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ABSTRACT

Some science educators who are interested in conceptual development have considered the phenomenon of student misconceptions and alternative frameworks. Researchers have used a variety of terms to describe the situation in which students' ideas differ from those of a scientist about a particular concept. This digest was produced to briefly describe what this area of research encompasses, including a delineation of the terminology being used, ranging from misconceptions, to preconceptions, naive theories, alternative conceptions, and alternative frameworks. The document highlights some of the findings from a few relevant studies involving secondary school students. In addition, it attempts to communicate some of the implications of misconceptions research for teaching secondary school science. (TW)

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SECONDARY SCHOOL STUDENTS' COMPREHENSION OF SCIENCE CONCEPTS: SOME FINDINGS FROM MISCONCEPTIONS RESEARCH

Introduction

One day in a discussion of weather in a seventh grade science class a student told me that wind was caused by trees waving their branches. This explanation had served her well through twelve years of her life and it was only through a discussion of weather fronts and differences in air pressure that she was confronted with an alternative explanation. How many more misconceptions or alternative frameworks of science concepts do secondary students possess even after they have studied science in school?

Science educators interested in conceptual development have considered this phenomenon and have used a variety of terms to describe the situation in which students' ideas differ from those of scientists about a concept. Some researchers talk of students' misconceptions; others write of preconceptions; still others, of naive conceptions or naive theories; some, of alternative conceptions; and some, of alternative frameworks.

This digest has been produced to describe briefly what this area of research encompasses, to highlight a few relevant studies involving secondary school students, and to communicate some of the implications of misconceptions research for teaching secondary school science.

Implications of Terminology

Driver and Easley (1978:62) consider that semantics indicate the user's philosophical position. They point out that Ausubel talks of "preconceptions" which are ideas expressed that do not have the status of generalized understandings characteristic of conceptual knowledge. Those who use the term "misconception" indicate an obvious connotation of a wrong idea or an incorrectly assimilated formal model or theory. Those who use "alternative frameworks" indicate that pupils have developed autonomous frameworks for conceptualizing their experience of the physical world.

In an article about children's understanding of dynamics, Roger Osborne used the term "mini-theories" (1984:505-506). According to Osborne, mini-theories are developed through learning about the world, from the day an individual is born. Mini-theories apply to specific situations and help individuals make predictions and decide on certain actions, as well as enabling people to describe and explain phenomena. These mini-theories have a finite range of applicability and are context dependent.

Driver and Easley also think that the term chosen to describe students' ideas that are not congruent with the accepted scientific definitions is related to the user's view of science. They contrast the empiricist view of science with that of Popper, saying that one who holds an empiricist view of science considers that scientific ideas and theories are reached by the process of induction. Therefore, pupils are expected to observe facts objectively, make generalizations, and then form hypotheses or theories. It follows that if students hold alternative interpretations, these result from incorrect observations or faulty logic and are "wrong" ideas. If one holds Popper's view of science, hypotheses or theories are products of human imagination and are not related in any deductive or logical way to so-called objective data. With this point of view, alternative interpretations are products of the pupil's efforts to explain events in keeping with experience and are partial explanations of limited scope (1978:62).

Findings Related to Secondary School Science

In their review of studies of concept development in physical sciences during the adolescent years (with an emphasis on British European research), Driver and Easley classify these studies being nomothetic or ideographic in character (1978:64). Nomothetic studies are those in which the researcher(s) assessed pupils' understanding in terms of congruence of students' responses with "accepted" scientific ideas. Ideographic studies are reports of research about children's interpretation of events and the way these interpretations change with age. In the ideographic studies, students' conceptualizations are explored and analyzed on their own terms without assessment against an externally defined system.

The reports of findings presented here are drawn from both kinds of research. Most come from journal articles although there is a collection of research papers on misconceptions presented at an international conference at Cornell University in 1983 (Helm and Novak, 1983). Another such conference was held in the summer of 1987, also at Cornell, and will result in a collection of research papers.

Reports on misconceptions research are more plentiful in the physical sciences than in biology. However, reports on students' understanding of biological science concepts do exist (Adeniyi, 1985; Bell, 1985; Engel Clough and Wood-Robinson, 1985; Bell, 1981; Trowbridge & Mintzes, 1985). Bell's 1981 report dealt with students' understanding of the concept of "animal," a concept basic to biology. Most science teachers would assume that pupils would possess a scientifically acceptable version of the concept "animal," but Bell found when she interviewed 39 10-15 year old New Zealand students that only 4 (of the 39) classified organisms as animals or non-animals in the same way as biologists (1981:214). Bell concluded that there was a common as well as a scientific meaning for "animal" and that the common meaning was restricted to four-legged, terrestrial mammals.

Bell continued her research on the concept of animal by developing a six-item, multiple choice survey. Respondents were shown drawings of a spider, a grass plant, a cow, a worm, a person, and a whale and asked to indicate yes/no if the organism pictured was an animal and to support this choice by identifying four reasons, from a list of 26, for the answer to each picture. She used this survey with 49 11-year-old students, 34 first-year primary teacher trainees, and 67 university students. The correct categorization was given by 14% of the 11-year-olds, 59% of the teacher trainees, and 97% of the university students (1981:217).

Trowbridge and Mintzes also investigated students' understanding of the concept animal, using a structured clinical interview with 21 fifth grade students, 20 eighth grade students, and 21 non-science majors enrolled in an introductory college biology course. They asked "Can you name five animals?" and "What do you mean by the word 'animal'?" They found that misclassification persisted across grade levels and that the respondents failed to generalize and to discriminate among examples and nonexamples of a group. They concluded that students need to develop a concept prototype (mental model) and to develop skills of discrimination and generalization (1985:313).

Engel Clough and Wood-Robinson (1985:125) have speculated that more research on students' conceptions has been done with physical science topics than biological science topics because Piagetian frameworks have tended to involve physical science concepts. They also cite a remark by Shayer to the effect that biological science concepts are more difficult to analyze because they are non-hierarchial and less discrete (interwoven with related concepts).

Engel Clough and Wood-Robinson contend that we need to have more detailed descriptions of pupils' thinking prior to teaching a topic and as that teaching progresses. They investigated common belief patterns, if any, which students of different ages held about aspects of biological adaptation by interviewing 84 12-16 year old students in three comprehensive (British) schools. The researchers did not try to decide if the pupil's learning had come from school science or from out of school experiences. They concluded that students of secondary age found adaptation difficult, that the context of the question influenced student thinking, and that, when trends with age were considered, no progress toward better scientific understanding from ages 12-14 occurred, but that there was a clear improvement at 16 years. However, teleological interpretations pervailed and persisted for two-thirds of the 12-14 year old students and almost one-half of the 16 year olds (1985:128-129).

Misconceptions research dealing with physical science topics has been widely reported (Engel Clough and Driver, 1985; Osborne & Gilbert, 1980; Watts and Zylbertajn, 1981; Watts, 1982, 1983; Solomon, 1983; Summers, 1983; Hewson & Hewson, 1983). Space restrictions limit the amount of information that can be reported in an ERIC digest. However, Solomon's statement (1983:228) that pupils can hold two different systems of knowledge in their minds and choose which one to use in science lessons and which to use in daily conversation seems applicable to all reports cited. Difficulties are associated with the teaching of physical science concepts such as energy, heat, and force because the meaning of terms varies for teachers and students.

Osborne (1984:505-506) has illustrated this problem by his discussion of dynamics in which he talked about children's dynamics as being divided into gut dynamics and lay dynamics. Gut dynamics are based on direct experience and may be unarticulated and not necessarily conscious. Lay dynamics are based on form and content of language through accounts and images conveyed by media, books, and people. In comparison to these two types of children's dynamics, there is physicists' dynamics which are Newtonian dynamics with a linguistic and mathematical superstructure of their own and which are sometimes counter intuitive.

Implications for Teaching, Curriculum

These variations in conceptions seem to persist despite instruction. If these alternative ideas persist among secondary school students, why are they not more apparent? Engel Clough and Driver (1985) think alternative conceptions are not more apparent because students learn labels and phrases to use and teachers do not check for underlying understanding. Teachers do not normally ask students to use ideas in slightly different contexts. Instead, teachers use selective attention and tune in for responses they hope to hear (1985:181).

Watts (1983:213) described another aspect of the problem:

> One source of difficulty arises from the failure of teachers to acknowledge that students have well developed ideas around many of the words in science, long before formal teaching of the ideas takes place. Such ideas and meanings for words are not simply isolated misconceptions, but are a complex structure which provides a sensible and coherent explanation of the world from the youngster's point of view. . . .

Brumby (1984:501) had a comment about the effect of instruction on students:

> Perhaps one of the problems is the way science is presented in lectures . . . . seen as a body of absolute knowledge, most of which is recorded in books, or yet to be discovered by experts. They see their task as students as primarily to accept this and to learn all the 'facts' so they will increasingly 'know' all the answers. . .

This leads to skill at rote learning - learning "what," not "how" so that students are able to recite their knowledge but not use it. Brumby concluded that lectures were insufficient in themselves to create sufficient conflict in students' minds to alter their existing understanding of science concepts. It is necessary to spend time in problem solving, in the application of concepts to real-world situations in order to bring about conceptual change in students.

Textbooks, because they are a major source of science information, may also be a source of misconceptions. Cho et al. (1985) examined what they considered to be the three most widely used high school biology textbooks (BSCS green, BSCS yellow, *Modern Biology*). They identified four possible major sources of misconceptions and learning problems as being (1) conceptual organization, particularly sequencing of topics; (2) conceptual relationships; (3) use of terms, and (4) mathematical elements. They found inadequacies in all four areas in the three books examined (1985:717).

Trowbridge and Mintzes (1985:314-315) suggested a lesson plan that would encourage students to develop a mental model of a concept:

1) introduce and define the concept
2) provide several examples of the concept
3) list the critical attributes of the concept
4) develop a concept prototype (mental model) by
   - providing matched pairs of examples and non-examples of the concept
   - identifying the critical attributes the non-examples lack
   - presenting examples and non-examples and asking pupils to select examples of the concept and explain their choices
   - providing feedback at the conclusion of this part of the lesson
5) present additional illustrations of examples and non-examples with questions focused on the critical attributes of the concept.

If teachers are to base their instruction on what students already know and teach them accordingly, they must determine what knowledge students possess. Many researchers have emphasized the need for a classroom environment in which discussion is encouraged and where students feel free to share their ideas without fear of ridicule or a grade attached to the response. Minstrell (1983:53-54) has suggested that teachers may want to describe a situation and ask students what will happen as one way of determining what ideas students have on a topic. He also suggested that teachers ask students for explanations of their observations concerning an activity they have done. Teachers should encourage students to think rationally about any discrepancies between their ideas (preconceptions) and experiences (observations).

Teachers also need to be aware of grade placement problems: when to teach a concept. Driver and Easley (1978:64) feel there is a fundamental difficulty in establishing adequate criteria for specifying the conceptual understanding required. In order to do this, researchers and/or curriculum developers would have to specify the level of understanding and provide some indication of the range of possible contexts in which the concepts is to be used.

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