time after the instruction.

Limitations of the study

This study focused on changing students' alternative conceptions of 'current consumption' for electric circuits. Past research findings revealed that students' understanding of electric current in electric circuits was confused by many alternative conceptions (Shepardson and Moje 1994, Stockmayer and Treagust 1996). One may question whether there is any use in isolating current consumption without addressing other alternative ideas with regard to current, voltage, energy and resistance. If this study could have allowed more time for conducting the pre-interview and research treatment, the researchers could have achieved a better understanding of students' different alternative conceptions related to electric circuits. These then could have been addressed in the treatment to examine how students of different alternative conceptions would respond to the conflict map instruction.

For the purpose of direct comparisons between pre-test and post-test, this study used the same two-tier test item to assess students' conceptual change. It is realized that with only one item it may be difficult to provide potential insights about the depth and breadth (across contexts) of the new conception in which students acquired. However, the same item provided a quick and clear way to document students' conceptual change. Also, this study conducted two rounds of flow map interviews to explore students' ideational networks, which were intended to probe students' conceptual knowledge about electric circuits in a deeper level. Nevertheless, if this study could have used more ways of assessment, for example, assessing students' ideas of electric current in other contexts, the effects of conflict map instruction on students' ideas might be examined in a larger scope. In this way, this study could have given more information to distinguish between students being able to give the right response and their understanding of the concepts. At the same time, the validity and reliability of the results obtained and the conclusions drawn in this study could have been enhanced.

Some other analogies of supporting the scientific conception could be provided in the final period of the conflict map instruction. For example, carrier analogies (e.g. current 'particles' carrying bags of energy) might be more successful than the water circuit analogy. Due to the time constraints, this study only used the water circuit analogy, which was frequently used by Taiwan's textbooks and teachers, and in this case, the water circuit analogy was used only superficially.

Conclusions

This study proposes a 'conflict map' framework of changing student alternative conceptions. The conflict map is based on the theoretical perspectives of conceptual change model. This study presents a case of using conflict map to overcome students' prevailing alternative conception that current is used up in electric circuits. Although the treatment was relatively short, the findings drawn from this study suggested that the use of the framework of conflict map as an instructional guide could help students achieve conceptual change, as well as construct greater, richer and more connected ideational networks about scientific knowledge. Because the conflict map carefully addresses student alternative conception and emphasizes the connections among relevant perceptions and conceptions, it is reasonable to find that students in the conflict map group not only achieved conceptual change, but also displayed better ideational networks, than those instructed by traditional teaching strategies. Certainly, more studies on using conflict maps about student other alternative conceptions are necessary to further examine the effectiveness of using conflict maps in a wider scope.

Moreover, how to design proper discrepant events and critical events may be the most difficult part of developing conflict maps. Science teachers need to explore the origins of student alternative conceptions and then to design responding events to challenge students' alternative conceptions as well as resolve the conflicts among existing and new ideas.

One may still argue that the use of conflict map is based on the paradigm of 'cold' conceptual change. It is well recognized that students' conceptual change involves various domains, including content (or conceptual), epistemological, ontological, emotional and other factors (Pintrich *et al.* 1993, Tyson *et al.* 1997, Tsai 1998c, 1999c, 2000a). However, the use of conflict maps, at least, at the content level, could be a promising tool for assisting students' conceptual change. Also, the critical events in the conflict maps, in some cases, can address some epistemological and ontological issues. For example, the critical events can challenge student existing ontological views about electrical current, heat or forces, changing from a matter-based ontological view to an event-based ontological perspective.⁶ The use of conflict maps, coupled with student changes in other domains (e.g. epistemological, ontological), could overcome student alternative conceptions in science.

In addition to employing the frameworks of conflict maps to organize science lessons, science teachers can present the frameworks of conflict maps to students after implementing all of the instructional activities involved in the maps. It is expected that the frameworks can help students construct more connected and scientifically solid knowledge structures about the target scientific concepts. Furthermore, the use of conflict maps could be viewed as a metacognitive tool. The role of metacognition on conceptual change has been well elaborated in science education literature (White and Gunstone 1989, White and Mitchell 1994, Dekkers and Thijs 1998). These science educators have developed ways or conceptual tools of enhancing student awareness of cognitive dissonance and the development of their own thinking. In the case of the conflict maps, teachers can help students develop their own conflict maps to review their ideas and to monitor their processes of conceptual change. In this way, students can use conflict maps as a metacognitive tool to reflect upon their learning and conceptual development. In sum, the ideas of

conflict maps may contribute to the research literature of alternative conceptions, and then provide practical instructional guidelines for conceptual change.

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Notes

1. Certainly, the water circuit analogy can also be viewed as supporting concept. However, as previously defined, perception is viewed as 'interpretations of phenomena or events that obtained from five senses or from imaginative acts' (see Tsai 2000a, p. 286). Under this definition, the water circuit analogy is likely viewed as supporting perception in the conflict map.
2. The instruction guided by the conflict map often asks students to reflect upon their prior knowledge and make connections among prior knowledge, the new conception and other relevant conceptions and perceptions. Consequently, it is expected that the use of the conflict map may possibly help student engage in deep processing.
3. Although some science educators have pointed out serious limitations of using water circuit analogy, it has widely appeared in students' science resource books in Taiwan and it has been frequently used by Taiwan's science teachers. Therefore, this study included it in the instruction.
4. No such tutorial problems were practiced in the conflict map group.
5. The flow map interview used in this study is somewhat different from that employed in Tsai (1998b) and Tsai (2000b), which asked interviewee to 'freely' recall scientific information without the assistance of any other material. In the earlier studies, meta-listening was conducted only once. Hence, the interviewee could only listen to a replay of his or her ideas expressed in the first part of flow map interview, and the interviewee did not have a chance to listen to a replay of the ideas added in the meta-listening for possible modification. In present study, the researcher showed a graph (i.e. a series electric circuit) to help students recall ideas, not simply 'free' recall. This way of exploring students' ideas was similar to the 'interview-about-instances' method. Moreover, the 'meta-listening' technique in this study was possibly repeated several times until the interviewed subject did not have any additional idea elicited.
6. Chi (1992) believed that students often viewed electric current, heat and forces as material substance-based entities. However, scientists conceive of them as a kind of constraint-based events. That is, their existence rests on the values or status of other variables. For example, electric current exists only when charges travel between two points in an electric field.

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