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A Review of Misconceptions of Electricity and Electrical circuits.

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ABSTRACT

This paper is a review of articles and published reports concerning misconceptions about electricity and electrical circuits. This comprehensive review of literature identifies and describes the misconceptions of students from age 8 through adults, and methods of instruction that have addressed the misconceptions. The review of articles indicates that misconceptions about electricity and electrical circuits may be divided into two primary categories, (a) the concept that current is consumed in a circuit, and (b) the concept of a battery as a source of constant current. Methods of instruction that are purported to be effective in correcting misconceptions have been presented with implications for teaching, teacher education and further research.

INTRODUCTION

As society becomes increasingly technological, more and more of our everyday activities include the use of electrically activated devices. One aspect of electricity that has been reported is that there is an element of fear associated with electricity. Solomon, Black, and Stuart (1987) in their study of 11-12 and 13-14 year old students document that "as year changes from 1 to 3, the proportion of fearers decreases" (p. 20). They documented that almost one third of the younger group was initially identified as being afraid of electricity. They stated

> Such evidence, obtained from group interviews, cannot give rise to significant statistical data but it does suggest a possible causal interpretation. Most parents, we imagine, try to protect their children by repeated warnings not to touch electrical fittings in general and plugs in particular. (p. 15)

We fear what we do not understand. An understanding of electricity may reduce student fears. Electricity is a topic of study from the elementary grades through the university level, not only in the United States but in other countries as well.

Ronald Good (1991) stated, "alternative conceptions, preconceptions, naive theories, intuitive theories, alternative frameworks, children's ideas, and children's science are among the labels proposed to replace the more negative term, misconceptions" (p. 387). He went on to propose the use of the term "prescientific conception" (p. 387). The various terms identified by Good have been used to describe the pre-existing ideas that students bring to the learning situation. Although it may not be the least offensive term, the word misconception will be used in this paper because convention has established it as the most recognizable among the variety of terms that are available.

Mestre and Touger (1989), in discussing students' misconceptions, state that "these theories are ones that they--and everyone--arrive at as part of living in the world and making sense of what happens around us" (p. 448). Psillos, Koumaras, and Valassiades (1987) in their study of 50, 14-15 year old Greek students stated, "pupils do hold views about the electric current in simple circuits prior to or with little formal instruction. These views do not necessarily coincide with the scientists' conceptual system of the DC circuits" (p. 185). They also stated that "what is self evident for the scientists is not necessarily so for the pupils who can construct various meanings about the data" (p. 197). Mestre and Touger (1989) stated that "we should bear in mind that what physicists think of as a misconception may seem plain common sense to many people" (p. 450). One of the problems with trying to identify misconceptions is that a lack of knowledge may be confused with a misconception. As Ganiel and Eylon (1987) said, in commenting about why students are unable to explain what is happening in a circuit, "this situation does not necessarily represent misconceptions, but rather the lack of any clear concepts" (p. 178).

In the field of current electricity several studies have identified the misconceptions that students bring with them. The misconceptions include a belief that current is consumed in a circuit (Osborne, 1983, Shipstone, 1985, and Gauld, 1988) and a belief that a battery is a source of constant current (Dupin & Johsua, 1987). Research has also identified methods of teaching that address student misconceptions. These methods include having students confront their misconceptions (Mestre & Touger, 1989), demonstrations (Gauld, 1988), and using analogies (Dupin & Johsua, 1989).

Gardner (1987) in discussing his definition of intelligence, stated that "my definition is culturally relative" (p. 25). There may also be a cultural component in learning science. One aspect of this cultural component is language. Language allows students to communicate their understanding of a subject to the teacher. Research has also identified language as one of the possible reasons for what may be considered a misconception. Gott (1984) acknowledges that students do have "alternative frameworks" (p. 70), but he states "what is not clear is whether it is the ideas which are confused or the vocabulary needed to make them explicit" (p. 70). McDermott and Zee (1984) in their study of 23 undergraduates and nine pre-service or inservice teachers, found that tHe students did not have a clear understanding of the terms "current, energy, power, potential difference or voltage" (p. 41). Fredette and Lochhead (1980) in their study of undergraduates found some students used the term "complete circuit" (p. 194) incorrectly. The students were aware that a complete circuit was necessary for the bulb to light, but did not demonstrate an understanding of the "passing through" (p. 195) nature of elements of an electric circuit. They stated, "both our clinical interview and group-survey data indicate that many students enter college-level introductory physics courses without a clear understanding for the passing-through process" (p. 198).

Research on students' understanding of electricity is not limited to identification of misconceptions and treatments. Researchers have also tried to document why students perceive problems in a certain way. Fredette and Clement (1981) in their paper reported that five of fifteen 2nd semester physics students, did not recognize the role of a (short circuiting) wire in an electrical circuit. They identify four possible reasons for this. The first is what they call "pattern matching" (p. 284). They state that "students are primarily exposed to idealized, simplified cases such as the basic series circuit and parallel circuit" (p. 284). They go on to say that "unfortunately, many students will succeed on test questions used in the course only if they closely match this idealized framework developed in class" (p. 284). The second factor they identify is "the students' tendency to shift irrevocably away from the concrete materials once the translation to a diagram has been made" (p. 285). For the third factor, identified as assimilation, they state

> According to this explanation, the fact that the student's scheme for a standard circuit has been activated by the context of the problem (electrical circuits) means that he attends selectively to certain features (in this case wires and elements) of the problem, and ignores others. (p. 285)

The fourth factor they identify is that "the theoretical principles learned in physics do not in and of themselves carry the information on when and how to apply them" (p. 285).

Heller (1987) in her study of 16 inservice teachers reported that

> Knowing that teachers have a common set of core propositions is not sufficient to predict performance on a given problem or set of problems. The variability in their predictions arose from (1) the different core propositions teachers had about the direction of current flow, the effect of wires on current, and what happens to current at a junction, and (2) the adjustments they made to their core propositions to account for previously learned facts that contradict the predictions of the sequential model. Moreover, the teachers did not consistently apply their core propositions across similar problems. The perceptual cues in the problem task tended to sway their judgement about which propositions to apply. In addition, they do not appear to know the applicability conditions for their propositions. (p. 234)

The two preceding studies agree that knowing a particular concept does not necessarily mean that the individual will know when to apply that concept.

Andre and Ding (1991), in their study of 80 undergraduates, in which they used interviews to assess student knowledge, stated, "the results indicated that students performance was influenced by their knowledge of relevant declarative facts and the stimulus conditions of the experiment as well as by their models (or misconceptions) of the electrical situations" (p. 303). They stated that "even students who possess a correct model have to know specific facts in order to be able to map the concepts in their model to the features in the real world problem situation." (p. 305)

Cognitive theory

Piaget's theory has had a major impact on science education. Piaget (1970) in discussing his stages of cognitive development stated, "if we restrict ourselves to major structures, it is strikingly obvious that cognitive stages have a sequential property" (p. 711). Monk (1990) used "survey data reported by Shayer & Adey to predict the proportion of pupils in any given age cohort that will be able to successfully tackle questions on simple DC circuits" (p. 133). Monk identified a statistical relationship between the "Piagetian stage theory of genetic epistemology" (p. 133) and "children's ideas about series DC circuits" (p. 133). Monk stated that

> The data analysed from a genetic epistemological point of view lend support to the claims that:
>
> (i) there is a genetic epistemological stage related ceiling to the cognitive processing on the part of pupils;

> (ii) pupils can benefit from tuition such that their performance on test items can be increased to the limit set by their then current stage of genetic epistemological development. (p. 142)

He documents a relationship between a formal stage and the scientific view of current. However, Rhöneck and Grob (1987) in their qualitative study of eighth and ninth grade students, did not report a significant correlation between a "Piaget test on formal operations" (p. 573), and a retention test which "recapitulates the problems of the first class test with similar items two months after the first class test" (p. 574). Rhöneck and Grob document that being able to "structure knowledge in a formal way" (p. 576) does not necessarily indicate that the individual will "develop a correct representation" (p. 576).

Piaget (1970) in discussing assimilation stated, "indeed, no behavior, even if it is new to the individual, constitutes an absolute beginning. It is always grafted onto previous schemes and therefore amounts to assimilating new elements to already constructed structures" (p. 707). Novak (1987) in discussing constructivism stated "depending on the user's orientation, the word has some kind of reference to the idea that both individuals and groups of individuals construct ideas about how the world works" (p. 349). Buchweitz and Moreira (1987) stated,

> In the light of Ausubel's theory the most important single factor affecting students' learning is their existing knowledge prior to instruction. In this view, learning (conceptual change in learner's cognitive structure) involves the interaction of new knowledge with existing knowledge (conceptions and alternative conceptions). (p. 54)

Much of the research seems to be based on a constructivist approach to learning. This paper is written from that perspective, that is, the author believes that new knowledge is built on prior knowledge. A simile that shows how the author understands concept attainment would be that knowledge is like branches of a tree, where each concept is built on the preceding concepts, for example:

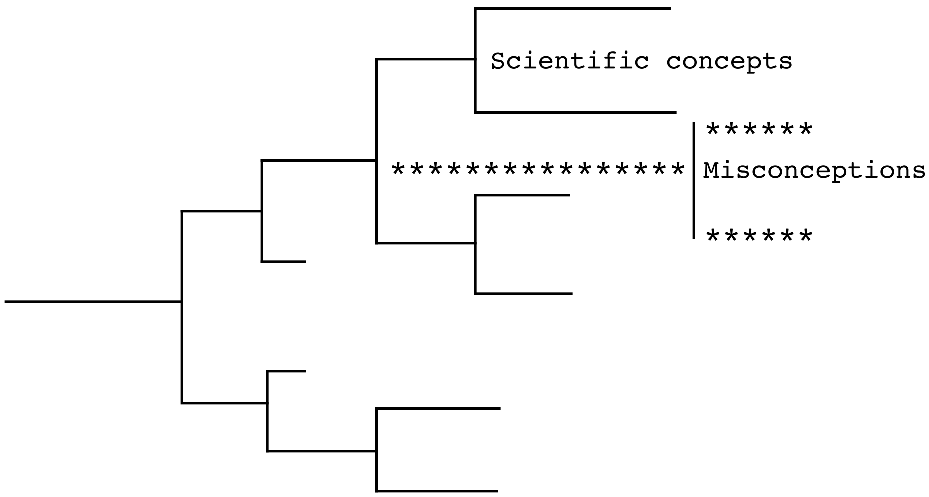

Figure 1.

The research identifies two primary misconceptions, (a) current is consumed in a circuit, and (b) a battery supplies the same current in every circuit. The first misconception has been identified in students from eight years old (Osborne 1983) to inservice teachers (McDermott & Zee 1984). The second misconception has been identified in students from sixth grade (Dupin & Johsua 1987) to inservice teachers (McDermott & Zee 1984).

Statement of the Problem

The subject of electricity, unlike a topic like simple machines, deals with an invisible something, whose effects can be seen, while the agent which causes the action remains hidden. A fifth grade teacher, teaching a unit on first class levers, may say that a 20 pound force here, will lift a 100 pound weight there. If there are students in the class who do not believe the statement, then the teacher can take the class to the playground and demonstrate that the teacher is telling the truth. An acceptance of the scientific view about electricity requires an element of faith, in the teacher, on the part of the learner. With a topic like electricity, where not only is the active agent invisible, but the devices used to "show" this agent are boxes which have been described to the students by the teacher, the teacher, must be perceived as truthful. If students have doubts about the teacher's honesty, the students may not accept the explanations that are given to them. In addition to being perceived as honest, the teacher must also know the subject matter. The course of study for most elementary teachers does not include extensive study in science. Andersson, Karrqvist, Renstrom, and Petersson (1982) stated that "at the very age (7-12 years) when they start getting interested in science, e.g. electricity, pupils are taught by teachers coming pre-dominantly from lines of upper secondary school where little is known about electricity" (p. 7). Shymansky et al. (1990) stated that "most teachers admit to a lack of understanding of the science concepts which they are expected to teach"

(p. 3). Lawrenz (1986) in his study of 333 elementary school teachers stated that "the results of this study help to support the belief that elementary school teachers may not have adequate backgrounds in physical science" (p. 659). If elementary teachers do not know the content, it is unrealistic to expect them to be able to teach it. The lack of content knowledge is not limited to elementary teachers, it has also been reported in middle grades teachers (Meisner & Lee, 1988).

Research Questions

This paper examines research literature that has documented misconceptions about electricity or electrical circuits. The purpose of this paper is to address the following questions:

(1). What are the misconceptions about electricity and electrical circuits that students bring with them to the educational setting?

(2). What methods have been identified for correcting the misconceptions?

(3). What are the implications for teaching and teacher education programs?

(4). What are the implications for further research?

Definitions

Ammeter demonstration:

In a simple DC circuit composed of a battery, a bulb and two wires, an ammeter is placed on each side of the bulb. The ammeter readings are equal.

Capacitor: "A device giving capacitance and usu. consisting of conducting plates or foils separated by thin layers of dielectric (as air or mica) with the plates on opposite sides of the dielectric layers oppositely charged by a source of voltage and the electrical energy of the charged system stored in the polarized dielectric" (Webster's Ninth New Collegiate Dictionary, 1988, p. 203)

Concept: "Regularities in objects or events designated by some label, usually a term. Whether a process (e.g., precipitation), a procedure (e.g., titration), or a product (e.g., carbohydrate), concepts are what we think with in science. Concepts can be connected with linking words to form propositions (e.g., turtles are classified as reptiles, sucrose tastes sweet, ontogeny recapitulates phylogeny)." (Wandersee, 1990, p. 927)

Concept Map: "A schematic device for representing a set of concept meanings embedded in a framework of propositions." (Novak & Gowin, 1984, p. 15)

Knowledge: "Declarative knowledge comprises the facts that we know; procedural knowledge comprises the skills we know how to perform" (Anderson, 1980, p. 222)

Misconception: "Misconception is the term commonly used to describe an unaccepted (and not necessarily `wrong') interpretation of a concept illustrated in the statement in which the concept is embedded.

The expressed meaning is not, however, a misconception to the person who holds it, but a functional meaning." (Novak & Gowin, 1984, p. 20)

Misconception: "Misconceptions refer to ideas that students have incorporated into their cognitive structures that they use to understand and make predictions about the world. Such knowledge is based upon the students' experience, but often incorrectly represents the natural world." (Andre and Ding, 1991, p. 303)

Models of current flow:

a) Unipolar. There is current from one terminal of the battery only and all of this is used up. Some children think that one wire from that battery terminal to the lamp (for example) will be sufficient while others see a connection to the other terminal as necessary but passive, with no current travelling through it.

b) Clashing currents (Osborne, 1981). Current leaves the battery through both terminals and is used up.

c) Attenuation. Current round the circuit in one direction only, with more leaving one terminal of the battery than returns to the other. In a circuit with a series combination of identical lamps this model leads to the conclusion that those which receive the current last will get least.

d) Sharing. Similar to the attenuation model but in this case the current is regarded as being shared out equally amongst a series of identical lamps.

e) Scientific. Current travels in one direction in the circuit and is conserved. (Shipstone, 1984, p. 73)

REVIEW OF LITERATURE

Misconceptions

Shipstone et al. (1988) in their study of data from five European countries, in which they examined how students understood electricity, stated "it must be emphasized that the overall impression conveyed by the results of this study is of a pattern of difficulties experienced by students which is substantially the same across countries" (pp. 313, 315). They went on to state, "this suggests that there is an almost `natural' coherence to the learning difficulties within cognitive structure. . . . The consumption of current, the constant current from a battery . . . and sequential reasoning are all consistent with this picture" (p. 315).

Shipstone (1984) documented that the percentage of students who held a particular misconception changed with age. Dupin and Johsua (1987) in their study of 920 subjects who ranged in age from 6th grade to university, reported that French students' concepts about electricity changed between grade six and the university. Dupin and Johsua point out that some misconceptions are relatively easy to change, but that others are resistant to change. Dupin and Johsua, "propose the hypothesis that certain misconceptions could be produced by the very way in which pupils overcome in part the first difficulties they meet" (p. 791).

Heller and Finley (1989), in their study of five middle school science teachers and eleven elementary teachers, found that "most of the elementary and middle school teachers in this study shared a common set of propositions that made up a coherent, but incorrect and contradictory sequential model of current flow" (p. 14). Rhöneck and Grob (1987), in their study of eighth and ninth grade students, stated that "when the direction of current is introduced sequential reasoning is inevitable" (p. 571). Danusso and Dupre (1987), in their study of high school and university students, reported that 28% of 230 university biology students used sequential reasoning.

<u>Current is consumed</u>

The misconception that current is consumed in a circuit has been reported by several researchers. Gauld (1988), in his study of 14 year old boys, found that one of the reasons students accepted a current is consumed model and rejected a scientific model was that batteries wear out. He also found that students used fairly sophisticated cognitive processes including "reconstructing memories of the empirical evidence" (p. 273) to justify their belief in a particular model. Dupin and Johsua (1987), in their study of 920 subjects who ranged in age from 6th grade to university, found that many students thought that current was consumed, about 60% of sixth graders held this view. Andersson, Karrqvist, Renstrom, and Petersson (1982) reported that about 80 percent of the 550 7th - 9th grade students in their study used a "source-consumer model" (p. 8).

The misconception that current is consumed may be broken down into more specific misconceptions. Osborne (1983) identified four models of current flow in simple circuits that children between the ages of 8 to 12, and 12 to 15 hold, the (a) "no current in return path" (p. 74) model, the (b) "clashing currents" (p. 74) model, the (c) "less current in the return path" (p. 74) model, and the (d) "scientific model" (p. 74).

Shipstone (1984) identified five models that children ages 12 to 17 use to explain current flow in simple circuits the (a) "scientific" (p. 75) model, the (b) "clashing currents" (p. 75) model, the (c) "unipolar" (p. 75) model, the (d) "attenuation" (p. 73) model, and (e) the "sharing" (p. 73) model. The attenuation and the sharing model are more specific examples of Osborne's (1983) "less current in the return path" (p. 74) model.

Gauld in his 1988 study identified four basic models of current flow, two of them are consumption models, "(model A), all of the electricity is used up in the lamp. If any electricity is left over (model C) it flows along the second wire and into the other end of the battery" (p. 268). The two other models he reported were model B, in which "the electricity flows out of both ends of the battery and `reacts' in the bulb to produce the glow" (p. 268), and model D, "all the electricity flowing out of one end of the battery, `squeezing' through the filament of the lamp and then continuing back to the battery" (p. 268).

Osborne (1983) in his study with 8-12 year old students identified the "no current in return path" (p. 74) misconception in the one 8 year old student and 11 of the 17, 9 year old students. Shipstone (1984) identified this misconception as "unipolar" (p. 75). Monk (1990) identified students who held this view as being at a "pre-operational" (p. 137) stage. Students who hold this view proceed, or are led, to another view in which the bulb lights.

After students manage to get the bulb to light, they attempt to make sense of what is happening. Without specific instruction that this system has current flowing in one direction, and with the knowledge that a connection is required to both terminals of the battery, then the next step is that something comes from both ends of the battery, which Osborne identified as a "clashing currents" (p. 74), view. Monk (1990) identified students who held this view as being at an "early concrete" (p. 139) stage. Osborne (1983) reported that 35 of the 40, 8-12 year old students in his sample when asked to describe how current would flow in a circuit described a "clashing currents" (p. 74) model. Shipstone (1984) reported that at age 12 approximately 35 percent of the sample held this view, by age 14 the percentage had declined to about 10 percent, and then there was a fairly steady drop to 0 percent at age 17 (Figure 2, p. 75). Gauld (1988) documented that prior to an ammeter demonstration, 18 of the 29 students in his study, held this model. The next model is one in which current flows in one direction through the circuit.

Current flowing in one direction is a step toward adopting a scientific view of current flow. Osborne (1983) reported that, 5 of the 40 students in his sample, when asked to describe how current would flow in a circuit, described a "less current in return path" (p. 74) model. After students adopt a "unidirectional" (Shipstone 1984, p.75) view, they may interpret it in their own fashion. This interpretation may be either an "attenuation" (Shipstone, 1984 p. 73) model, which Monk (1990) identifies as occurring at a "late concrete" (p. 139) stage, or a "sharing" (Shipstone, 1984, p. 73) model, which Monk (1990) identifies as occurring at a "late concrete early formal transition" (p. 139) stage. Shipstone (1984) identified a "unidirectional without conservation" (p. 75) model in almost 50 percent of the 12 year old sample, the percentage rose to almost 60 percent at age 14 then declined to about 40 percent at age 17

(Figure 2, p. 75). Within this area Shipstone documented that a belief in a "sharing" (p. 75) model was held by about 15 percent of the student sample who were 12 years old, this percentage declined, then rose to about 30 percent at age 15, then declined to about 15 percent at age 17 (Figure 2, p. 75).

The "attenuation" (Shipstone, 1984 p. 73) model is not only held by young students. McDermott and Zee (1984) in their study of 23 undergraduates and nine pre-service or inservice teachers found that of the undergraduates "about one-third of the students predicted that the `first' bulb of the series circuit would be brighter than the `second'" (p. 40). Heller and Finley (1989) in their study of five middle school science teachers and eleven elementary teachers found that 10 of the 14 teachers thought that the bulb consumed current.

The battery is a constant current generator

Dupin and Johsua (1987) in their study, found that almost 50% of the subjects from sixth grade to tenth grade thought of the "battery as a constant current generator" (p. 798). They suggest that one reason for this belief is the emphasis put on teaching the conservation of current. McDermott and Zee (1984) in their study found that "about half of the introductory physics students interviewed based one or more predictions on the belief that the battery supplies the same amount of current in all circuits" (p. 41). Heller and Finley (1989) in their study, found that 13 of the 14 teachers thought that the battery supplied the same current to every circuit. Licht (1987) in his study of secondary students, and Steinberg (1988) at the high school and college level, have also identified the concept of the battery as a supplier of constant current as one of the misconceptions held by the students in their studies.

Treatments

The goal of having students adopt a scientific view about current flow in electrical circuits requires not only identification of student misconceptions, but also identification of effective treatments. The first requirement is to design an instructional package that addresses student misconceptions. Heller and Finley (1989) in their study of inservice teachers, used the teachers' existing conceptions of electricity to plan "a physical science course for inservice elementary school teachers" (p. 3). Arnold and Millar (1987) in their study of 11 and 12 year old students, reported on their "experiences in developing and implementing an introductory course on electrical circuits based on a constructivist model of curriculum development" (p. 554). In discussing a student prediction Arnold and Millar stated

> Though based on a misconception, this last prediction accords with observation! The fact that unorthodox yet plausible explanatory frameworks *can* lead to successful prediction should perhaps serve as a warning against a too ready acceptance of the notion that our experiments `clearly

> demonstrate' the validity (or truth) of the scientific model, and indicate some of the pitfalls which may face an approach which aims to use conceptual conflict to promote concept change. (p. 557)

McDermott and Zee (1984) developed instructional materials consisting of "a battery, a bulb, and a piece of nichrome wire" (p. 46). They say "the length of nichrome wire in the circuit can be varied with a sliding contact. For visual emphasis, bulb brightness rather than an ammeter is used as an indicator of current" (p. 46). Steinberg (1988) proposed the use of capacitors in a simple DC circuit to aid students' understanding of electricity.

Psillos, Koumaras, and Tiberghien (1988) in their study of 15 year old students, in which the order of instruction was voltage, current and then resistance, suggest that voltage be used as a primary concept in a unit about electricity. Cohen in his 1984 study of 11th and 12th grade students "tried to change the attitude of the students from `current minded' to `voltage minded'" (p. 110). He stated "the first step was to get them to understand the relationship between potential difference and current by using an hydrostatic model" (p. 110).

Duit (1984) reported that "the geometric structure <u>of the equipment</u> used in a practical test appeared to be of greater influence on students' actions than the representation of the electric circuit gained during instruction" (p. 92). Shipstone (1984) in discussing the standard flashlight bulb, which he calls an "MES lamp" (p. 76), stated

> The construction of these lamps, which are now widely used in the teaching of electricity, presents a considerable problem, particularly since pupils see the threaded part of the lamp base as serving to hold the lamp in its socket and not as a contact. (p. 76)

Osborne in his 1983 study of 8-12 year old students reported that the students in this study were more successful in getting the bulb to light when they were given a bulb that already had two wires connected to it.

Licht (1987) reported some success in teaching secondary school students using a model of "the concept of electron concentration" (p. 278) in reducing the number of students who thought current was consumed and that a battery was a constant current generator.

<u>Students confront their beliefs</u>

Mestre and Touger (1989) recommend physics teachers "help students articulate how they think about a problem being studied and, in doing so, be alert to misconceptions that students may bring to the surface (and tenaciously defend)" (p. 450). They go on to state, "a technique some have found effective involves helping students to confront an inconsistency or contradiction between their assumptions and actual physical behavior" (p. 450).

Kärrqvist (1987) in her study of 14-16 year old students stated:

> The study shows that it is possible [to] stimulate learning by challenging the original conceptions that the pupils hold and training their operative readiness so that they themselves can verbalize questions, formulate hypotheses, test these and go on developing their own knowledge. (pp. 294-295)

Lawrenz (1986) stated "They [teachers] must be given the opportunity to make predictions based on their personal belief patterns and then be presented with concrete experiences which conflict with these misconceptions so that they will be forced to reassess their beliefs" (pp. 659-660).

<u>Demonstrations</u>

Psillos, Koumaras, and Valassiades (1987) found that students "did not conceive the ammeter as a measuring instrument which just lets the current through ... the pupils were able to provide `right' predictions and give meanings to the equal readings which did not coincide with the scientific ones" (p. 193). They recommend further research on "pupils' conceptualisation of the use of the ammeter" (p. 193).

Gauld (1988) examined how 14 year old students remembered events three months after they happened. He documented an ammeter demonstration lesson. Immediately after this demonstration 25 of the 29 students adopted model D, three months later only one of the 14 students interviewed used this model. He noted that the arguments used to support a particular belief were "internally consistent to a significant degree" (p. 271), and that the students' "memories of the empirical data presented during the lessons often differed from pupil to pupil" (p. 271). He suggests a "representation" (p. 273) of the data at a later time to help students adopt a scientific model. Gauld stated, "the early change, immediately after the critical lesson, to the `squeezing' model (D) was not consolidated"(p. 272). Piaget (1970) in discussing learning stated

> Learning under external reinforcement (e.g. permitting the subject to observe the results of the deduction he should have made or informing him verbally) produces either very little change in logical thinking or a striking momentary change with no real comprehension. (p. 714)

Gauld used a small sample in his study, but his results suggest that a post-test immediately after instruction may not give results that indicate a permanent conceptual change.

<u>Analogies</u>

Dupin and Johsua (1989) document several studies that use analogies to teach about electricity. They propose guidelines for a "modeling analogy" (p. 210). Analogies may be useful in teaching about electricity, but like many tools, they should be used carefully. Osborne (1983) provides an example of how analogies can be used to support misconceptions. Dupin and Johsua in their 1989 study on the use of analogies with students in the sixth, eighth, and tenth grades, found that among the sixth and eighth grade students "after animated discussion, this conception of `current consumption' becomes unanimous" (p. 214). After they were given the ammeter demonstration, the sixth grade students rejected the experimental result, and the eighth grade students accepted the result but did not understand it. The sixth and eighth grade students were then presented with a "train analogy" (p. 212). The analogy is that a "continuous train moves around a circuit. There is no engine, only cars linked to each other. In a station, men push the cars with a constant force. Obstacles can exist in the circuit which act on the train speed" (p. 212). Dupin and Johsua acknowledge that there could possibly be some difficulties with this analogy. In the tenth grade, they used an analogy that compared an electric circuit to a refrigerator in a closed room. Dupin and Johsua recognized the limitations of their procedure, but they stated, "comparative analysis of pupil performances after teaching would seem to show a positive effect of using our analogies" (p. 222).

Concept Maps

Concept maps are another tool that has been used in teaching electricity. The December 20, 1990 issue of the Journal of Research in Science Teaching was devoted to concept maps. Rhöneck and Völker in their 1984 study used semantic structures to describe students' views. They used concept mapping to support "an analysis of the students' view of the electric circuit. The purpose of this analysis is to separate the students' energy view from a correct view of the circuit" (p. 99). Shymansky et al. (1990) also used concept maps. They stated, "To study changes in teacher understanding of concepts in electricity and simple circuitry, we required that the teachers generate concept maps on the topic at multiple points throughout the inservice" (p. 5).

Identify student misconceptions

Shymansky et al. (1990) in their study of 15 inservice teachers reported on "an experimental inservice education model designed to enhance teacher science background by having teachers study student ideas related to a particular topic" (p. 2). They stated that

> These early data suggest that an action research approach focusing on analyses of student ideas related to a target topic can effectively enhance teacher understanding of science concepts and broaden teacher skills for assessing student understanding and facilitating conceptual change. (p. 14)

CONCLUSION

Research has identified the misconceptions of students, and methods of correcting the misconceptions. Much of the research has concentrated on misconceptions about current. Osborne's (1983) statement that "electric current is the important and basic idea and a less abstract concept than electrical energy" (p. 80) is perhaps one of the reasons that electricity is introduced to students with a study of current. An ammeter demonstration that proves current is conserved in a circuit, may not convince students. In the words of one of the students in Dupin and Johsua's 1989 study "I don't understand. It's not logical" (p. 214). The student was talking about the conflict between current conservation in a circuit and the fact that the battery wears out. The author suggests that one of the reasons for student resistance to, acceptance of the conservation of current view, is that we are asking them to deny a basic truth they have learned, that being "you cannot get something for nothing." We show them a circuit wherein we have a bulb that is transforming something into light and heat, then we introduce the concept of current as one measure of what is moving in the circuit. We demonstrate with ammeters that current is conserved, and expect the students to agree with the scientific model. Students know that something is being transformed. Psillos, Koumaras, and Tiberghien (1988) stated that "in our treatment, the voltage concept is introduced as a primary one" (p. 41). The author proposes that this area deserves further study. The use of a voltmeter should be subject to the same constraints as the use of an ammeter, but it may be useful in teaching students about electricity. A voltmeter connected between either side of the bulb and the battery will show a voltage drop across the bulb. This voltage drop allows students to reconcile their belief that "you cannot get something for nothing" with the transformation of something into light and heat. The author proposes that after this demonstration the introduction of the concept of conservation of current would be more easily accepted.

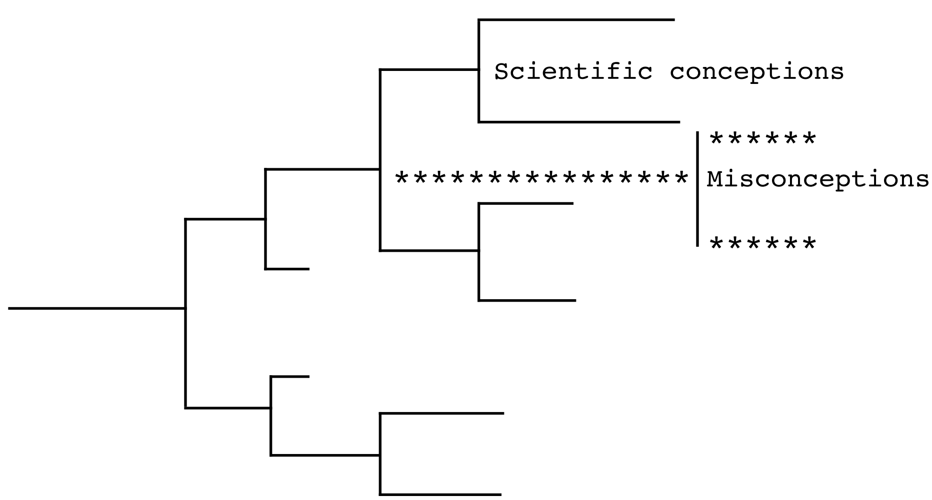

Figure 2.

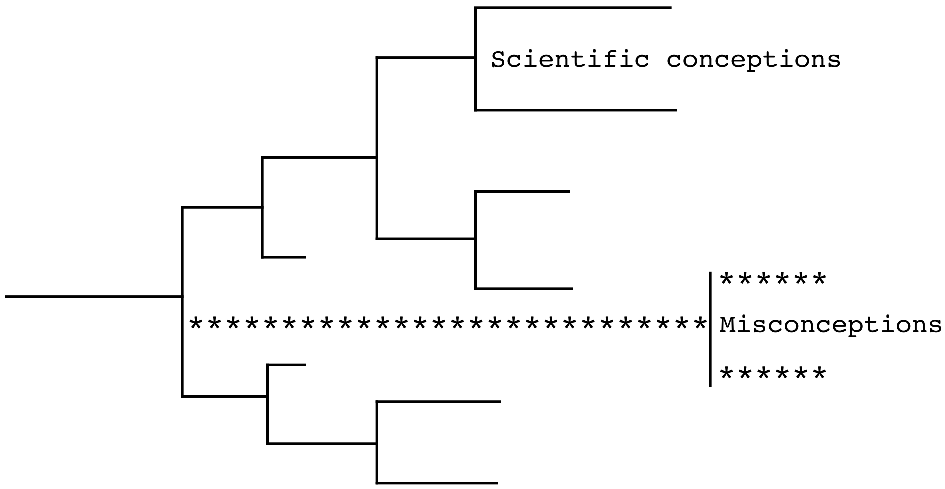

Figure 3.

Andre and Ding (1991) stated that "while model related to performance, the regression analysis we carried out made it clear that the model the student possessed was related to the previous experiences and sex of the subject" (p. 312). The statements of Andre and Ding (1991) in relationship to the information presented by Monk (1990) and Rhöneck and Grob (1987) raise a question. Given the statistical relationship documented by Monk, the qualitative data presented by Rhöneck and Grob (1987), and the preceding statement by Andre and Ding, is there a relationship between the level of cognitive development, the experience and sex of the subject, and the model of current flow that an individual adopts? Rhöneck and Grob (1987) propose a relationship between the development of a correct representation and the ability "to accept spontaneously the new concepts and rules" (p. 576). They analyzed ten factors in an attempt to document "predictors of successful learning" (p. 574). They did not relate the sex or experience of the subjects to the acquisition of scientific concepts.

Implications for teaching

Andersson et al. (1982) in their investigation of 536 upper secondary students, noted a difference by gender in the number of correct answers given as well as a difference depending on the particular course of study, that is between the "science and technology lines" (p. 10) and the "non-science lines" (p. 10). They recommend that "firstly, a constructivist view of learning must be put in place of the prevailing passive, receptive one. Secondly, teaching processes must be created at detail level which will lead to permanent conceptual changes" (p. 14).

Teaching a unit on electricity is not an easy task. The research has indicated that there may be approaches which are effective in reducing student misconceptions. Teachers should recognize that students come to the learning situation with ideas about how electricity works. Having students claim their ideas leads to self-recognition of their beliefs, which is the initial step in changing student beliefs. A method which allows students to compare their beliefs with scientific beliefs may be effective in correcting misconceptions. As Monk (1990) recommends, a recognition of the students' "current stage of genetic epistemological development" (p. 142) should be considered when planning instruction. A recognition of the role that language plays in concept development and acquisition should also be kept in mind. At the elementary level (K-5), the use of ammeters should be approached cautiously, and the use of light bulbs which have two terminals might be effective. The middle school level (6-8), should also use an ammeter demonstration cautiously. High school (9-12) and university level students might benefit from the use of Steinbergs' (1987) proposal concerning the use of capacitors in a circuit. University level students might also benefit from the use of nichrome wire in a simple circuit as reported by McDermott and Zee (1984).

Implications for teacher education

Research has documented the misconceptions of elementary and middle school teachers. Meisner and Lee (1988) collected data from 30 highly selected middle school science teachers, and surveys from nearly 300 randomly selected middle school principals, and 558 randomly selected middle school science teachers. They made several recommendations, but the recommendation that applies to this paper is that "Departments of Public Instruction at the state level need to require one year of `conceptual' physics for middle school science teachers" (p. 9). Lawrenz (1986) recommended inservice physical science education for elementary teachers, he gave specific guidelines for the inservice education, including "colleges must tailor the training to fit the needs of the teachers" (p. 659). The author interprets the last statement to mean that an introductory college physics course may not be the best preparation for teaching elementary or middle school science. Inservice teachers would probably benefit from the proposal of Shymansky et al. (1990), that is, an identification of student misconceptions. Teacher education programs that are considering adding another science course for preservice teachers, or offering a science course for inservice teachers might consider following Heller and Finley (1989) who stated that "our judgment is that the knowledge we gained from analyzing the sources of variability in performance on a problem solving pretest was invaluable in developing the instruction" (p.16).

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Is there a connection between cognitive level and a particular misconception? Monk (1990) documented a statistical relationship, but does qualitative research support his position?

2. Is there a progression from one misconception to another? Monk (1990) presents evidence that supports this statement, and, if as he claims, misconceptions are tied to particular levels of cognitive development, then qualitative research should support his position.

3. Are misconceptions language-based? Is it the lack of precision in the everyday usage of terms concerning electricity that leads students to adopt an unscientific view of current flow?

4. What is the effect of using voltage as the primary concept in teaching about electricity, then introducing current?

5. What is the difference, if any, between how technicians and physics students are taught about electricity?

6. Is there a relationship between the level of cognitive development, the experience and sex of the subject, and the model of current flow that an individual adopts?

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