Third Misconceptions Seminar Proceedings (1993)

Paper Title: TEACHING EXPERIMENT METHODOLOGY in the Study of Electricity Concepts

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Keywords: concept formation,research methodology,educational methods,concept teaching,cognitive development,cognitive restructuring,change strategies,qualitative research,misconceptions
General School Subject: physics
Specific School Subject: electricity
Students: secondary school

Macintosh File Name: Katu - Electricity
Release Date: 12-15-1993 C, 11-6-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

original publication of this proceedings was supported by a grant from the National Science Foundation, and the transformation of this collection into a modern format was supported by the Novak-Golton Fund, which is administered by the Department of Education at Cornell University. If you have found this collection to be of value in your work, consider supporting our ability to support you by purchasing a subscription to the collection or joining the Meaningful Learning Research Group.

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TEACHING EXPERIMENT METHODOLOGY in the Study of Electricity Concepts*

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Paper presented at the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Ithaca, New York
August 1993

* The authors acknowledge the important contributions of Dr. Martin A. Simon, Penn State University, to the research reported in this paper.

Introduction

This study investigated the dynamic changes in the conceptions of simple electric circuits of a small number of high school students. A "teaching experiment" design (Steffe, 1983) guided the research. Learning and development of more scientific understanding were expected in this study as a result of teaching interventions and interactions between the students and the researcher who acted as a teacher. This paper reports a detailed analysis of the teaching experiment conducted with one student.

Rationale

Although some science educators have claimed success in promoting changes and development of more scientific conceptions, others have expressed concerns about: (1) the extent to which their instructional strategies influence the status of individual students' thinking; (2) their knowledge of individual student's conceptions before, during, and after instructional treatments, and (3) their ability to monitor the development of individual students' conceptions (Hewson & Thorley, 1989; Licht & Thijs, 1990; Steffe, 1983).

The methods used in many studies to change students' misconceptions have been based principally on quantitative studies of students' generalized common conceptions (Clough & Driver, 1986; Hewson & Thorley, 1989; Cobb & Steffe, 1983). In addition, Cobb and Steffe (1983) suggested that many researchers in mathematics education have missed opportunities to interpret the dynamic changes of students' conceptions during the implementation of instructional strategies by distancing themselves from teaching and assessment in the classroom. To help students develop more comprehensive knowledge, a teacher must have a strong background in the knowledge to be taught and a good understanding of each student's conceptions about the topic to be able to follow dynamic changes in those conceptions.

Purposes of the Study

This research was designed in response to concerns in the teaching of introductory electricity similar that were similar to those of Cobb and Steffe (1983) . It was anticipated that strategies might be developed on the basis of research of this kind that would help teachers to teach science concepts more effectively. The purposes of the study were to develop a coherent understanding of the development of a student's conceptions during a series of teaching interventions, to explain the nature of the changes and the development of the students conceptions, to design and apply teaching interventions intended to promote the development of more scientific concepts in basic electricity, and to examine the student's reactions to specific teaching interventions.

Methodology

The researcher conducted this study with a small number of students to diagnose and monitor the dynamic changes of each student's conceptions of simple electric circuits. He interacted with individual students in a series of interviews and teaching interventions. The researcher acted as interviewer as well as teacher. As interviewer, the researcher interpreted the conceptions or conceptual framework the student used in explaining an event or phenomenon. He also constructed a holistic and coherent story about how the student thought the simple electric circuits worked. As teacher, the researcher responded to the student's conceptions throughout the teaching sessions and designed appropriate and relevant teaching interventions.

In preceding pilot studies, the researcher synthesized and tested a five phase conceptual change teaching strategy based upon the work of several researchers (Hewson & Hewson, 1983; Licht, 1987; Shipstone, 1988; Tasker & Osborne, 1985). The five phases of the teaching strategy involved practical activities as a central element and were intended to accomplish the following outcomes:

Phase 1. Help the student become aware of his or her existing ideas about the topic under consideration;

Phase 2. Enable the student to perceive a contrast between those ideas and the events that occurred in electric circuits;

Phase 3. Help the student find alternative explanations for the events that were different from the predictions;

Phase 4. Provide opportunities for the student to apply and test his or her newly developed ideas;

Phase 5. Help the student become aware of the changes that had occurred and to review and compare the old and new ideas.

While elements of the conceptual change strategy were regularly employed, the five phase strategy as a whole was not employed in the main study. The researcher interpreted the status of the student's conceptions at successive instances and constructed a holistic picture of the dynamic changes of the student's conceptions throughout the teaching sessions. Each teaching intervention was intended to be particularly responsive to the student's existing conceptions, and each was developed as the study progressed.

A qualitative phenomenography research methodology (Marton, 1988), more specifically the teaching experiment methodology (Cobb & Steffe, 1983, Glasersfeld, 1987), was employed in the study. Evidence from studies in mathematics education showed that this methodology enables researchers to participate actively in the student's learning activities and to monitor and interpret the status of the student's conceptions at successive times during the study. A teaching experiment consists of a series of student interviews and teaching episodes. The researcher acts as the teacher as well as a participant-observer in the study (Steffe, 1991).

This paper reports interactions with one student in a series of eight sessions. The first three sessions were focused on diagnosing the student's prior conceptions about how simple electric circuits work. The five sessions that followed were focused on teaching interventions designed to help the student develop more comprehensive knowledge about how simple electric circuits work; in addition, the student's conceptions were examined throughout all sessions.

Two experts with skills in classroom observation and in physics teaching observed the videotapes of the teaching experiment sessions. The principal tasks of the observers were to interpret the student's conceptions demonstrated or inferred during each session, identify important turning points in that session, provide feedback to the researcher about the researcher's behavior, and suggest possible teaching activities for the next session. The observers provided written reports of their observations and discussed them with the researcher before each successive session began.

The study took place at a private high school in a small town in central Java, Indonesia. The subjects of the study were students from grade 10. The selection of the subjects was based in part on the ability of each subject to express his or her own ideas orally. The selection was also based on recommendations from the subjects' teachers. Another criterion for the selection was the willingness of the subject to cooperate in the study and to participate in the scheduled sessions. The study with one student reported here was conducted across 2.5 months. Basic electricity concepts related to simple electric circuits with batteries, bulbs, and resistors were the topics addressed in the study.

Data Processing and Analysis

Data for the main study were recorded and gathered from videotapes of eight sessions, the researcher's field notes, student's worksheets, observers' notes, Indonesian transcripts, English transcripts, and background information about the student.

The videotape of each session was transcribed in the Indonesian language . The accuracy of the transcripts was then checked by comparing them with the videotapes. While doing that, the researcher put notes on the transcript to explain what the student or the researcher did at a particular moment, what diagram was used in a particular activity, what kind of connection the student made when he or she tried to light the bulb and so on. When the transcriber could not clearly recognize a word or words from the videotape, the researcher would help by listening to the tape. If he could not recognize the words, he would ask colleagues for help in identifying what words had been used.

Next, the Indonesian transcripts were translated into English. The first translation was done by the researcher. The translations then were validated by one of the observers competent in the English and Indonesian languages and in physics education. He compared the English and the Indonesian transcripts and provided critical commentary which was used to improve the validity of the translations. The English transcripts were then sent to two experts for further review and validation.

One of the problems the researcher faced in translating the transcripts was that the grammar and structure of Indonesian language are different from the grammar and structure in English. The researcher was concerned that some important meanings might be modified if he tried to perfect the English translations. Therefore, he decided to translate exactly what had been said by the students and the researcher in imperfect English. Another problem was that there are not precisely equivalent words in the two languages. A student using a particular Indonesian word might intend to express one of several different meanings. For example, the word "sama" in common Indonesian language may mean "the same," "identical," "equal," or "similar." So, sometimes the researcher might translate the same Indonesian word into different English words depending on the context in which the word was used by the subject. Another problem concerned the use of singular and plural forms.

In Indonesian the plural form is represented by repeating the same word twice. However, many times people forget to do that and commonly use the noun one time for both singular and plural forms. For example, the student said "lampu" to represent one bulb or several bulbs. Thus in making translations the researcher needed to be aware of that problem as well.

The researcher first analyzed the data chronologically to develop an understanding of the conceptual model being constructed in the student's mind. The student's model was inferred from his or her explanations about how simple electric circuits worked during the teaching experiment. The researcher assembled "chunks of data" from the transcripts into a "big picture", fitting those elements of data together to construct a coherent story of model and conception development. He also matched, contrasted, and compared all evidence from the field notes and the transcripts to understand the student's global ideas (LeCompte & Goetz, 1982).

Reliability and Validity

The study employed multiple data collection and interpretation methods. The researcher carefully recorded relevant information including procedural information describing the behaviors of the student and the teacher / researcher. He also recorded background information about the student's prior education and about the social, physical, and interpersonal contexts. The researcher's notes provided a detailed description of how data were collected and interpreted.

To increase the probability of valid observations and interpretations, the researcher utilized multiple methods of data collection and multiple methods of data interpretation. Data in this study came from videotapes of the sessions, Indonesian and English transcripts of the sessions, field notes, observers' notes, and additional information from appropriate sources. Moreover, an expert observer cross-validated the Indonesian and the English versions of the transcripts. In addition, the English transcripts were given to two other experts in science education and in mathematics education for validation review. The researcher also discussed his interpretations of the student's conceptions with those experts. To compare the subject's ideas with scientific consensus, the researcher developed scientific definitions based upon definitions of the concepts in physics textbooks and discussions with several experts in physics education. It is important to note that while the study may suggest promising hypotheses that can inform further research and implications for teaching, the results of this study can not be generalized because it was conducted with very small numbers of subjects.

Findings

Prior to Teaching

Analysis of the data revealed that the subject strongly held several ideas which he used consistently in predicting events that occurred in simple electric circuits. The narrative descriptions suggested that the subject did not change these particular ideas during the first three sessions and that he regularly applied these ideas in combination with other ideas in interpreting the events which he thought occurred in electric circuits. These several basic ideas served as a basis from which the subject reasoned about electric circuits. The basic ideas were:

1. Current consists of the flow of electrons from the negative pole of the battery through the circuit to the positive pole of the battery;
2. Electrons bring energy from the battery to the circuit and part of it is converted into heat and is used by the circuit elements;
3. Current is the movement caused by consecutive collisions between electrons inside the circuit. These collisions transfer energy and produce heat;
4. The amount of current supplied by a battery to a series circuit is constant and is independent of the energy of the current. Thus the number of electrons leaving the battery in a unit of time is constant and is independent of the speed of the electrons;
5. The energy and the electron flow of a circuit are not affected by bulbs and resistors until after the electrons flow through them. This idea in conjunction with #4 leads to the following two-part concept which relates to what scientists might call "resistance."
    a. The energy of the electron flow is affected by the bulbs, resistors, and wires. As the electrons flow through a circuit element, the collisions between electrons result in a portion of the kinetic energy of the electrons being converted into heat. The energy (speed) of the electron is reduced as it passes through each circuit element. Thus, the electrons have their greatest amount of energy when they leave the negative pole of the battery and have the least energy when they arrive at the positive pole;
    b. A resistor reduces the number of electrons that flows through it by blocking some of the electrons that enter. So, the amount of current leaving the resistor will

be smaller than the amount of current that enters the resistor. Wires and bulbs on the other hand do not reduce the amount of current flowing through them;

6. The brightness of the bulb is proportional to the energy used by that bulb;
7. The brightness of each bulb is predetermined by the characteristics of that bulb. Each bulb lights with a given brightness;
8. The wattage and voltage drop of each bulb are predetermined as printed on the bulb.

These ideas probably reflect the sense the subject made from experiences with electricity at home and from what he learned in school.

During and After Teaching

The teaching activities during sessions four through eight focused on engaging the subject in making predictions, in testing predictions by using practical activities with batteries, bulbs, and resistors, and in making inferences from what he observed. The activities enabled the subject to reject several of his prior conceptions and to adopt new ideas which were more useful in making predictions about electric circuits. These ideas included:

A1. <u>The quantity of current flowing in a circuit consisting of bulbs in series</u>. Prior to teaching the subject thought that the quantity of current flowing through a series circuit consisting of bulbs remained unchanged when additional bulbs were added; the quantity of current was constant and always equal to the quantity of current supplied by the battery. After teaching the subject believed that when a bulb is added in series to an existing circuit, the amount of current supplied by the battery remained the same and is shared by the bulbs;

A2. <u>The function of the resistor</u>. Prior to teaching the subject thought that a resistor affected the current only when current arrived at and passed through a resistor, i.e., that it reduced only the current between it and the positive pole of the battery. During teaching the subject realized that a resistor reduced the current in a circuit on both sides of the resistor. However, the subject could not explain the occurrence in terms of his model of resistor resulting in a series of alternating ideas;

A3. <u>The brightness of the bulb</u>. Prior to teaching the subject thought that the brightness of each bulb is predetermined and does not change. Thus the amount of energy used by each bulb is always constant. After teaching the subject realized that the brightness of each bulb was dependent on the energy available to the bulb. For example, in a series circuit consisting of two identical bulbs, the brightness of each of the bulbs was dimmer because the energy available to each of the two bulbs was smaller than to the bulb in a single bulb circuit;

A4. The quantity of energy supplied by the battery. Prior to teaching the subject believed that energy supplied by the battery (per unit time) increased when more bulbs were added in series. After teaching the subject assumed that the amount of energy supplied by a particular battery (per unit time) was constant irrespective of the number of bulbs connected in series. The bulbs in series shared the energy supplied by the battery per unit time;

A5. Potential difference across the bulb. Before teaching the subject assumed that the potential difference across each bulb was predetermined by the voltage printed on the bulb and not a variable. After teaching the subject concluded that the potential difference across each bulb was dependent on how the bulb was connected to the battery. If it was connected in series with other bulbs, the bulb shared the battery's voltage with others. If the bulb was connected in parallel with other bulbs, potential difference across the bulb was equal to the voltage supplied by the battery.

Even though the ideas the subject developed in working with the electric circuits enabled him to make more accurate predictions, his explanations indicated that several of his new ideas remained substantially different from the ideas about electric circuits of the scientific community. These ideas included:

B1. The quantity of energy supplied by the battery. The subject believed that voltage was a measure of energy. This idea seemed to be supported by the measurements that he made of voltage across the battery and the circuit elements. The data which he collected on voltage conformed to his expectations about energy, that is that the battery supplies a certain amount of energy that is shared by the circuit elements. Thus he concluded that the energy supplied by the battery was always constant since he believed that the voltage (which was constant) was a measure of energy;

B2. The current flowing through a circuit consisting of bulbs in series. The subject believed that when a bulb is added in series to an existing circuit, the amount of current supplied by the battery remained the same and is shared by the bulbs. The subject did not understand that adding more bulbs in series reduces the current. Even when the researcher's leading question resulted in the subject saying that "[another function of the bulb is] to resist the current," the subject failed to change his idea about current from a quantity that is shared by bulbs in series to the idea that adding bulbs will further reduce the flow of current. The subject seemed to adapt his model of energy sharing to account for the decrease in the current flowing when more bulbs were added to a series circuit. In lieu of a concept of bulbs resisting electron flow, the notion of sharing current among the bulbs seemed to account reasonably well for the data. Having developed a mental set that current was being shared equally by the bulbs, the subject did not entertain alternative explanations as the teaching sessions proceeded.

Some of the subject's ideas were similar to but not synonymous with ideas shared by the scientific community including:

C1. As the number of bulbs in series increases the current measured in the circuit decreases;
C2. Current is constant throughout a circuit that contains a resistor;
C3. The brightness of each bulb connected to a series or parallel circuit is dependent on the energy available to the bulb;
C4. The voltage supplied by the battery is constant and shared by the circuit elements in series. The sum of the voltages shared by the circuit elements is always equal to the voltage supplied by the battery.

Although the subject developed generalizations about current and voltage, he was unable to explain why the quantity of current in any part of the circuit was influenced by the presence of both bulbs and resistors. Several factors may assist in understanding this conceptual problem. First, the subject believed that current is "shared" by bulbs in series rather than reduced as bulbs are added (discussed earlier). Second, the subject did not have a conceptual model of current which he could use to make sense of the data he gathered. His notion of current being shared was linked to a particular notion of what current is. That notion was inconsistent with his earlier definition of current as the frequency of electrons passing through a given point in the circuit. Third, the subject believed that the movement of electrons inside the circuit was caused by consecutive collisions between electrons: how fast an electron will move is determined only by the speed of the electron coming toward it. Thus his ideas about collisions may have prevented him from thinking about the simultaneous flow of electrons. Fourth, the subject did not have a scientific understanding of the relationship between current and energy. His preconception about current indicated that he thought current was independent of energy. The subject did not perceive that the quantity of current was related to the net movement of electrons and thus related to the energy supplied by the battery. Fifth, the subject's lack of understanding of the relationship between current and energy hindered his understanding of resistance. The subject did not understand that bulbs resist current. The subject understood that energy of the electrons was consumed by the bulb but did not perceive the presence of bulbs as a factor that reduced the flow of current in a circuit.

Discussion and Implications

Learning Electricity Concepts

This study revealed several important issues related to learning and thinking about electricity.

Sources of conceptual development. Conceptions about electricity develop from everyday experiences with electricity, from formal instruction on the subject of electricity, and from informal media. The researcher labeled ideas that are "less developed", often unscientific, and derived from daily experiences with electricity as "primitives" (diSessa, 1987). For example, the subject thought that bulbs have predetermined brightness, that the brightness of a bulb is the same regardless of the presence of other bulbs in the circuit. The subject knew that at home a 25-watt bulb has a certain brightness even when other bulbs are turned on. The study revealed that primitive ideas may be very persistent. Although the subject saw evidence that refuted it, he still sometimes used this particular primitive to make predictions. Research can inform instruction by demonstrating the existence of such primitives and by identifying particular primitives which are commonly held by students.

Complexity and the importance of interrelationships. The research suggests that developed, sophisticated understanding of electric circuits results in a densely connected network of concepts. Before instruction, students have ideas about energy. Students know that energy is something that is consumed by electrical devices such as a lighted bulb. However, ideas about current, potential difference (measured in volts and often referred to colloquially as "voltage"), and resistance are "taught" in school. All three concepts are tightly interrelated with one another and with energy. Current has energy; it consists of electrons which have energy related to their speed. Current and energy are affected by the magnitude and direction of the potential difference supplied by the battery and the magnitude of resistance of a circuit. Students often may not understand the interrelationships amont the several electric concepts taught in school, and they may tend to use them independently. It is appropriate to hypothesize that students are not likely to develop sophisticated understanding of relationships among these concepts if they are taught about them independently, one at a time. The concept of a circuit system is one that probably can best be developed through a series of practical experiences interwoven with discussions about theoretical explanations, through a sensitive blend of theory and practice. The interconnections of the concepts of current, potential difference, resistance, energy, and circuit system are central, yet they may not regularly be understood in a developed, scientific conceptual framework by novice learners. The teacher's job of identifying appropriate early learning experiences and of helping students perceive relationships among concepts is very challenging. It requires knowledge of the discipline and of the students' developing understanding.

The study revealed that the concepts of electricity taught in school are many and varied going well beyond basic ideas associated with current, potential difference, and resistance. Students often do not understand the interrelationships among these ideas, and consequently they use them independently. The study showed that the two terms: potential difference and voltage generated different meanings in the subject's mind. The subject thought of potential difference as a measure of electron imbalance, while he thought of voltage as a measure of energy.

Levels of students' thinking about data from practical experiences with electric circuits. The study of the subject's work with electric circuits suggests that students at this level may engage in at least three levels of thinking about observed phenomena. At the first level, this student described what he saw or measured from the learning activities. For example, the subject asserted that two bulbs connected in series to a battery were each dimmer than one of those bulbs connected to the same battery. At the second level, the student identified a pattern which indicates a generalization beyond the particular data the had observed. For example, the subject identified a quantitative pattern that in every series circuit the voltage supplied by the battery is shared by the circuit elements. He came to understand that the sum of the potential differences across each of the elements in a series circuit was equal to the potential difference across the battery. This generalization helped him make correct predictions about the effects of adding bulbs and resistors on the potential difference across each of the circuit elements. At the third level, the student might have developed an explanatory model or assimilated the data within an existing explanatory model. (An explanatory model, in this case, is a scheme which allows the student to make sense of the events occurring in a circuit.) This subject did not develop a scientific model to explain circuit events during the teaching experiment. An hypothetical example of how he might have developed an explanatory model of electric circuits from his earlier model of energy consumption follows. The subject already had a weak concept of current as the flow of electrons, and he knew that the bulbs use the energy of the electrons. Thus energy of the electron flow is reduced by the presence of the bulbs. The teacher might have helped him understand the effect of reducing the energy of the flow on the net speed of the electrons by introducing an analogy such as the "chain analogy". This analogy might help the subject connect the reduction of energy of the electrons to "slowing down" the flow of electrons through the bulbs and throughout the circuit. From here, the subject might be able to develop understanding about the relationships between current and energy and begin to perceive the bulbs as resistors of current. An important goal of science instruction should be to help students develop this third level of thinking with an explanatory model; understanding the nature of scientific, explanatory models us an important part of scientific literacy.

Knowledge across different circuits. The research suggests that making predictions about electric circuits involves identifying information derived from experiences with circuits and from explanatory models that may be useful as a starting point for reasoning about circuits not previously encountered. One element of this kind of reasoning is identifying relationships that are invariant from one circuit to another. The subject used what he knew about the characteristics of an electric circuit from his observations and measurements on a single bulb circuit to interpret more complex circuits.

Scientific understanding. The research contributed to clarifying what it means to have developed understanding of electric circuits. Developed understanding of electric circuits includes knowledge of the complexity and the importance of the systemic interconnectedness of current, potential difference, energy, and resistance. Explanatory models account for the events occurring in a circuit, and they enable the student to identify useful starting points for reasoning about new circuit situations not previously encountered.

Role of practical work. The hands-on activities with materials used in this teaching were effective in enabling the subject to observe relationships among the brightness of bulbs, the numbers of bulbs and resistors, the magnitude of current at different points in a circuit, and magnitudes of potential difference. However, the subject did not relate these observed and measured relationships to his earlier ideas about electron flow. As a result he did not develop fully sophisticated scientific understanding of the interrelationships of voltage, current, energy, and resistance. They did not enable him to develop a scientific model of a circuit system.

Role of algorithms. Research suggests that mathematical algorithms and formulas may play different roles depending on the knowledge of the user. For someone with a developed conceptual knowledge of electric circuits, Ohm's formula can represent an understanding of the interrelationship of potential difference, current, and resistance. On the other hand, for the subject reported in this paper, the Ohm's formula bridged conceptual gaps allowing him to make correct predictions without full understanding. To cite one example, the subject learned that current in a series circuit was constant throughout the circuit. By measuring, he found the potential difference across the brighter bulb (V1), was greater than potential difference across the dimmer bulb (V2) in a circuit with two non-identical bulbs in series. By using the Ohm's law formula, he used his observations, i.e.., the current flowing through the bulbs is equal and V1>V2, to determine that the resistance of the brighter bulb (R1) is greater than the resistance of the dimmer bulb (R2). With little or no understanding about the concept of current and that bulbs resist current, the subject was able to relate these quantities algebraically to make a correct inference about the relatives sizes of the resistances of the bulbs. His correct quantitative predictions were based upon a very limited conceptual understanding. If his conceptual understanding of electricity were to continue to develop he would ultimately come to perceive Ohm's formula as one representation of a more sophisticated understanding.

Teacher questioning. Clearly, teacher questioning was very important and influential in this study, but the study also revealed that the student's responses to the teacher's leading questions can create an illusion of understanding. For example, in response to one of the teacher's questions, the subject said the bulb resisted the current. Although the subject said those words, he never adopted the concept that bulbs resist current. Evidence of this assumption can be found in the fact that he maintained throughout the teaching sessions that the bulbs in series "share" the current supplied by the battery. At the conclusion of the teaching experiment, the subject still thought that the total current supplied by the battery was equal to the sum of the currents flowing in each of the bulbs in a series circuit.

Interpretation of words. The study showed that the teacher and the student may perceive a statement or a question in different ways. Each may construct a different meaning even though the language and words are shared. To cite one example, when the teacher/researcher posed a question about connecting two batteries in series, the researcher saw the problem as: “what happens to the brightness of the bulb when the potential difference supplied to the bulb is increased.” For the subject the problem was: “what effect do two batteries connected in series have on the energy supplied to the circuit." This example provides evidence that a teacher cannot assume that the student interprets a problem in the same way that the teacher does even when the student responds with the "correct" words in response to a question. An effective teacher investigates how the student interprets a problem during the process of teaching.

Teaching Electricity

This study revealed several important issues related to the teaching of electricity concepts. Each teaching intervention followed some of the steps of the five phase conceptual change teaching strategy developed during the pilot study. Practical activities with batteries, bulbs and resistors, and circuit diagrams were used to help, and the subject did develop understanding of electric circuits. The teaching activities employed in the study had advantages and limitations.

The study showed that the teaching strategy and practical activities used in the study were effective in promoting understanding of electric circuits. It suggests that:

1. Activities with batteries, bulbs, and resistors enable a student to test his or her predictions about the events the student thinks occur in an electric circuit when the circuit configurations are changed. Activities with batteries and bulbs are very useful for creating discrepant events that may promote conceptual conflicts in a student's mind. Such internal conflicts have the potential to stimulate adaptation of the student's conceptions.
2. Activities with batteries, bulbs, and resistors can help a student develop a more complex understanding of the interdependence of electricity concepts in series and parallel circuits. Experiences of this kind can serve as a foundation for developing relationships between concepts.
3. Engaging a student in dialogue enables a teacher to learn about effects of different types of questions and interactions on the development of the student's understanding.
4. Engaging a student in dialogue enables the student to develop skills in observing, in interpreting, and in explaining observations and measurements.

The study also revealed limitations in the teaching strategy as employed in the study. The research suggests that:

1. Not all the “basic” circuit concepts that are currently part of introductory electricity are directly observable. The subject had difficulties in conceptualizing the idea of resistance and in relating the concept of energy to potential difference, current, and resistance. The practical activities were limited in their power to promote conceptual change because energy and resistance are abstract concepts and are not directly observable.

2. A student does not necessarily link the generalizations he or she develops from observations and measurements to explanatory models. For example, the subject did not relate the generalizations he developed for current and energy to his explanatory model of electron flow. Teachers may use practical activities to focus on observation, prediction, or explanation. The activities themselves are neutral, but the teacher-student interactions can emphasize specific problem-solving processes, concepts, and interconnections.

3. Practical activities do not inherently introduce new or improved explanatory models. The development of new models is a creative act which comes from other related activities and interactions such as the use of analogies, graphic representations, and simulations.

4. The processes of measuring current and potential difference may not have been understood even though the subject made many measurements. For example, the subject probably did not verbalize why potential difference was measured by placing the voltmeter across two points or why current was measured differently by placing the ammeter in the circuit in series.

Analysis of the effects of the conceptual change teaching suggests the following implications to improve elements of the strategy:

1. More intensive probing of the relationships between the generalizations from the data and explanatory models such as electron flow may promote the development of more sophisticated conceptions.

2. Analogies such as the water analogy and the bicycle chain analogy (Dupin & Joshua, 1989; Glynn, 1989) or computer simulations (Lunetta et al., 1987) may help students develop a visualization of aspects of electric circuits such as resistance, energy, potential difference, and battery or power supply, and their interconnections. Students can also discuss the limitations of the analogies and simulations in representing the electric circuits, thus contributing to the development of their understanding.

The Research Methodology

Advantages. The study revealed advantages of the teaching experiment methodology as an important medium for the study of the teaching and learning of electric circuit concepts. It provided information about a student's primitive ideas, about ideas learned in school, and about interconnections between these ideas. The study revealed information about conceptual development and about conceptual difficulties for one student. This information can be investigated further to determine its generalizability. The methodology enabled elaboration of the complexity of electrical circuit concept development and of the meaning of understanding of electrical concepts. It revealed how mathematical algorithms may be used by students and provided insights into the impact of different kinds of teacher-student interactions and teacher interventions. The methodology also enabled intensive analyses of the use of practical activities with electric circuit materials in teaching basic electricity concepts.

The study revealed that in conducting a teaching experiment study the researcher should have developed knowledge about the subject matter and highly developed interview skills. A neutral stance in interpreting the students behaviors and concepts is also essential. Measures should be taken to insure that the researcher's own concepts and beliefs do not bias his or her observations and prevent him or her from looking at every possibility. It is important for the researcher to continually ask whether or not all possibilities to understand and to help the student have been explored.

The study suggested the importance of having a team of experts to advise the researcher throughout the teaching experiment research. This team of experts can provide alternative interpretations of the data gathered during the study, thus contributing to more sensitive interviewing and teaching and to the depth and the richness of the analysis.

<u>Limitations</u>. The data from this teaching experiment study provided rich information about the student's concepts and learning processes and about the effects of different kinds of experiences and teacher-student interactions. However, the study was limited in several ways. First, the study reported data of one student, and therefore the generalizability of the observations is not known. Second, the student was involved in a relatively small number of teaching sessions. Therefore, the researcher cannot make claims about the effects of long term instruction nor about the long term effects of this instruction. Third, decisions to ask particular questions or to create and change specific teaching interventions were based on inferences the researcher made about the status of the student's conceptions at the time the teaching occurred. Subsequent careful analyses of the transcripts sometimes yielded interpretations of the student's understandings that were quite different from the interpretations on which the teaching interventions were based. Fourth, additional information about the student's concepts might have been gathered had the researcher asked particular probing questions or in certain cases provided more open-ended opportunities for

the student to respond. These decisions influenced the depth and the nature of the information gathered.

The third and fourth limitations outlined in the preceding paragraph, are general limitation of qualitative research. In qualitative studies the researcher is analogous to a research instrument. Therefore, the quality of the data collected is determined, in part, by the researcher's experiences and skills. A fifth limitation in the study exists because the subject did not develop sophisticated and fully inter-connected concepts of potential difference, current, resistance, and energy. Thus, the study did not reveal some important aspects of the development of these concepts. The knowledge gained was limited to an early phase of the developmental spectrum. The knowledge gained through this study does provide, however, an important foundation upon which to construct hypotheses for more comprehensive studies of electrical concept development.

Implications for Teaching and Teacher Education

The results of this study suggest several implications for teaching school science.

1. Practical (hands-on) activities with appropriate materials can help students reject primitive conceptions and develop bases for more scientific conceptions.
2. Practical activities should be combined with other activities including discussion of explanatory models, analogies, diagrams, graphic representations, and simulations to help students develop higher levels of scientific understanding.
3. The visibility of the teacher's misinterpretations about a student's understanding even in this careful research study suggests that teachers need to develop interview skills and to focus on the process of learning from the student's point of view. "Leading" the student to problem solutions did not generally result in the construction of scientific understanding. This study suggests that teachers should ask more open ended questions and more probing questions which can promote and reveal students' thinking as a basis for the development of more scientific concepts.
4. Teaching and learning electricity and probably other science concepts involve complex processes. Thus the education of teachers should include activities which help them develop a sense of the complexity of such learning. Opportunities to conduct interviews with students about their understanding of the concepts being taught should be incorporated within teacher education programs. The development

of increased sensitivity to student learning difficulties is one step toward helping teachers develop better ways to teach concepts in their disciplines.

5A. This research suggests the hypothesis that electricity concepts are best taught as a network of ideas and not independently.

5B. It is also important for teachers to promote more precise use of language to increase concept discrimination and understanding. This research identified several points where imprecise language may have inhibited concept development. One example is the failure to discriminate clearly between potential difference and the volt or voltage. Another example was the frequent colloquial use of the Indonesian word "sama" which can mean similar as well as equal or identical.

Implications for Future Research

The study suggests several questions that warrant investigation in future research.

1. How can practical activities with batteries, bulbs, and resistors be used optimally to promote bases for the student to develop explanatory models of electric circuits?
2. How can the student's initially less developed explanatory models about electric circuits be engaged as a basis for developing more scientific explanatory models?
3. How are analogies such as the water analogy and the chain analogy best incorporated with practical activities with batteries, bulbs, and resistors to help the student develop appropriate explanatory models of electric circuits?
4. What kinds of graphic representations and simulations can be incorporated with activities to help the student develop explanatory models of electric circuits?
5. What are the effects of the introduction of selected concepts in school on the development of conceptions in electricity, e.g., the nature of current as the flow of positive or of negative charges, potential difference and voltage, power and energy, and power supply and voltage source?
6. What are the best ways of integrating the measuring processes, e.g., use of the voltmeter and the ammeter, to promote the development of conceptual understanding about electric circuits?
7. What kinds of peer interactions can promote learning and scientific concept development in the teaching of electric circuits?

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