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Effect of Different Instructional Methods on Students' Conceptual Change Regarding Electrical Resistance as Viewed from a Synthesized Theoretical Framework

Tao Jiang [1], Sanjun Wang [2], Jingying Wang [3*], Yongjun Ma [3]
[1] College of Physics & Electronic Engineering, Taizhou University, Taizhou, CHINA
[2] College of Physics & Electronic Engineering, Henan Institute of Finance and Banking, Zhengzhou, CHINA
[3] Normal College & School of Teacher Education, Qingdao University, Qingdao, CHINA

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ABSTRACT

This study sought to investigate the effect of different instructional methods on students' conceptual change and to explore junior secondary school students' misconceptions about electrical resistance. Quasi-experimental design was employed to compare whether or not there are significant differences among various teaching methods. The participants (165 junior secondary school students in China) were enrolled in three classes instructed by the same physics teacher. This study was carried out in a synthesized theoretical framework and found that the inquiry teaching method was effective in learning about resistance. Meanwhile, didactic learning supplemented with mathematical deduction was better in developing conceptual understanding of equivalent resistance. The crux of the matter is not whether the instructional method is traditional, but whether it brings mental disequilibrium and achieves conceptual framework shift. The findings distinguished a teaching strategy rooted in cognitive psychology from a strategy derived from physics itself. It also demonstrated the importance for teachers to use strategies derived from physics to accomplish students' conceptual framework shift. Meanwhile, this study investigated the opinions held by students and found a number which had not previously been reported. Therefore, it is essential for physics teachers to probe students' misunderstanding of a certain physics concept and design corresponding teaching method to accomplish students' conceptual framework shift.

Keywords: conceptual change, electrical resistance, instructional method, metacognition

INTRODUCTION

In recent years, there have been great interests in students' conceptual understanding in science. A vast body of researches have been conducted on students' misconceptions in many areas of science (e.g., Borges & Gilbert, 1999; Gönen 2008; Park & Kim, 1998; Viard & Khantine-Langlois, 2001). Previous research pointed out that misconceptions could develop both from external and internal sources (Bar, 1989; Bar & Travis, 1991; Ross & Shuell, 1993). It was seen as something that developed from TV and other media, peers, and family, in addition to the classroom inside, often from poor instruction (Gomez-Zwiep, 2008). In this paper we focus on students' difficulties dealing with the concept of electrical resistance. Although extensive researches have investigated students' difficulties in understanding the behavior of a simple electric circuit (Küçüközer & Kocakülah, 2008; Shepardson & Moje, 1994; Stockmayer & Treagust, 1994), there is few documents explore students' misconceptions about electrical resistance. McDermott and Schaffer (1992) first noted a tendency of students to focus on number of circuit elements rather than on configuration in an electric circuit when a resistance was added in parallel to a network. Students

✉ hopejt@163.com ✉ sanjunwang6@aliyun.com ✉ wangjingying8018@126.com **(*Correspondence)**
✉ kbmayongjun@126.com

Contribution of this paper to the literature

- This is the first article to investigate the effect of different instructional methods on students' conceptual change in the context of China.
- The results indicate didactic learning supplemented with mathematical deduction was better in developing conceptual understanding of equivalent resistance.
- The crux of the matter is not whether the instructional method is traditional, but whether it brings mental disequilibrium and achieves conceptual framework shift.

often have not been explicitly confronted with the fact that the equivalent resistance decreases with the addition of the element. Viard and Khantine-Langlois (2001) pointed out that the existence of the common term of resistance in the everyday language could be the root difficulties in the understanding of the working of electric circuits for students. In the case of Chinese students, their understanding of electrical resistance is even more incorrect, and it came from three different dimensions: firstly, as the electrical resistance is translated into Chinese language , it is endowed with additional meaning; secondly, the electrical resistance is a complex concept, even some teachers are confused with electrical resistance because it is defined neither by law of resistance nor by Ohm's law, actually it is defined by the deformation formula of Ohm's law; thirdly, when it comes to such conceptions like resistance, density, velocity, capacitance and so on, Chinese students' fixed way of thinking is to understand physical quantity's meaning by means of mathematical formula. Therefore, these students persist in the consistency between mathematics and physics, especially mathematics is considered to be the foundation of physics. As students' misconceptions about electrical resistance are too stubborn to change, Chinese physics teachers are used to say the resistance is an attribute of the object to emphasize its invariance, i.e., it is not changed according to the voltages across the resistor and the currents it carries (though it is tenable only for ohmic materials and the conductor's resistance will change according to its cross sectional area, length and temperature).

In this study, taking the traditional teaching method of electrical resistance as example, we investigate the effectiveness of different inquiry teaching method in Chinese secondary school students. As the traditional Chinese cultural is concerned, secondary school students seldom query their teachers, not to mention the textbooks, they are always ready to accept the concept that teacher should tell them. Unfortunately, though they are ready to accept the knowledge, some of them just can not change their misconceptions. They can recite the definition of a scientific concept fluently. But do not be aware of the differences between the scientific concept and their own everyday concept. Thus his usage of it is not always do execution. This study aims to investigate what opinions have been held by students about the electrical resistance and whether inquiry teaching method has good results in comparison with the traditional instruction so can contribute to the conceptual change theory.

LITERATURE REVIEW

Misconceptions are rooted in students' everyday experience and thus too stubborn to change. Some researchers have shown that traditional teaching approaches have not been influential as much as we expected on changing students' misconceptions (Çepni & Keles, 2006; Gomez-Zwiep 2008). According to the conceptual change model (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner 1992), students' misconceptions are unshakable to change because their misconceptions are not merely false beliefs but instead, students possess their own cognitive support groups and defense mechanisms. Thus when a discrepant event which provided students novel evidence to contradict their misconceptions was presented, they could just ignore it. They either made an explanation in accordance with their misconceptions or modified the "protective belt" and preserved the "hard core" of their misconceptions. Meanwhile, others argued that students were more apt to accept contradictive evidence obtained by an integrated science inquiry skill (controlling variables) than by a basic science inquiry skill (observation), thus could be successful in conceptual change (Park & Kim, 1998).

To carry out our research, we must be conscious of our epistemological presuppositions firstly. The experience of teaching physics history for undergraduates made the first author to be a believer of Kuhn and Lakatos' theory. Posner et al. (1982) likened the change in individuals' conceptions to changes in the knowledge of scientific communities during a paradigm shift (Kuhn, 1970). Thus made an explanation of the difficultness for a physics teacher to interpret that magnetic phenomenon is electrical in nature to his/her students. Mankind has spent hundreds of years on understanding it, and for individual, it is desired to be fulfilled in a couple of days. If it were not for abandoning his existing misconceptions system, this would not happen. On the contrary to abandoning their existing beliefs, students used to modify the "protective belt" and preserve the "hard core" of their misconceptions, the prototype of students' behavior can be found in Lakatos' scientific research programme model. Lakatos (1994) explained that experimental results in themselves were not sufficient to eliminate a hard core, and that any theory could be insulated from refuting results by adjusting the protective belt, either by suggesting auxiliary hypotheses to modifying initial conditions or by giving suitable reinterpretation of its terms. As a consequence, students are content with the fact that they do make some changes after formal education. When they deal with a problem in physics and have to make a decision, in some cases, compared with their original ideas, they use the more sophisticated conceptions to solve the problem, and in other cases they come back to the original ideas and fail to make a correct response. To walk away from this teaching puzzle, it is necessary to pay attention to Piaget's theory of cognitive development. Researches have shown that cognitive conflict must be generated in students' minds to challenge their misconceptions about natural phenomena. Various methods or strategies were suggested by science educators to help students achieve mental disequilibrium, for instance, hands-on, minds-on activities and questioning (Gomez-Zwiep, 2008), concept mapping (Horton et al., 1993; Roth & Roychoudhury, 1993), and metacognition (Georghiades, 2004; White & Gunstone, 1989). Compared to the Conceptual Change Model (Posner et al., 1982; Strike & Posner, 1992), Yuruk, Beeth, and Andersen (2009) also put forward metacognition as another theoretical framework to explain the nature of the change in learners' alternative conception.

The above discussions made the authors' epistemological presuppositions distinctly. According to Kuhn and Lakatos' theory, traditional instruction with simply presenting students the correct information is far from sufficient to guarantee students' conceptual change. It requires subversive evolution in students' inward world to achieve conceptual framework shift. As viewed from the physics history, the evolution of scientific concept was not accomplish at one stroke, instead, it is always transited from adjusting the protective belt to modify the hard core. Even the adjusting of protective belt made the concept more sophisticated. Thus to some extent, it can be viewed as scientific concept though it is not the concept possessed by scientists. Most of the successful methods in conceptual change include initiating some type of cognitive conflict within the students' inner beliefs and the contrary evidence presented by formal instruction. In addition, to facilitate students' concept learning, metaconceptual knowledge and metaconceptual processes also should be considered in the teaching design. In other words, we believed it is necessary to take advantage of both the CCM and the metacognition to explain the nature of students' conceptual change in science. Therefore, the study of Chinese students' conceptual change regarding electrical resistance was carried out in a synthesized theoretical framework.

The Chinese educational system was designed as pre-school, primary school, junior secondary school, senior high school and university. Pre-school education is given to children between 3-6 ages. Although it is not compulsory, these pre-schools extended all over the country. Parents select the kindergarden carefully to make sure their children will win at the starting line. Primary school is compulsory and it continues 6 years (between 6-12 ages), science lessons are given from 3th to 6th grades with two or five lessons per week. Chinese, English, mathematics and science are set to be core curriculums. Junior secondary school is also compulsory and it continues 3 years (between 12-15 ages). During this period, physics is taught both 8th and 9th grades with four lessons per week. Senior high school is not compulsory and it continues 3 years (between 15-18 ages). All the senior high school students have to study physics in the first year to get 6 credits, and it is the minimum requirement for graduation. Though they are not compelled to choose and study other physics units to get more credits, most of them insist on studying optional physics units in the following two years. Otherwise they will not be allowed to register for science department or engineering department in universities.

Given that physics pervades modern civilization, the life of a student who persistently performs poorly in physics achievement can become a nightmare either to himself or to the society. Actually, most Chinese students failed in science learning at the very start, which put them at a serious disadvantage. Under the circumstances, in recent years, there has a tendency of transformation from elite education to quality education to realize the goal of "Science for All". The policymaker introduced the constructivist perspective and inquiry teaching to science teachers as a magic drug. Ministry of education of the people's republic of China (2001) emphasized that "inquiry" is the core of this time's physics curriculum reformation (p.32). However, the insufficient preparations of theory, as well as the strong influence of the traditional teaching methods, making many science teachers come back to their didactic teaching. In their opinion, the didactic lecturing is the best teaching method. For the lack of pedagogical knowledge, they can not employ inquiry learning and cooperative learning perfectly in their classrooms, and they don't think it is a matter. Also as the limited class period they seldom do demonstrative experiment, not to mention permitting students to do laboratory experiment. In current teaching practices, the nature phenomena and experimental results are described to students. For the pressure of exam-oriented education, they generally finished the concept teaching in a hurry, and then set aside lots of time to do numerous exercises. On the one hand, both students and teachers make efforts to be successful, and on the other hand, the losers of science learning are produced from their school continuously.

METHODS AND PROCEDURES

Research Design

The effect of different instructional methods on students' conceptual change was investigated in this study. Two quasi-experiments were employed to statistically compare students' conceptual understanding of electrical resistance.

The design of these two quasi-experiments is based on the diversity of students' misconceptions about electrical resistance. Before the instructional interventions, we distinguished two categories of students' misconceptions:

Category 1 Firstly, some students are inclined to treat electrical resistance as an attribute of the electrical circuit, therefore, once the status of the electric circuit (e.g., the voltage across the conductor or the current in the conductor) changed, they believe the resistance of the conductor changed consistently. This kind of misconception can be changed through the teaching of Ohm's law. The first quasi-experimental design was applied to conceptual change in cases of this kind. The traditional instruction is lecturing format supplemented with demonstrations. Recently, the physics curriculum standard of the full-time compulsory education in China (2001) suggests students to apply control variate method to design an inquiry-based laboratory experiment in learning of Ohm's law. Though controlling variables is an integrated skill which inquiry teaching emphasizes, we don't think it is the best inquiry skill to conceptual change regarding electrical resistance. In control variate method, the fact that the electrical resistance remains constant is implicit. In other words, the cognitive conflict between the electrical resistance as a constant and the misconception that the resistance is relevant to the voltage or current is hidden. Students pay efforts to make a feasible experimental design or comprehend their teachers' design, be busy in replacing the electrical resistance, shifting sliding rheostat to get voltage and current value which are convenient for comparison. The above activities distract their attention and lead to their disregard of the electrical resistance. When the experiment is finished, they get a formula as a result and try to understand electrical resistance with this mathematical equation. Compared with control variate method, image method is easy to understand. In this instance, students manipulate a simple circuit to get voltage and current value, and then draw a current voltage diagram. In the diagram, electrical resistance is the slope of volt-ampere characteristic curve, it is a constant. As the voltage and current change, the electrical resistance remains the same, thus the conceptual conflict between the scientific concept and students misconceptions is explicit. Therefore, we infer that the image method is the best inquiry teaching design.

Category 2 Secondly, they often think that the resistance is an increasing function of the size of the conductor and in particular of its cross section (Johnstone & Mughol, 1978). When a resistor was added in parallel to another, the equivalent resistance increased. This kind of misconceptions can be changed through the teaching of "the equivalent resistance of the circuit". The second quasi-experimental design was applied to conceptual change in cases of this kind. In traditional teaching, the knowledge of equivalent resistance was explained by the teacher mainly in lecturing format without any hands-on experiments or demonstrations. Because in Chinese physics textbooks, the section of "Ohm's law" is followed by "the equivalent resistance of the circuit" immediately, as much time has been spent in the inquiry teaching of Ohm's law, it is unnecessary to make another hands-on experiment or demonstration. The lecturing format contains two typical conditions: the first teaching method is language description; teachers often liken the equivalent resistance to the school gate. In series circuit, equivalent resistance increases when two resistors are connected end-to-end, it is similar to when you squeeze through the narrow passage and find there is another passage in front of you, which make you exhausted. In parallel circuit, equivalent resistance decreases with two resistors connected in parallel, it is similar to build a new passage, so we can get through more easily. The second teaching method is getting the equivalent resistance equation of series circuit or parallel circuit by logic reasoning and mathematical deduction. Compare with the lecturing style, inquiry teaching with students' laboratory experiments was unusual. We were hesitating to presuppose which method would work best among these teaching methods. Each individual student has his/her own personality. Language description method may lead to the maximal conflict in students' who are good at imagination. While the logic reasoning and mathematical deduction method may lead to the largest conflict in students' who are good at logical thinking and mathematics. Meanwhile, the inquiry method may lead to the supreme conflict in students who are fond of verifying things by hands-on activities and observation.

Metaconceptual Knowledge and Processes

Yuruk et al. (2009) pointed out that metaconceptual knowledge and processes can be classified into four components: metaconceptual knowledge, metaconceptual awareness, metaconceptual monitoring, and metaconceptual evaluation. In Chinese physics curriculum standard of the full-time compulsory education (2001), science inquiry is resolved to seven components, such as "raising a question", "guessing and hypothesizing", "drawing up a plan and designing the experiment", "carrying out the experiment and gathering the evidence", "analyzing and proving", "evaluating", "communicating and cooperating". The first component "raising a question" requires students to pose a question either by their daily life or by the observation of an experiment. Students are dissatisfied with their existing beliefs as it is too crude to explain the natural phenomenon. They are aware of there must be some changes regarding their conceptual framework in order to answer the question they proposed. In this component they had to recognize the elements of their existing conceptual structure which has been defined by Yuruk et al. (2009) as metaconceptual awareness. The second component "guessing and hypothesizing" requires students to put forward hypothesis based on their experience and prior knowledge. Yuruk et al. (2009) suggested that the metaconceptual knowledge can be defined to include one's stable and statable knowledge about concept learning and the factors influencing concept formation. To be explicit, Yuruk et al. (2009) made a further explanation that the metaconceptual knowledge is something acquired through experience and stored in the memory. As to pose their hypothesis, students need to not only retrieve their experience but also make reference to their past conceptual structure. It is clear that the former represents students' metaconceptual knowledge and the latter represents their metaconceptual awareness. The third component "drawing up a plan and designing the experiment" requires students to try to consider the main factors which influence the issue, then use control variate method to design an experimental program. In this step, they should make reference to their past conceptual framework to decide which factors would be primary to the issue. This is a manifestation of metaconceptual awareness. In addition, they have to make clear the known and unknown things, the methods, materials and procedures be about to employ in the experiment. In other words, to formulate a reasonable program, they had to generate information about their cognitive state or thinking process which was defined as metaconceptual monitoring by Yuruk et al. (2009). The fourth component "carrying out the experiment and gathering the evidence" requires students to obtain data from observation and experiment. As students are monitoring information coming from the experiment, checking the consistency between the existing conception and new information, this stage can be classified as metaconceptual monitoring. The fifth component "analyzing and proving" demands students to make a brief comparison between the information gathered from the experiment and from other sources, draw conclusions from cause-and-effect relationships, defend his opinions with evidence and debate with others who have different opinions. Students are often organized as groups to discuss the different opinions, make impartial assessment to his and others opinions. By conducting a simple comparison and drawing the conclusion, he monitors the consistency between the existing beliefs and new conception. By discussing opinions coming from other students, he monitors his and others conceptual change. By making assessment on others opinions, he evaluates the validity and limitations on competing conceptions impartially. Students' status of metaconceptual monitoring and metaconceptual evaluation is clearly. The sixth component "evaluating" demands students to consider whether their experimental results and conclusions are contradictory to their prior knowledge. Meanwhile pay attention to the defects of their experimental plan, finding new questions which should be handled later. The last component of science inquiry is "communicating and cooperating", which requires students to respect others opinions during the cooperative learning, analyze the differences between his and others opinions. Both the sixth and the last component of science inquiry are metaconceptual monitoring and evaluation processes.

In the last three components of science inquiry, as long as student's opinion is proved to be false in the group debate or classroom discussions, he is assumed to admit his error and abandon it immediately. However, it should be pointed out that in these steps, students' status of abandoning their misconceptions and changing to the scientific conception is an idealized outcome of concept learning. Though the metaconceptual knowledge and metaconceptual processes are integrated to the science inquiry properly, it maybe not sufficient for lots of students to eliminate the "hard core" of their misconceptions.

Participants

This study took place in a public junior secondary school located in an urban school district in Zhengzhou of China. Four-fifths of the students in this school come from the rural migrant worker's family and the socioeconomic status of most families was in lower-income group. It represents the typical student situation in public junior secondary schools in large cities of China. The participants (165 junior secondary school students) were enrolled in three classes taught by the same science teacher, they were randomly assigned to each class by a computer scheduling program at the beginning of 7th grade and rearranged according to his or her academic performance at the end of 7th grade. The classes' arithmetic means on physics term examination of the first semester of 8th grade had no significant difference. The teacher who voluntarily participated in this research had more than 5 years of experience in physics teaching and was familiar with the inquiry teaching theory as she graduated from a normal university after year 2002.

In Chinese educational system, all the junior secondary school students are compelled to study physics course at the beginning of 8th grade, the electrical resistance is taught at the beginning of the second semester. Teaching approaches (inquiry teaching or traditional instruction) were randomly assigned by the researchers to each classroom.

Table 1. Five items used in the pre-test

Item 1: When an electric hand torch has been used for a long time, the dry battery's voltage decreases, the bulb light is dimming. It means the resistance of bulb: (a) is constant; (b) increases; (c) decreases; (d) other Because,
Item 2: When we shift the slide rheostat to enlarge the circuit current, the bulb light grows brighter. It means the resistance of the bulb: (a) is constant; (b) increases; (c) decreases; (d) other Because,
Item 3: Two 5Ω nichrome wire resistors are connected in series to each other, the total resistance is: Because,
Item 4: Two 5Ω nichrome wire resistors are connected in parallel to each other, the total resistance is : Because,
Item 5: When a wire was elongated four times, how its resistance changed? (a) is constant; (b) increases; (c) decreases; (d) other Because,

In the first quasi-experiment, students in class A (comparison group) were instructed by the traditional methods while students in the experimental group (class B, class C) were exposed to inquiry circumstances. There were 54 students in class A and 46 of them were identified to have misconceptions (category 1) in the pre-test. To be more precise, the comparison group was made up of students who have misconceptions. There were 56 students in class B and 50 of them were identified to have misconceptions of category 1, students who had misconceptions constituted the first experiment group taught by inquiry method using control variables. There were 55 students in class C, 50 students who had misconceptions (category 1) were chosen to be the second experiment group taught by inquiry method using image skill. In the second quasi-experiment, students in class A were exposed to inquiry circumstances while students in class B and class C were instructed by the different traditional instructional methods.

Typically, students are instructed by the physics teacher and led to build an understanding of Ohm's law for themselves in the first 45-minute lecture. In the second 45-minute lecture, a few minutes are spent to get students familiar with the formula of Ohm's law and its deformation formula (Otherwise, some students may failed in solving the problems in post-test 1 not according to they have not a scientific comprehension of resistance but due to they can't employ the formula into calculation. Meanwhile, the formula teaching is not involve with the decision whether the electrical resistance is constant), then they are given 10 minutes to solve the problems in post-test 1, after that they participate in the discussion and solve other problems. The third and fourth lectures usually designed to review the concept of resistance and Ohm's law, and some complicated problems are introduced to students. In the first lecture of the next week, students are involved in the concept learning of equivalent resistance. At the first 10 minutes of the second lecture, they are demanded to complete the post-test 2, the rest time are used to solve various equivalent resistance problems. Pre-test and Post-test all done in the lecture. If they are arranged to be homework, students may get answers from consulting reference book or check their answers with classmates before they hand in it.

Data Source and Analysis

Pre-test In order to probe the manifestation of students' misconceptions about electrical resistance, a paper and pencil test consisting of 5 open-ended questions was developed. The prototype of this instrument can be seen in Park and Kim's (1998), similar design also can be seen in Gönen's study (2008). Furthermore, a group of physics educators and physics teachers checked the test for validity and then confirmed the content validity of the instrument. Pre-test was completed by students in the first physics lecture of the second semester of 8th grade. The test items in the pre-test are shown in **Table 1**. Item 1 and 2 were designed to identify students' misconceptions about electrical resistance of category 1. The rest were designed to identify students' misconceptions about electrical resistance of category 2. According to the different type of inferential statistics used in quasi-experimental treatment, the first two items were analyzed under the following categories suggested by Abraham et al. (1994), i.e., sound understanding, partial understanding, and partial understanding with specific misconception, specific misconceptions and no understanding.

Student's achievement score was determined by the following method. Sound understanding was recorded as 4, partial understanding was recorded as 2, partial understanding with specific misconception was scored with 1, specific misconception and no understanding was scored with zero. There is no score of 3 was given for items 1 and 2, this scoring approach was used to show the big disparity between sound understanding and partial understanding. Though students with partial understanding didn't display some kind of misconceptions, they also

Exercise 1. The resistance of a conductor is 4 Ω. How much current does the conductor carry when connected to a 2V source? When the conductor is connected to a 4V source. What is the resistance of the conductor?

Exercise 2. Look at the circuit shown in the right side. This circuit consists of a battery, a slide rheostat and a bulb. To measure the voltage across the bulb, we place a voltmeter parallel with the bulb. When the voltmeter measures the voltage between the two ends of the bulb's filament is 6V, the bulb carry a current of 1A. What is the resistance of the bulb? As we shift the slide rheostat to increase the current in the bulb to be 2A, What is the voltage across the bulb?

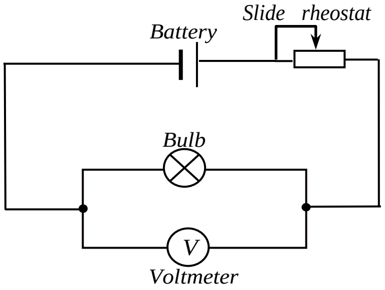

Figure 1. Post-test 1 problems

Table 2. Three Exercises used in the post-test 2

Exercise 1: When a 10Ω resistor is connected in series to a 40Ω resistor, what is the equivalent resistance? When they are connected in parallel to each other, what is the equivalent resistance?
Exercise 2: You are required to assemble a 15Ω resistor, you already have a 10Ω resistor, which resistor does you need and how you connected them? After that you are asked to assemble a 10Ω resistor, you already have a 20Ω resistor, which resistor does you need and how you connected them?
Exercise 3: An 1Ω resistor is connected in parallel to an 100Ω resistor, the total resistance of them is: A. 101Ω B. 99Ω C. more than 1Ω, less than 100Ω D. less than 1Ω

didn't make a reasonable explanation for their choice or gave an explanation. Students whose scores were less than 2 were considered to be unsuccessful and chosen to participate in the first quasi-experimental treatment.

The latter three items in **Table 1**, which distinguished the misconceptions about resistance of category 2, were analyzed by the five-grade marking system. The correct responses to item 3 or item 4 were scored with 1.5; item 5 was 2 points because it is involved with synthesized judgment of cross sectional area and length. This scoring approach was much different from it for items 1 and 2. Student's achievement score of items 1 and 2 was used as a basis merely to distinguish whether or not he/she was successful. However, in the second quasi-experiment, analysis of covariance (ANCOVA) was generated to adjust the effect of instructional treatments on students' conceptual understanding for differences in their conceptual understanding prior to the instructional interventions. Students' pre-test scores of items 3, 4 and 5 were used as the covariate. To highlight the numerical feature of the data we got from the latter three items, the five-grade marking system was employed according to the habit of the junior secondary school's physics teacher.

Post-test 1 was used to evaluate the teaching effectiveness on Ohm's law. Two problems in the post-test 1 were shown in **Figure 1**.

Students were demanded to calculate the value of voltage and current. To achieve these calculations they had to use the unchanging electrical resistance in the formula. Some students were puzzled by the formula as it says that the resistance is proportional to voltage and inversely proportional to current. Whenever they changed the resistance, they were identified to be unsuccessful after the teaching of Ohm's law. Therefore, the data we got from the post-test 1 were also classified into two categories, then the chi-square test statistic was calculated to show whether there was significant difference among different teaching methods. The chi-square test method was used to emphasize particularly on the perfect effect on students' conceptual understanding of Ohm's law. As previously mentioned, even the students who solved one of the two exercises right were identified to be unsuccessful as they didn't had the firm belief that the resistance of the conductor is constant. As Ohm's law is one of the most important concepts in Chinese junior secondary school physics curriculum, it is reasonable to take the teaching effect undergo this rigorous test. But the data used in the chi-square test are nominal variable, thus lose some information which were inherent in the paper and pencil tests.

Post-test 2 was used to examine the teaching effectiveness of "the equivalent resistance of the circuit", which requires 5 times calculations and twice judgments. Post-test 2 was shown in **Table 2**.

Student's post-test 2 marked on a scale from 0 to 10. This scoring method recorded student's varying degrees of conceptual understanding of equivalent resistance after the instructional intervention. Though the chi-square test was the most suitable method to test the teaching effect of Ohm's law, we used different inferential statistics method in the second quasi-experiment. It rooted in the following two reasons. Firstly, compare to the chi-square test, ANCOVA preserved the data information to a maximum extent. Student's pre-test score is a "covariate". Analysis of covariance allows us to adjust the treatment effect to the mean pre-test score of all participants.

Secondly, if the different inferential statistics methods came to the same conclusion, we had more confidence to say that one teaching method was superior to another.

Twenty students in class D of 8th grade (taught by the same physics teacher who instructed classes A, B and C) were selected randomly to participate in a pilot study. They were taught by the traditional method from beginning to end. Above two paper and pencil tests (post-tests 1 and 2) were administered to them before and after the instructional intervention. In the pilot study, student's achievements marked on a scale from 0 to 10, t value were found to be 8.182 for post-test 1, and 7.272 for post-test 2. Because the test is a right-tailed test, $\alpha = 0.001$, and $df = 19$, the critical value is $t_0 = 3.579$. As t is in the rejection region, the results of t test indicate that after teaching intervention, students' scores were significantly higher. Thus the content validity was confirmed. The test-retest reliability of the post-tests was calculated through the Pearson product-moment correlation coefficient method. The reliability coefficients were found to be 0.627 for post-test 1, and 0.862 for post-test 2. The first one seems to be low due to two aspects. On the one hand, to limit the time costs on the post-test, the problems in it were rather few; on the other hand, students were bored to do the same post-test repeatedly and just finished it in a hurry. In the practice of Chinese educational measurement, it is widely accepted that so long as the reliability coefficient of a test compiled by the instructor is no less than 0.60, it is able to be used in the examination (Dai, Zhang, & Chen, 2005; Wang, 2005).

Other Date Sources One purpose of this study is to investigate the common sense held by students on electrical resistance. As far as some students who were not good at written language were considered, the data regarding students' misconceptions were also derived from other sources: audio-recordings, classroom discussions, conversations with teacher after class. These data sources were necessary for capturing the real thoughts of students. Though some students did not write anything to explain the reason for their choices in pre-test's items, their inner beliefs did emerge from the conversations with classmates and teacher.

RESULTS

Students' Misconceptions about Electrical Resistance

In the last month of the first semester of 8th grade, students participated in the learning of chapter 5 "Current and Circuit", though electrical resistance was not discussed in this chapter, students did come into contact with the entity and the symbol of electrical resistance (Peng & Du, 2006a) and a brief statement was made to explain the effect of resistance in the circuit (Peng & Du, 2006a). Some students would rearrange their experiences and get their everyday concept of resistance. However, not all the false responses found in the pre-test were listed in the following tables because some of them are just guesses rather than stable, existing beliefs. Either the false response reappeared in several students' homework, post-tests and conversations with teacher after instructional intervention, or students who made a specific false response were more than 33 (20% of the population) on items 3, 4 or 41 (25% of the population) on items 1, 2 and 5 can it be identified as misconception. Because students may believe the equivalent resistance of a series (parallel) combination of resistors is the sum (subtraction, product or quotient) of the individual resistances or equal to one of the individual resistances, therefore, the probability of the one be chosen are no more than 20%. Meanwhile, there are four choices in the items 1, 2 and 5, the probability of the one be chosen are no more than 25%. The certain option be chosen was just a possibility, but it actually chose by lots of students represented a universality, so it can be an inner misconception. In addition, some entries which listed in the following tables as misconceptions also showed some kinds of logical deduction or mathematical deduction. It was a sign that students have placed this kind of misunderstanding into their existing conceptual framework internally.

This section is devoted to describe students' misconceptions about electrical resistance. This activity is meaningful for conceptual change. When students' real thoughts were known to teacher, the teaching strategies can be developed to not only generate the maximal conceptual conflict, but also achieve the conceptual change. Pseudonyms were used to protect the students' identity.

Misconceptions of Category 1 The following excerpts were taken from students' presentations in pre-test, classroom discussions and communications with teachers and represented students' misconceptions about electrical resistance of category 1.

Amy:	When the electrical resistance decreases, the current is lessened, so the bulb light is dimming.	The electrical resistance is proportional to current
David:	The more current the conductor carries, the more obstacles it meet, the bulb light grows brighter at the same time.	
Lisa:	The resistance decreases with increasing current, so the bulb light grows brighter.	The electrical resistance is inversely proportional to current
Christy:	As the battery's voltage decreases, the bulb's resistance lessens, and the bulb light is getting dimmer.	The electrical resistance is proportional to voltage
Doug:	The resistance is an obstacle to voltage, therefore, the voltage decreases as the resistance increases, the current flowing through the circuit is diminished and the lamplight is growing weaker.	The electrical resistance is inversely proportional to voltage
Brenda:	The slide rheostat is an element which can change other electrical elements' resistance, thus contribute to the illumination of a bulb.	The resistance has relevance to slide rheostat

It was not surprising that students considered the electrical resistance was proportional to voltage and inversely proportional to current. What astonished the researchers was that students believed the electrical resistance was inversely proportional to voltage and proportional to current. Most of them were conscious of their current ideas as they could write it down in the paper. Though student had not studied electrical resistance in the formal teaching context, he/she put forward explanations based on everyday experience and logical reasoning (maybe it is incomprehensible to teacher, it is reasonable to himself/herself). In addition, the great majority of students came to their conclusions with mathematical proportional relations, which showed their ability and willingness to supplement logical reasoning with mathematics.

Misconceptions of Category 2 Students misconceptions about electrical resistance of category 2 are even more complicated and confused. The following excerpts revealed that students employed rational analysis and analogy to get their conclusions.

Paula:	As two resistors connected in parallel, the voltages across the resistors are the same because each is connected directly across the battery terminals, i.e., $V = V_1 = V_2$, the relationship between the equival resistance and the individual resistances is the same as the voltages, i.e., $R_T = R_1 = R_2 = 5\Omega$.	Reasoning and analogy
James:	The current of a series circuit is invariable from one place to another, i.e., $I = I_1 = I_2$, the relationship between the equivalent resistance and the individual resistances is similar to the above relationship, i.e., $R_T = R_1 = R_2 = 5\Omega$	
		Qualitative analysis of item 5
Julie:	As the length and cross sectional area changed simultaneously, the resistance inherent in the wire is constant.	Resistance is dependent on the body
Leigh:	Since the circumference of the wire is unchanged, the resistance is constant.	Resistance is dependent on circumference
Cheryl:	Whatever how many times the wire is elongated, as long as the volume is constant, the resistance will be unchanging.	Resistance is dependent on volume
		Integrated quantitative and qualitative analysis
Jon:	In a parallel circuit, the current breaks into two parts and flowing through 5Ω resistor separately, thus the total resistor is 10Ω.	Vivid imaginations
Willie:	I used to believe that the upper branch was shortened by the nether branch, so the total resistance of the parallel circuit is 5Ω. Now I changed my opinion, as the current was set back twice, the total resistance should be 10Ω.	
Jason:	Unfortunately, both of you are wrong. Since the electrons are not idiot, they just flow through one branch, so the total resistor of parallel circuit is no more than 5Ω.	
Ted:	I believe the total resistance of parallel circuit is 0, as the currents flowing through different branches conflict with each other on the node of the electric circuit, thus lead to the resistance reduced to 0.	
Kevin:	In a series circuit, the current flowing through two resistors is the same, since resistance is the representation of an obstacle which current confronted, so long as the current is unchanging, the total resistance of the series circuit is 5Ω.	Logic thinking

Table 3. Effectiveness of Different Teaching Strategies on Ohm's Law

Teaching strategy	Conceptual understanding		Total
	successful	unsuccessful	
Lecturing format	2	44	46
Inquiry with control variate method	9	41	50
Inquiry with image method	16	34	50
Total	27	119	146

$\chi^2(2, n = 146) = 12.17, p < .01$

Some students operated analogy method to get the relationship between the equivalent resistance and the individual resistances consciously. They wrote down: "In the parallel circuit, the voltage across the total resistance is equal to the voltage across the individual resistance, so the total resistance is equal to the individual resistance." Besides, some students deduced the relationship between resistors from the relationship between currents.

The excerpts in above two tables also show some students' metaconceptual activities. Despite tremendous differences between experts and novice learners had been reported (Glaser & Chi, 1988; Sternberg, 2001), we found that novice learners do manifest their inner awareness of their cognitive structure to a certain extent. They could transfer prior knowledge into a clear expression, support their opinions by logical reasoning. This behavior displayed "one's knowledge and control of one's own cognitive system" which defined as metacognition by Brown (1987). Maybe junior secondary school students are not good at metacognition, but their desire to display the progress in science learning made them execute a conscious metaconceptual activities. Especially their aspirations were ignited by group debate and classroom discussion.

Meanwhile, students' status of mental disequilibrium also immerged in the classroom discussions and conversations with their teacher, students questioned: "A conductor has its resistance while the voltage across the conductor, the current in the conductor. Why the voltage across the conductor and the current it carries can be changed, its resistance can not be changed?" Some of them asked: "You (physics teacher) said that the resistance is an attribute of an object, it is a constant. But why the resistance of the conductor changed according to its length and cross sectional area? You had told us that the mass is also an attribute of an object, and the object's mass would still be constant as its shape changed. It seems that your statements are inconsistent with each other. But you are a teacher. You would not make mistakes, what's wrong with me?"

Even the extracts above are examples of students' misconceptions about resistance, we are aware of the positive aspect of these examples. Students' enthusiasm to share opinions with classmates, their employment of rational analysis and analogy, and their metacognitive activities made the science learning has a massy foundation.

Effectiveness of Different Teaching Strategies on Ohm's Law

To investigate the effect of different instructional strategies on students' conceptual understanding, we selected subjects who displayed misconceptions about resistance of category 1 in Pre-test. This meant that 46 students in class A, 50 students in class B and 50 students in class C were selected.

Class A was comparison group instructed by didactic lecturing supplemented with demonstrations. Class B and class C were experimental group instructed by inquiry methods. Students' conceptual understanding after instruction were identified by post-test 1 and classified into two categories: successful and unsuccessful. See **Table 3**.

Because $\chi^2 = 12.17$ was in the rejection region, there was enough evidence at the 1% level of significance to conclude that the teaching strategy and conceptual understanding were dependent. In other words, the difference of conceptual understanding on Ohm's law among different teaching strategies was statistically significant. Three 2×2 contingency tables were used to make further testing. The results showed that when lecturing format or inquiry with control variate method was applied to students, the difference of conceptual understanding was statistically significant ($\chi^2(1, n = 96) = 4.4, p < .05$). The difference between lecturing format and inquiry with image method was also statistically significant ($\chi^2(1, n = 96) = 13.26, p < .01$). Contrary to what the first quasi-experimental design has expected, the difference among two inquiry teachings using different skills was not statistical significant ($\chi^2(1, n = 100) = 2.26, p > .05$). From these differences above we may conclude that students were more apt to change their misconceptions by inquiry teaching than by lecturing format.

Pines and West (1986) proposed three possible outcomes of instruction when there is a conflict between the academic knowledge and student's belief system, i.e.: conceptual exchange, compartmentalization, and no learning. Compartmentalization is a status where the new knowledge and old belief system coexist. However, according to the synthesized model another possible outcome is "partial change", which means students just modified the "protective belt"(e.g., electrical resistance is inversely proportional to voltage) and preserved the "hard core" (electrical resistance changed according to the voltage across the conductor) of their misconceptions. In this study,

Table 4. Levene's test of equality of error variances[a]

F	df_1	df_2	Sig.
2.519	2	162	.084

Dependent Variable: Post-test

[a] Design: Intercept + Teachingmethod + Pre-test + Teachingmethod * Pre-test

Table 5. Tests of between-subjects effects
Dependent Variable: Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Teaching method * Pre-test	3.680	2	1.840	.345	.708

46 students (32%) changed resistance in both two exercises, some of them didn't make any progress in conceptual understanding, the others did make some modifications on the "protective belt" of their misconceptions, all of them were classified to be "no learning" and "partial change". 73 students (50%) who use the invariable resistance in one problem and the changed resistance in another problem were classified as compartmentalization (total=146). For these 73 students who had special mistakes checked out from post-test 1. We found that 7 students (9.6%) made a right response to exercise 1 without circuit diagram, and 66 students (90.4%) did a correct calculation to exercise 2 with a circuit diagram. This phenomenon had a significant educational implication on conceptual understanding. When students thinking were assisted by some kinds of diagram, it may be helpful to inhibit his intuitive knowledge and release the scientific concept.

Effectiveness of Different Teaching Strategies on Equivalent Resistance

In the learning of Ohm's law, students who used control variate method got the formula: $I = \frac{V}{R}$, then they deformed it to be: $R = \frac{V}{I}$ (students who used image method get this formula directly). Resistance is defined as the ratio of the voltage across the conductor to the current it carries. For many ohmic materials, the resistance remains constant over a wide range of applied voltages or currents. To obtain multifaceted comprehension of resistance, students should engage in additional studies on "the equivalent resistance of the circuit". So the Ohm's law and equivalent resistance are combined to the same section or contiguous sections in Chinese physics textbook (Peng & Du, 2006b; Yan & Wang, 2006).

In this study, the second quasi-experiment was designed to investigate the effectiveness of different teaching strategies regarding the equivalent resistance. The purpose of this quasi-experiment mainly focused on the re-examining the effectiveness of inquiry teaching. It has been mentioned that class A was instructed by inquiry method (IM), and class B, C were instructed either by language description (LD) or logic reasoning and mathematical deduction (LRMD). From the first quasi-experiment, we had concluded that the difference of conceptual understanding regarding Ohm's law between inquiry method and didactic lecturing format was statistically significant. Does inquiry teaching always do better than lecturing format? If it is true, the results must be repeated. Students' post-test 2 scores were analyzed by using ANCOVA to adjust the effect of instructional treatment on students' conceptual understanding for differences in students' conceptual understanding prior to the instructional interventions. The results were analyzed by using SPSS statistical software and the Levene's test of equality of error variances can be seen in **Table 4**. So the error variance of the dependent variable is equal across groups. Tests of between-subjects effects can be seen in **Table 5**.

Since the significance value was 0.708, there was no interaction between covariate and fixed factor. Therefore, the two primary conditions of ANCOVA were met. The results of the ANCOVA generated to compare group's mean scores on post-test 2 were presented in **Table 6**. Meanwhile, the univariate tests resulted in significant F values ($F=6.475$, $p<.05$), which consisted with the pairwise comparisons. These results indicated that there was a significant mean difference among groups when the significant difference in students' pre-scores was statistically controlled. Students instructed by didactic lecturing format with LRMD strategy were more successful in conceptual change regarding equivalent resistance. From this finding, the inquiry method did better in students' conceptual change regarding Ohm's law, which had not been repeated. Thus we might conclude that inquiry teaching would not always be the best strategy in conceptual change. After an in-depth study on the inquiry teaching, we find the difference between this inquiry and previous inquiry. In previous inquiry, most students got the conclusion after the inquiry experiment and group debate. When it comes to the inquiry experiment of equivalent resistance, though they did find that the total resistance of the parallel circuit decreased, as the relationship between the equivalent resistance and the individual resistances is nonlinear, they just could not get the formula by themselves. The conclusion was told by the teacher, so students' metaconceptual processes didn't have a beginning and an end, especially the solution of their largest cognitive conflict between existing beliefs (the simple relationship between the equivalent resistance and the individual resistances) and scientific conceptions (the

Table 6. Pairwise Comparisons
Dependent Variable: Post-test

(I) Teaching method	(J) Teaching method	Mean Difference (I-J)	Std. Error	Sig.
LD	IM	.075	.441	.866
	LRMD	-1.337*	.441	.003
IM	LRMD	-1.411*	.441	.002

Based on estimated marginal means
* The mean difference is significant at the .05 level.

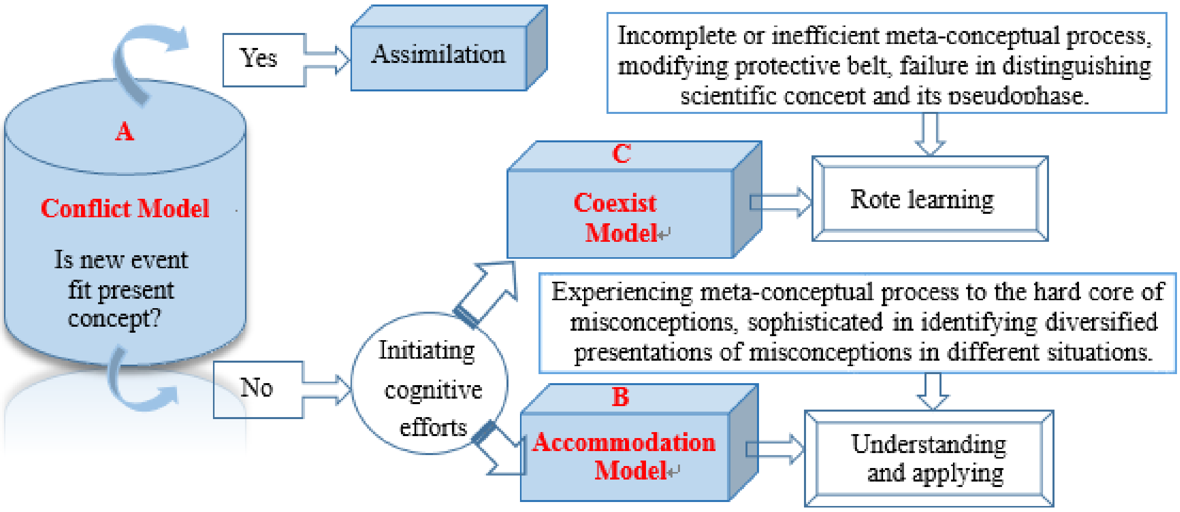

Figure 2. Synthesized students' conceptual change framework: Three models

nonlinear relationship between the equivalent resistance and the individual resistances) was not achieved by themselves. The same thing happened in the language descriptive teaching. In the logic reasoning teaching, though there were not so much extinct metaconceptual processes, some students comprehended their teacher's mathematical deduction and deduced the formula later respectively, thus achieved conceptual change.

DISCUSSION

By integrating the meta-cognition to explain students' conceptual change and our finding result, we develop a synthesized theoretical framework as shown in the Figure 2. The conflict model is developed based on CCM theory, students are not satisfied with the new events contrary to their existing belief system, and arising learning requirements. Generally, meta-conceptual process in coexist model is inadequate, students could not find all the mistakes inherent in their original concept, and failure in affirming the consistency between their original concept and the scientific concept. Which students experiencing adequate meta-conceptual process is accommodation model, they confirming all errors in their original concept and understanding the scientific concept (meta-conceptual awareness), familiar with the acquisition/deducing process of the scientific concept, knowing exact location where the original concept been proved false (meta-conceptual monitoring), identifying and applying the scientific concept to solve problems in all kinds of situations (meta-conceptual evaluation).

What we pay more attention to is the Conceptual Change Model (CCM). The CCM is viewed mainly as a process dimension of conceptual understanding (Posner et al., 1982). To make a successful science education, it is vital to achieve conceptual framework shift. Though the CCM, cognitive conflict, metacognition all contain some kinds of practical activities, we think that the methods or strategies in CCM are different from their counterparts in cognitive conflict and metacognition. We distinguished teaching methods or strategies into two categories. The first refers to hands-on, minds-on activities and questioning, concept mapping and classroom discussion, which can lead to metacognition or conceptual conflict. This kind of teaching methods roots in cognitive and educational psychology. The second refers to control variate method, image method, analogy, mathematical deduction and so on. They are teaching methods as well as research approaches employed by physicist. This kind of methods derived from physics and mainly discussed in physics and philosophy of science. What the procedures drawn from educational psychology and from physics have in common is that they are some kinds of communication and interaction between students and their teacher. As far as the individual's metacognition is concerned, it also contains some kinds of dialogue and communication with his/her existing conceptual structure. However, the procedures drawn

Table 7. Students' conceptual framework shift of electrical resistance of category 1

Processes	Students' understanding of electrical resistance of category 1
Typical misconceptions	The more/less current the conductor carries, the more/less obstacles it meets As the battery's voltage decreases, the bulb's resistance decrease/increase
Metaconceptual knowledge and awareness	The lightbulb brightness is influenced by its current The lightbulb brightness is influenced by its voltage
Metaconceptual monitoring	Students retrieve what they had done in the inquiry classroom and have a clear vision: unchanging the conductor in the circuit, its current grows in pace with the voltage; replacing the conductor and keep the voltage unchanging, the current in resistor is inversely proportional to its resistance.
Metaconceptual evaluation	Students got the formula $R = \frac{V}{I}$ and defined resistance as the ratio of the voltage across the conductor to the current it carries. Therefore, they came to the hard core of their misconceptions that resistance can be changed, and finally realized that resistance is a fixed constant of variation

Table 8. Students' conceptual framework shift of electrical resistance of category 2*

Processes	Students' understanding of electrical resistance of category 2	
Typical misconceptions	In the parallel circuit, as far as $V = V_1 = V_2, R_T = R_1 = R_2$ In the series circuit, as far as $I = I_1 = I_2$, $R_T = R_1 = R_2$ In the parallel circuit, the total resistance is equal to the sum of individual resistance where current flows through, i.e. $R_T = R_1 + R_2$	
Metaconceptual knowledge and awareness	The voltage drops across the resistors in the parallel resistance circuit must be equal In the series circuit, all the current that flows through one resistor must also flow through the other Resistance is a fixed constant of variation Mathematics has much better efficiency than vivid imaginations	
Metaconceptual evaluation	Parallel circuit: $V = V_1 = V_2$ $IR_T = I_1R_1 = I_2R_2$ $\because I \neq I_1; I \neq I_2$	Series circuit: $I = I_1 = I_2$ $\frac{V}{R_T} = \frac{V_1}{R_1} = \frac{V_2}{R_2}$ $\because V \neq V_1; V \neq V_2$
	$\therefore R_T = R_1 = R_2$ would not stand. Students experiencing logic reasoning and mathematical deduction, evaluating their former opinion and find the errors. However, rely on this process can not eliminate mental disequilibrium, further efforts need be done to find the reasonable explanations.	
Metaconceptual monitoring	Parallel circuit: $I = I_1 + I_2$ $\frac{V}{R_T} = \frac{V_1}{R_1} + \frac{V_2}{R_2} \quad \Theta V = V_1 = V_2$ $\therefore \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$	Series circuit: $V = V_1 + V_2$ $IR_T = I_1R_1 + I_2R_2$ $\Theta\ I = I_1 = I_2$ $\therefore R_T = R_1 + R_2$
	Student's thinking process was guided by mathematical deduction, shifting his conceptual framework from the equality relationship (hard core of their misconceptions) to the reciprocal relationship (parallel) or sum relationship (series) As mathematics has much better efficiency than vivid imaginations, students abandoned the sum relationship (parallel circuit, hard core of their misconceptions) and shifted to the reciprocal relationship	

*Taking LRMD method as an example

from physics emphasize its instrumental value, i.e., the scientific methods derived from physics act as a bridge to make the dialogue among contradictory things feasible.

We sorted out and analyzed students' conceptual framework shift based on the mental process with their metaconceptual processes and knowledge categories, as shown in **Table 7** and **Table 8**.

CONCLUSION

The findings of this study improve the theoretical framework of conceptual change. The inferential statistic of the second quasi-experiment has shown that traditional teaching approaches can be effective in student's conceptual change. The crux of the matter is not whether it is traditional, but whether it brings mental disequilibrium and metacognitive activities, then achieved conceptual framework shift. Back to the history of physics, we found that every scientific conception has its evolutional history. Since the conception is concrete and diverse from each other, there can not be a teaching method which would do better in all the circumstances. Meanwhile, based on this study and other researches (Georghiades, 2004; Horton et al., 1993; Yuruk et al., 2009), there are some specific teaching methods effectively on the conceptual change of a given concept. As it is shown in this study, the inquiry method is effective in the learning of Ohm's law and didactic lecturing format with LRMD strategy do better in conceptual understanding of the equivalent resistance.

There are some conceptual frameworks in research of students' conceptions, e.g., the conceptual change model (Posner et al. 1982; Strike & Posner, 1992), cognitive conflict (Gomez-Zwiep, 2008; Kang, Scharmann, & Noh, 2004), and metacognition (Georghiades, 2004; White & Gunstone, 1989; Yuruk et al., 2009). None of them can make a satisfied explanation about the results of this study. But from the synthesized framework it can be interpreted elaborately.

In the matter of cognitive conflict, there are some teaching methods effective in igniting students' mental disequilibrium. It is meaningful in concept learning, but relying on these methods merely are not sufficient to accomplish conceptual framework shift. As discrepant events which contrary to their existing beliefs were observed in the experiments, videos or concept mapping, students were confused with contradictory events. Even though they were aware of the inaccuracy of their existing beliefs, most of them could not change to the scientific concept entirely (Wang, Jou, Lv, & Huang, 2018). They either modified the "protective belt" and preserved the "hard core" or let the new knowledge and old belief system coexist. Thus partial change or compartmentalization status was formed.

In the metacognitive activities, students are aware of their existing conceptions, monitoring their comprehension of the new conception, evaluating the relative status of the new conception in relationship to their existing conceptions (Yuruk et al., 2009). Compared to cognitive conflict, students' initiative activities are strengthened, the discrepant events which they faced before were under scrutiny (Merlin, Maisha, & Max, 2016).

Take this research for an example, to achieve conceptual framework shift, it is vital to employ the instruments or strategies derived from physics. On the learning of resistance, the formula $R = \frac{V}{I}$ was presented to students, their old conceptual framework to comprehend it were merely from the mathematics. The mathematics expressed the resistance is proportional to voltage and inversely proportional to current; however, the physics teacher said the resistance is constant. Therefore, students were puzzled with the contradictory events. To achieve conceptual framework shift, the image method act as an instrument to expose the current is proportional to the voltage for ohmic materials (that is exactly what the mathematics expresses), thus the ratio of voltage and current is invariable. As the mediation of image method, neither the mathematics nor the physics teacher tells lies. The contradiction roots in the misunderstanding of the formula, as the mathematics still be effective in the image method, the mental disequilibrium was eliminated. A new conceptual framework come into being that no matter what the voltage and current vary, the resistance is constant. On the learning of equivalent resistance of parallel circuit, students' old conceptual framework was simple linear relationship, for example, $R_T = R_1 = R_2$, with the teaching strategy of mathematical deduction, it change to a new conceptual framework-"the reciprocal relationship", that is $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$.

Though this study elaborates the positive impact of scientific methods and mathematical method on students' conceptual framework shift, it doesn't mean the methods drawn from physics can always be effective alone. In students' inquiry learning of Ohm's law, the mental disequilibrium and metacognitive activities also contributed to their conceptual change. Meanwhile, the researchers don't confirm the methods drawn from physics, in any event, are superior to metaconceptual processes on students' conceptual framework shift. It roots in two aspects, firstly, the participants are not selected randomly and assigned to each class, and instead, we had to use the currently available classes. Secondly, the junior secondary school physics teacher is not expert in igniting students' metacognitive activities in their inquiry learning.

The findings of this work enlightened the importance for teachers to pay efforts to probe students' misunderstanding of a certain physics concept and design correspondent teaching method to accomplish conceptual framework shift. The scientific methods and mathematical method provide clear, feasible and effective approaches.

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