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ABSTRACT

Misconceptions, shown to be prevalent in students even at the college level, may affect the cognitive process of making predictions in biology. The purpose of this study was to: (1) identify students' misconceptions about important biological concepts; (2) identify students' cognitive behaviors associated with making predictions about these concepts; and (3) examine the relationship between students' misconceptions and their cognitive behaviors of prediction. Information processing theory provided the theoretical framework for this research. Think-aloud interviews were employed in this study to collect videotape data on students' cognitive processes associated with their misconceptions and subsequent predictions about selected biological concepts. A computer simulation program, "Pollute," allowed students to manipulate five independent variables affecting water quality. Three-stage instruction was given based on the learning cycle. This paper found that subjects who were successful were formal operational and exhibited fewer misconceptions than unsuccessful subjects. Misconceptions identified are listed. Recommendations are made for science teaching techniques that will help to identify and eliminate students' misconceptions. Forty-six references are listed. (Author/YP)

THE RELATIONSHIP BETWEEN THE PROCESS SKILL OF PREDICTION AND STUDENTS' MISCONCEPTIONS IN BIOLOGY

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Abstract

The science process skill of prediction is recognized as an essential component of scientific inquiry and a terminal objective for science education research. Misconceptions, shown to be prevalent in students even at the college level, must affect the cognitive process of making predictions in biology.

Extensive literature review revealed a paucity of science education studies dealing with the thinking mechanisms of prediction and the relationship between predictions and misconceptions. Thus, the purpose of this study was to:

1). Identify students' initial conceptions (misconceptions) about important biological concepts.

2). Identify students' cognitive behaviors associated with making predictions about these concepts.

3). Examine the relationship between students' initial conceptions (misconceptions) and their cognitive behaviors of prediction.

Information processing theory, which has proven quite useful for studying how people think, provided the theoretical framework for this research. A useful naturalistic research tool for collecting data on thinking processes is the clinical "think aloud" interview. Think-aloud interviews were employed in this study to collect videotape data on students' cognitive processes associated with their initial conceptions (misconceptions) and subsequent predictions about selected biological concepts. Data was analyzed using the techniques of verbal protocol analysis and comparative systematic analysis.

The results of this study strengthen the research base dealing with the cognitive processes of prediction and misconceptions in science. Recommendations are made for science teaching techniques that will help to identify and eliminate students' misconceptions.

Introduction

The teaching and learning of science process and problem-solving skills has become a major goal for science education research and curriculum development (Butts et al., 1978; Linn, 1978; Bennett, 1988). Science process skills, which include hypothesizing, inferring, analyzing, experimenting, and predicting, are critical skills for scientific problem solving (Gagne, 1965).

Importance of the Learning Cycle:

It is well documented that instruction based on the three-phase Karplus learning cycle (Karplus, 1977), involving phases of exploration, concept introduction, and concept application, improves conceptual understanding and process skill achievement compared to traditional instructional methods (Abraham and Renner, 1986). In making reference to the success of the learning cycle, Lawson, Abraham, and Renner (1989) commment: "It is not only a good way to teach science, it is *the* way to teach science." The learning cycle is, therefore, a logical instructional model with which to study how students acquire and utilize science process/problem-solving skills.

Importance of Prediction

Prediction is a very significant process skill that is fundamental to the value, progress, and teaching of science (Good and Lavoie, 1986). Adding prediction to the learning cycle with feedback loops among the four main components (see Figure 1) gives this cycle greater flexibility and instructional power (Good and Lavoie, 1986). Science teaching involving prediction skills should motivate students to: 1) further investigate the subject of interest, 2) organize and re-structure their conceptual framework, and 3) use other science process skills. More relevant to this study, student's predictions should provide the teacher (researcher) with a mechanism for learning what conceptions (i.e., misconceptions) students possess concerning concepts studied or about to be studied.

Misconceptions

The recently established field of cognitive science emphasizes that students learn concepts by organizing new patterns and relationships in long-term memory relative to the structure of patterns or relationships that already exist (Shuell, 1987). Learning, therefore, becomes the minds attempt to incorporate a meaningful conceptual framework in lieu of the already existing one. These previously existing frameworks are often referred to as misconceptions.

Misconceptions have been defined as knowledge spontaneously acquired from personal experiences with the world that is inconsistent with the established scientific theory (Driver, 1983; Posner, Strike, Hewson, and Gertzog, 1982; Lawson and Thompson, 1988). Misconceptions have been previously refered to as "child artificialism" (Piaget, 1951), "preconceptions" (Novak, 1977), "childern's scientific intuitions" (Sutton, 1980); "alternative conceptions" (Driver and Easley, 1978), "mini-theories" (Claxton, 1984), and "naive theories" (Resnick, 1983).

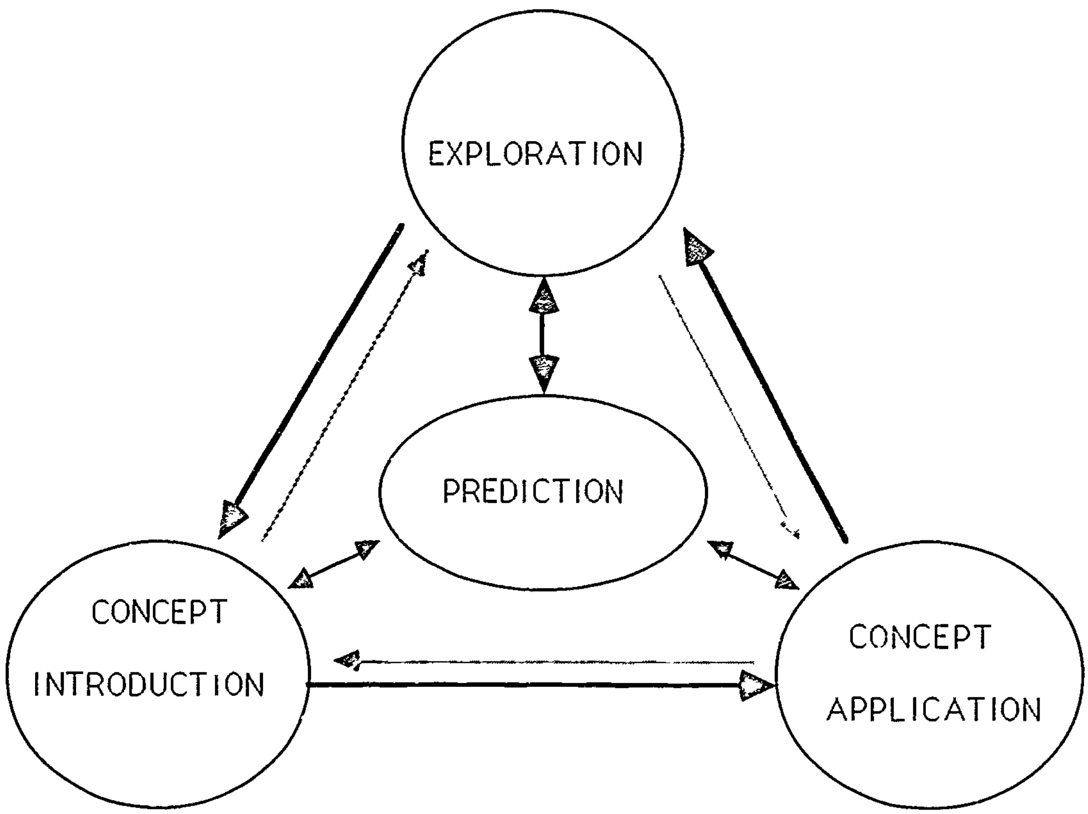

Figure 1. Flexible learning cycle with "prediction power"
(from Goc.i and Lavoie, 1986)

A number of research studies have shown misconceptions are prevalent in biology (Smith and Good, 1984; Brumby, 1984), physical science (Nussbaum, 1979; Sneider and Pulos, 1983), and chemistry (Shayer and Wylam, 1983; Camacho and Good, 1989). Research also implies these misconceptions are resistant to change, and that "truer" conceptions of reality are difficult to acquire via normal teaching methods (Champagne et al., 1982; Simpson and Arnold, 1982; Shuell, 1987; Renner, Marek, Abraham, and Grzybowski, 1987). Formal instruction actually appears to sustain students misconceptions, especially in biology (Barrass, 1984; Griffiths and Grant, 1985).

Further, there seems to be a misconception continuum from those misconceptions acquired as a result of recent instruction and those acquired over a long period of time. Recently acquired misconceptions are presumably easier to change (Griffiths et al., 1988).

Purpose

Thus, students previously acquired conceptions pose a very significant problem for science teaching since they are often: 1) inaccurate conceptions of reality, and 2) quite difficult to change. It seems likely that these misconceptions are major barriers to students learning science process and problem-solving skills which are important goals for science education.

Extensive review of the literature revealed little research has been done on the relationship between misconceptions and science process skills (Lavoie, 1986). It is clear that research must focus, first, on identifying, analyzing, and understanding how students' misconceptions affect science process skill performance. Then, science educators can develop effective ways to teach for conceptual change and for the development of problem-solving/process skills. Lawson, Abraham, and Renner (1989) recognize the identification of a such a taxonomy of misconceptions in science to be fertile area of research.

Objectives

This study addresses the above need by considering the relationship between students' misconceptions in biology and the process skill of prediction within the learning cycle. This involves the cognitive behaviors associated with predictions and misconceptions concerning a computer-simulated water pollution system. The specific objectives of the study are to:

1). identify student's cognitive behaviors associated with making predictions at different points in the learning cycle.

2). identify those specific cognitive behaviors that represent misconceptions.

3) examine the relationship between students' cognitive behaviors of prediction, Piagetian stage, and misconceptions.

Methodology

Theoretical Base

Information processing theory, which has proven quite useful for studying how people think (Stewart and Atkin, 1982), provided the theoretical framework for this cognitive science research study which describes the cognitive processes and pathways associated with prediction and related misconceptions.

Qualitative research methods have been recognized as very useful tools for science education research (Stake and Easley, 1978; Smith, 1982; Easley, 1982; Rist, 1982, Welch, 1983). A proven qualitative/naturalistic research method for collecting data on the thinking process is the "think aloud" interview (Larkin and Rainard, 1984). Think-aloud interviews were employed in this study to collect videotaped data of the cognitive processes associated with student's predictions. This was done while students made predictions following exploration and concept application phases of the learning cycle. The interviewer tried not to suggest any responses to the subject. When the subject failed to respond for greater than five seconds s/he was encouraged to think aloud. If a subject became disoriented or strayed from the problem s/he was prompted to return to and remain on task. Seven formal operational and seven concrete operational high school biology I and II students were selected for the learning cycle lesson interviews (Violino and DiGicacomo, 1981; DeLuca, 1977; Lawson, 1978).

Subject Matter

Predictions can by made about any dynamic system (physical or biological) involving interactions between the responding (dependent) and manipulated (independent) variables of the system. The dynamic system of this study involved a computer simulation program, "Pollute" (Educational Materials and Equipment Company). "Pollute" allows the user to rapidly manipulate five independent variables (temperature, waste type, dumping rate, type of treatment, and the type of body of water) that affect water quality. The pollution effect is displayed on a color plot graphically simulating the change of two dependent variables, oxygen and waste concentration, through time for 30 days. The simulated oxygen curve may continue straight across the graph or slope downward to eventually level off or reach zero. The simulated waste curve may continue straight across or slope upward to eventually level off.

The prediction problems consisted of parts A and B. In part A, a prediction problem involving different parameters of the five independent variables was posed to the student. In part B, the value of one or two independent variables were changed and the prediction problem was posed again. Successful, transitional, and unsuccessful predictors were identified depending on the degree of accuracy of their prediction relative to the actual computer simulated result as well as their use of logical reasoning (e.g., correct use or relationships).

Instructional Sequence

During stage one, each student was allowed to explore the interactions between the variables of the computer simulation with

minimal instructional guidance. Following exploration, three written prediction problems were posed to the student who illustrated predictions on blank graph sheets with specified variables listed on the side. Stage two involved the student reading background information on water pollution that described the dependent and independent variables. In stage three, the student worked through several exercises with the computer program designed to illustrate some of the relationships and concepts he/she was exposed to previously. Then, each subject was asked to solve the same three prediction problems as given at stage one.

Analysis

Based on extensive review of the video tapes, using guidelines from Ericsson and Simon (1984) and Smith (1983), 63 cognitive behaviors, important to making predictions, were identified. These behaviors were subsequently analyzed with techniques of verbal protocal analysis (Ericsson and Simon, 1984) and "comparative systematic analysis" (Glaser and Strauss, 1967). This consisted of the identification of successful and unsuccessful behaviors of program exploration, stage-one prediction, and stage-three prediction. Specific misconceptions were indentified from students prediction behaviors.

Results

The results of this study are presented with regard to: 1) general trends, 2) a summary of misconceptions, and 3) selected examples of the relationship between misconceptions and predictions.

General Trends

Piagetian cognitive development, number of misconceptions, and predictive success at stage one and two for all students in the study are shown in Table 1. In general, successful predicting students were formal operational and tended to have less misconceptions related to the subject and the prediction process. They exhibited behaviors that were systematic and required more abstract reasoning. For example, they tended to explore systematically, predict and identify bi-directional and rati' relationships, plan, test, judge, and reach conclusions.

Unsuccessful predictors tended have more misconceptions, to be non-systematic, less abstract, and to not use many of the behaviors characteristic of successful subjects. Students' misconceptions directly affected their indentification of the important relationships. For example, they would often make e.rors and apply knowledge of non-directional and incorrect bi-directional relationships to make, test, and justify poor predictions.

It should be noted that to make accurate predictions in this study it was important to know the relationship between the dependent and independent variable relative to the direction of change. Subject's predictions were most accurate if they involved both the direction and magnitude of change. Four types of relationships were distinguishable in this study. Non-directional relationships involved noting that one independent variable affected a dependent variable, but not saying how (e.g., temperature affects oxygen).

Table 1. Summary of Results for Individual Subjects Indicating Piagetian Cognitive Stage, Number of Applied Misconceptions, and Predictive Success at Stages One and Three.

Subject	Piagtian Stage	Number of Misconceptions	Predictive Success	
			Stage 1	Stage 3
No. 1	Concrete	15	T	T
No. 2	Formal	0	T	T
No. 3	Concrete	7	U	U
No. 4	Formal	0	T	S
No. 5	Concrete	4	U	U
No. 6	Concrete	2	U	T
No. 7	Formal	1	T	T
No. 8	Formal	0	S	S
No. 9	Concrete	4	U	T
No. 10	Concrete	3	U	U
No. 11	Formal	0	S	T
No. 12	Formal	0	T	S
No. 13	Formal	0	T	S
No. 14	Concrete	2	T	S

Note. U = unsuccessful; T = transitional; S = successful.

Directional relationships involved the direct effect of one independent variable upon a dependent variable (e.g. high temperature means low oxygen). Bi-directional relationships were more dynamic. Their identification depended upon comparison of the range of values for one independent variable values with the range of a dependent variable (e.g., as the temperature increases the oxygen decreases; or waste is unaffected by changes in temperature). Ratio relationships, the most useful to making accurate predictions, required quantitative thinking over a range of independent-dependent variable relationships (e.g. for every rise of temperature of one degree, the oxygen decreases 3 ppm).

Summary of Misconceptions

Several misconceptions identified during the course of students' predictions are summarized in Table II. Many of these resulted from lack of understanding of concepts related to solubility, how waste and oxygen get into and out of the water, and the relationship between oxygen, bacteria, and waste.

Misconception Examples

Selected verbatim examples illustrating misconceptions at stage one and stage three have been chosen to give the reader an understanding of how misconceptions can affect student's predictions.

Student No. 7 had an interesting misconception that was related to the concept of equilibrium and to the dependence of oxygen and waste upon the volume of available space in the water. She recognized that oxygen would eventually reach equilibrium and level off, but for the wrong reason.

[Stage one prediction]

No. 7: [Predicts waste.] It will probably level off because it can't get any higher.

I: Why can't it get any higher?

No. 7: It's stationary, I mean there is no more oxygen. There will probably be no more oxygen by the time you get over here [points to right side of graph at 25 days]. It's accumulated so much.

I: You mean the waste takes up oxygen?

No. 7: No. It takes up space...a percentage.

I: Oh. You mean the water is filled up with waste.

No. 7: Yeah. There is no more room for the oxygen.

Student No. 7's misconception shows that she does not understand molecular concepts related to dissolving of solid or liquid industrial waste and gaseous oxygen in the water. The subject doesn't realize that industrial waste is almost never going to reach a state at which it has saturated the river, waste is often insoluble in water, and there could be no competition for space. Anyway, the subject should have correctly recognized that the reason for oxygen

Table II. Summary of Misconceptions Identified During Predictions.

1. Waste takes up so much space in the water that, after a time, there is no more room left for the oxygen.

2. Waste increases because it "eats" up the oxygen, and in the process gains energy.

3. Waste eventually becomes "thick" and blocks "holes" which would allow it to drain out.

4. Molecules that are colder will try to warm up by moving around more. This will help to unclog the "holes."

5. Oxygen enters the water by "popping" through "holes" in the waste, which is "thick" and on top of the water.

6. The "holes" in the surface of the water are eaten through by bacteria.

7. Oxygen will increase in a fast river, since it doesn't have to penetrate as "thick" of a waste.

8. Oxygen will increase in water that has lumber in it, because there is some air in the lumber.

9. A fast river will tend not to have organisms growing in it, and therefore, will not have any oxygen.

decreasing is due to bacterial breakdown, a process of which uses up oxygen.

Student No. 3 displays an interesting misconception illustrated in the next example which involved misunderstanding of the relationships among bacteria, waste, and oxygen as did student No.7 above. Her misconception seems to have arisen during reading of the background information which correctly explained the relationships. That is, bacteria break down the waste and use up oxygen in the process. Also, notice that student No. 3 did not consider the relevant independent variables affecting the waste, which is essential to making an accurate prediction.

[Stage 3 prediction]

No. 3: Waste would probably be high because it eats up oxygen and gets energy from it [misconception].

I: How does it do that?

No. 3: I think the water uses the oxygen to break the waste down. [misconception]

I: What about bacteria?

No. 3: Yeah, bacteria break down the waste.

Student No. 3 failed to realize, at first, that bacteria break down waste to obtain energy and in the process use up oxygen. However, in her second response she seemed to recognize that something besides waste breaks down oxygen, by saying water was responsible. When the interviewer hinted that bacteria may be involved, the student quickly agreed. It would seem probable that she could only remember from the reading that something broke down the waste, but could not remember what that "something" was.

In the next example, student No. 1 considered waste as a thick gooey substance that blocked holes for the sewage water to drain through. It's possible that he was thinking of waste going to the bottom of the body of water, accumulating, and then slowly leaching into the soil. Even if this were true the student still had a misconception in that "holes" do not actually exist.

[Stage one prediction]

No. 1: I predict the waste will probably go up some because it gets compacted and there's a lot of gooey stuff...and sewage is blocking the holes for water and sewage to drain out of [misconception].

Notice that the student did not consider the relevant independent variables affecting the waste (e.g., type of body of water, type of dumping, etc.), but accessed misconceived information from his past. The misconception, and the fact he did not consider the relevant variables, probably contributed to the student predicting waste to be much higher than it should have been.

The following example shows shows misconceptions related to the "holes" and to how temperature affects the waste and holes.

[Stage one prediction]

No. 1: It [waste] will maybe go up a little because it's cooling down some [incorrect bi-directional relationship], and since it's maybe moving around a little more.

I: What do you mean by "moving around a little more?"

No. 1: It's trying to warm up a little bit and the molecules kinda move around and try to unclog the holes.

Notice, in addition to the student's misconception of "holes", he thinks that molecules will try to warm up when they are cooled down. This implies he does not fully understand the relationship between temperature and molecular movement.

In the next example, student No. 1 had a misconception about how oxygen enters the water.

[Stage one prediction]

I: OK. Now it's a fast river. What will happen to oxygen and waste through time?

No. 1: The waste won't be as thick because it's moving faster than slow river...because when it's slow it piles up and is hard to move. When it's faster it's thinner and oxygen won't have to penetrate as thick of a waste, and maybe more air can get in.

[Student correctly predicts oxygen higher, but as sloping upward.]

Notice that student No. 1 actually used a correct bi-directional relationship (i.e., as the speed of the body of water increases the oxygen increases) to make an partially correct prediction of oxygen, but for the wrong reason. He incorrectly believed that oxygen must go through a layer of waste to get into the water. Perhaps the student had observed waste floating on the water and piling up as if the suface were covered by a layer of debris. Further, using the correct relationship didn't help since he inaccurately predicted the slope of the oxygen curve as rising up (positive).

Student No. 1 demonstrated a few more misconceptions as shown in the following excerpts where he considered the impact to the aquatic life in part A relative to part B. Notice that he expanded his reason for why oxygen can't penetrate a thick waste.

[Stage three prediction; after making a prediction.]

I: Will the fish be impacted or killed more in part A or part B, and why?

No. 1: I don't think the fish in the industry is gonna live as long as fish by the lumber company... because in some ways the lumber, even though the

rate is 10 ppm, it has some air in the lumber that might bring the air [in the water] up some [misconception].

I: Why will the fish die?

No. 1: Yes. Because bacteria won't be able to eat a big enough hole for air, oxygen, to come in, to pop through the sewage [misconception].

I: What do you mean?

No. 1: Oxygen won't be able to get into the water as quickly as the waste since the waste is probably on top, around it, or in it [the water] in some form [misconception].

Notice that subject No. 1 thought that oxygen came out of the lumber placed into the water. This error may have its basis in the fact that oxygen does indeed come from trees. The subject failed to recognize that they had to be living.

Also, notice that this subject often tried to get a visual picture of what was happening. For instance, he visualized sewage waste as, "on top" of the water in some form. Again, such imagery may reflect the experiences the subject has had viewing pollution films, or actual polluted rivers in which foam or debris was seen floating on top. In reality, waste may be distributed throughout the water column depending on factors such as solubility, density, specific gravity, etc.

Subject No. 1 expanded his view of how oxygen entered the water. He believed oxygen penetrated water by "popping" through holes in the waste, which were eaten through by bacteria. Such a view is probably related to two misconceptions which arose due to lack of understanding that: 1) bacteria use up oxygen during decomposition, and 2) oxygen dissolves in water and does not "pop" into it.

In sum, several misconceptions of subject No. 1 seemed to relate to inadequate understanding of concepts concerning oxygen and waste at the molecular level (e.g., basic chemistry concepts such as dissolving of a gas in a liquid, specific gravity, etc.).

In the following final example of misconceptions, unsuccessful subject No. 9 had the misconception that oxygen is increased by organisms growing in the water and decreased by the fast river destroying those organisms.

[Stage one prediction]

No. 9: The waste will be low and the oxygen high.

I: Why is that?

No. 9: No...maybe not [erases]. It [oxygen] will be lower because its going so fast [incorrect directional relationship].

I: And how will that lower the oxygen?

No. 9: It's going so fast there wont be any organisms growing in the water [misconception].

I: And how would that affect the oxygen?

No. 9: There would be no more plants?..

I: And plants affect the oxygen?

No. 9. [Laughs.] I guess...I don't know.

Notice the subject definitely knew that oxygen came from the organisms, but seemed uncertain of the concept tha oxygen is produced by plants. This relationship is a major concept in biology and it seems unusual that subject No. 9, a biology II student, would not have learned it. Another misconception of subject No. 9 is her belief that the speed of a river is detrimental to the organisms growing in it. This misconception may be the result of her having thought of a slow moving stream overgrown by vegetation and comparing it with her concept of a fast moving river without the lush greenery.

Conclusion

This study examined the relationship between student's misconceptions in biology and the science process skill of prediction. The think-aloud interview technique led to the identification of 63 program behaviors associated with prediction and misconceptions. Comparative systematic analysis identified successful and unsuccessful behavioral tendencies.

In general, successful predicting subjects were formal operational and exhibited less misconceptions than unsuccessful predicting subjects who were concrete operational. These findings agree with Lawson and Thompson (1988) who found a similar relationship between formal operations and misconceptions.

Many of the misconceptions that were identified in this study involved relationships between the independent and dependent variables, as well as concepts of solubility and bacterial decay relative to oxygen and waste. It is possible that some of the misconceptions demonstrated during stage three predictions arose due to misunderstanding or limited understanding of the information read from the background information. Perhaps if more time had been spent explaining the background information in stage two to the unsuccessful subjects they could have made more accurate predictions. In any event, misconceptions became major barriers to students making accurate predictions about the water pollution system.

It is also possible that in some cases, due to a limited vocabulary, students were judged to have misconceptions when if fact they did not. For example, when subject No. 1. stated that oxygen "pops" through the sewage he could have been conceptualizing a dissolving process but could remember the term dissolving. On the other side of the coin, students may use terminology they have memorized but do not understand conceptually. Two caveats to researchers and teachers conducting think-aloud interviews, or any class activity involving question and response (e.g., discussion, testing,

lecture): 1) recognize the problem with semantics involves both limited vocabularies and limited understanding, and 2) make a special effort to probe for further responses.

The question arises: how do we get rid of students' misconception barriers in science? Shuell (1987) addresses this point:

> The task of helping students to acquire new knowledge and more appropriate conceptions involves more than simply providing students with more and more information. Attention must be given not only to the ways in which various aspects of new information are interrelated, but also to ways in which its acquisition may depend on possible misconceptions inherent in the prior knowledge of students, how these prior conceptions influence perceptions and learning, and how it might be possible to change them (pg. 242).

Lawson and Thompson (1988) point out: for students to overcome their misconceptions, "they must be able to logically 'see' how the evidence supports the scientific conception and contradicts the naive misconception." That is, they must evaluate competing "hypotheses" and choose the most logical one.

At a basic level, the skill of prediction or hypothesizing seems dependent on understanding cause-effect relationships which can be manifested as misconceptions. In the present study, misconceptions affected students predictions, which depended on the understanding of relationships between responding and manipulated variables. Further, several misconceptions identified by this study centered on cause-effect relationships with solubility and density relative to how oxygen and waste enter and leave the water. Others involved cause-effect relationships between energy and aquatic life.

Logically, teachers should devote more energy to having their students explicitly identify the cause-effect relationships between possible interacting variables. For example, assignments could be given that require students to write about the cause-effect relationships between predator and prey, hormones and behavior, etc. This type of instruction, in addition to aiding the identification of students' misconceptions, seems to be one step toward the improvement of science process skills, such as predicting or hypothesizing, and should augment any conceptual change teaching strategy. It is also congruent with the growing field of cognitive science which views cause-effect or if-then thinking, refered to as production rules, as the format by which concepts are learned and stored in the brain (Greeno and Simon, 1986).

Another key for opening the door to conceptual change is "metacognative activities." These can be defined as those activities requiring the generation of one's own thoughts or ideas followed by their evaluation in light of: (1) other's thoughts and ideas and (2) the actual evidence collected. Science instruction for this type of metacognition could involve students making predictions or generating hypotheses about given cause-effect relationships identified by the teacher during a reflective discussion. Ideally, following initial general predictions/hypotheses more specific predicitions/hypotheses should be encouraged. Then, students would conduct experimental work to test their predictions/hypotheses. This would also be followed by a

metacognative evaluation of the original prediction/hypotheses relative to actual evidence. This simple model is displayed below (Figure 2).

```
       Identify
Cause/Effect Relationship
    |
Questions
    |
    |
  General      Metacognative     Specific       Metacognative
Prediction --> Activities   --> Prediction --> Activities --> Test
Hypothesis                      Hypothesis                  Experiment
    ^                               ^                            |
    |                               |                            |
    |                          Metacognative                     |
    <-----------------------    Activites    <--------------------
```

Figure 2. The relationship between metacognative activities the process skill of prediction/hypothesis and experimentation.

To help successfully implement the above strategy it is suggested that teachers: 1) give students enough time to think through and discuss the concepts and the ideas generated, 2) encourage students to look for relationships among concepts, predictions, etc., 3) provide the necessary laboratory apparatus for conducting experiments, etc., and 4) test students for their ability to develop predictions, hypotheses, and design experiments.

In conclusion, science teachers need to accept that their students will have misconceptions about even basic concepts, which has been shown to be true even at the college level (Capper, 1984); and, that traditional teacning methods will <u>not</u> effectively change these misconceptions.

This study has addressed the kinds of misconceptions students bring with them to the science classroom. Future research needs to concentrate on the design of instruction that will "unteach" these naive theories. At present, the most effective instruction for teaching conceptual understanding and for elimating misconceptions would seem to be a learning-cycle approach that builds from simple to complex, incorporates science process skills, and employs extensive metacognative activities.

Future research must also look at how students conceptions and misconceptions are stored and patterned in the brain (i.e., long term memory). Once this framework is better understood, perhaps we can more effeciently add to it, rearrange it, and actually restructure it to become a more accurate conception of reality (i.e., change the misconception).

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