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ABSTRACT

This paper attempts to create a vision of what it would be like to teach for understanding, to adopt the view of learner as constructor of his or her own understanding, and to share in the creation of an environment for reconstructing students' understanding and reasoning. Such a program is based on assumptions about the cognition of learners, aspects of curriculum, teaching strategies, and assessment consistent with these assumptions. The paper begins with a fictional story based on reform in science classroom teaching. Statements and questions provided by students are consistent with actual statements made by students as they attempted to negotiate meaning from their experiences in and out of the classroom. The vignette provides a vision of what it might look like when focus is on teaching for understanding, on helping students reconstruct their understanding and reasoning from prior ideas and experiences and from new experiences directly related to their initial ideas. Teachers who have incorporated ideas discussed in this paper have found significant change in their students' understanding and reasoning; the teachers themselves have felt revitalized with regard to their own teaching and learning. Some concerns expressed include resistance of students who believe that teachers should be imparters of information and demonstrators. Also, even when the approach is perceived as valid, it can be difficult to implement if a teacher is working alone. The conclusion is that the benefits far outweigh the costs. A discussion of the benefits and concerns derived from the teaching for understanding perspective completes the document. (LL)

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Creating an Environment for Restructuring Understanding and Reasoning

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Jim Minstrell and Virginia Stimpson

Creating an Environment for Reconstructing Understanding and Reasoning

Introduction

The world of the scientist, the mathematician, the writer, the world of most professionals is different from the world of the student. The professional has conceptual and reasoning tools that most students have not yet acquired. One view of the purpose of school is to bridge the gap between these two worlds, not necessarily to make professionals out of the students but to help open the minds of the students to different ways of observing, investigating, and representing the world around them. The teacher represents the professional world and helps mediate between the professional world and school activities, assisting the students in moving toward the professional world. The activities of school need to reach from the issues and concerns of the real, day to day, world of students to the issues, concerns and thinking of professionals engaged in their intellectual practice. To help bridge that gap, practices (like reasoning, decision-making, and valuing) that are part of the professional world and part of the students' world need to be part of the activities of school as well.

How do we help students move across the gap between their world and the world of professionals? The central charge in the writing of this paper is to create a vision of what it would be like to teach for understanding while adopting a view of learner as constructor of his or her own understanding. How might curricular materials or the ways they are used differ? How would the strategies of teaching , the ways students and teachers interact in the classroom be different from the dominant perspective of teacher, or textbook, as teller and student as the receiver of knowledge which has been predigested by the teacher or textbook author? How might the system deal with "making understanding accessible to all," given the diversity of students in our classes? How might assessments be made consistent with these perspectives on learning and teaching? What sorts of efforts and support are necessary for the implementation of such a vision?

Before we begin painting a vision of the relevant attributes of an environment for constructing understanding, we need to share some of our assumptions. The first is that by understanding, we mean understanding not only the products, results and conclusions of the discipline, but also understanding the nature and processes of the discipline. In mathematics, Lampert has called the latter "responsible teaching of mathematics," and addresses the question of whether "what is being learned is authentic mathematics." Do the skills and knowledge being acquired contribute to the students' ability actually to do the discipline?(Lampert, 1992)

To appropriately reflect the discipline, in-depth investigations into the nature and content of the discipline replace superficial coverage that is told or read and rotely memorized. The focus on depth has implications for the activities, teaching strategies, and the assessment of understanding. In our classes we try to create an environment wherein teacher and text are not the primary sources of knowledge or understanding, rather the teacher acts as a guide and, occasionally, as a summarizer of past activities. The text provides a resource that extends understanding developed through class activities. The learning environment becomes more like the issue-driven, investigative environment of the professional's work place than the placid, passive environment of a training school.

Others use the term "constructivist teaching" to describe an approach which engages students in meaningful experiences and discourse. While we try to avoid such labels, we share some of the assumptions of constructivist teaching identified by von Glasersfeld (1991). Teaching is different from training; the later focuses on the performance and observable actions, while the former focuses on the students' understanding. Knowledge probably exists in a network of conceptual structures, therefore knowledge is not transferred by words, but must be constructed by learner. Teaching is a social activity involving others, but learning is private, in one's own mind. It follows from these basic assumptions that teachers not only need to know subject matter but also they need to know about their students' understanding and reasoning in order to guide students toward the understanding and reasoning associated with the professional world.

In this paper we will share our view of what it means to create an environment for reconstructing students' understanding and reasoning. We begin with a fictional story based on experiences reforming our teaching in our science classrooms. The statements and questions by the students in the story are consistent with actual utterances made by our students as they attempt to negotiate meaning from their experiences in and out of the classroom. Hopefully this vignette will give the reader a vision of what it might look like when one focuses on teaching for understanding, on helping students reconstruct their understanding and reasoning from prior ideas and experiences and from new experiences directly related to their initial ideas. Within the story we will share the sorts of concerns and decisions that are addressed by teachers and students.

Our reformed program is based on some assumptions about the cognition of learners. We will debrief the story by discussing these assumptions and then by considering aspects of curriculum, teaching strategies and assessment that are consistent with these assumptions. We will refer back to the story as an example of how these aspects get played out in the classroom. While the story is about a science classroom, the aspects have implications in most school disciplines that deal with conceptual understanding and reasoning. Finally, we will conclude by talking about benefits and concerns about reforming education from this sort of teaching for understanding perspective.

A Story about an environment for building understanding and reasoning about electricity

On the first day of the study of electricity, students looked at typical electrical devices in their day to day world. Mr. Jones set out various devices that had been somewhat dismantled such as a toaster, an old calculator, a desk lamp, and a couple of different flashlights. Outside he had parked his car close to the classroom, so the students could see the many wires, the battery, and other electrical devices under the hood. Students were encouraged to think about general questions they had about electrical devices. Being able to give complete answers to these questions would be a major goal of the new unit.

On the second day, which will be described in detail, students begin their formal exploration by conducting an investigation using common flashlight cells (batteries) and bulbs.

While Jones checks the adequacy of the equipment he has set out for his next class, he reflects on how much more interesting and satisfying his work has become during the past ten years. Early in his teaching, he often began a unit by having students read a specific chapter in the assigned text and answer the questions in the book. He had believed that they needed to have an appropriate vocabulary and the main ideas before they could follow lab procedures. He remembered his instruction as being dominated by teacher talk at the chalk board and students reading and doing generally mindless end-of-chapter exercises. Certain students took the time to memorize facts from the text and learn steps to getting the answers to the exercises. Occasionally the students had performed experiments, but, as they filled in the blanks of their lab books, they did not seem to be excited by the phenomena. There were times when an interesting opportunity to apply the new ideas did come up, but he remembered how woefully superficial and inadequate the students' understandings were. Students bided their time through his class, apparently saving their interesting observations and conversations for other parts of the day.

Since he developed new understandings of teaching and learning, and since he began to modify his classroom practices, there tended to be more meaningful exchanges as students learned about science. Reflecting on the demands of paying attention to students' thinking and reasoning, and his own impatience with his initial ability to write questions which revealed students' ideas, he smiled. Those early changes in teaching had been pretty overwhelming, but revitalizing for him and for his students. The shift in perspective and approach to teaching had come slowly, initiated by university study, encouraged by reports of reform efforts at the national, state, and local levels, and sustained by regular conversation with a group of peers. This group began to focus on the classroom as a small community in which experiences interacting with the natural and human made worlds could serve as contexts for exploring ideas. The reward for the investment of time and effort was paying off in terms of the empowerment of his students. There was evidence that students during the past few years had applied their understanding and reasoning in the day-to-day world. The activities of the classroom seemed to have a much greater sense of purpose.

Note how the activities of the curriculum, the assessment, and the teaching strategies in the following scene are integral parts of meaning-making in the science lessons.

Getting Started:

Jones hands out a sheet of paper on which are drawn a few simple arrangements involving one flashlight cell, one bulb, and one or two wires. Jones shows the class a typical flashlight bulb, battery, and some ordinary wire. He asks the students to consider what they already know about arrangements of electrical devices. What each student writes will become an initial assessment of students' understanding and reasoning in the conceptual arena of current electricity. This brief probe, and others that follow, inform the teacher's decisions about appropriate instructional activities. As importantly, the students quickly realize that they begin this unit with some knowledge and many unanswered questions for which they are now motivated to get answered.

Jones: This is a situation where what you know and understand may change considerably. Yesterday you began a record of your ideas when your wrote down questions about electrical devices. Now I would like you to consider the arrangements of batteries and bulbs represented on this sheet. In which cases do you think the bulb would light? In which cases would it not light? Would it be brighter, or dimmer, in some? As best you can, write a summary of your ideas. How did you decide which would light, how bright, etc.? What are your present ideas about electricity that help you make your predictions?

Jones walks among the students, clarifying the task and noting students' answers and rationale. Some students predict that a single wire used to connect one end of the battery to the tip of the bulb will light the bulb. This suggests that those students believe that the battery is a source of the electricity and the bulb is the receiver. Even though Jones knows their prediction is incomplete, he knows that students will see the inadequacy of this idea as they design and perform tests of their predictions.

Jones: Once you have made your predictions and given your reasons, begin comparing your answers and ideas with other students. Don't change what you have written on the sheet. Rather, on another sheet begin writing questions you want to investigate or ideas about the nature of electricity that you want to test.

As students begin sharing their ideas with each other in small groups, we listen in on one conversation.

Sara: I think if you make the wire, like a pipe, from the top of the battery to this pointy thing on the bottom of the bulb, then the wire will carry the electricity to the bulb and make it light.

Martin: I don't think it will work. I heard on a TV show that you have to make a electrical circle, so the only ones that will light are when you have two wires helping make a circle with the battery and the bulb.

Sara: I don't know. I want to try my idea and see if I can make it work.

Martin: I think it's the circle idea that works. Mr. Jones, isn't that right? You have to make a circle to make the bulb light, right?

Jones: Well.. Ann and Chris, you two have been listening to Martin and Sara, but you have been pretty quiet, what do you think?

Jones wants his students to take responsibility for their learning, and since they have not sufficiently discussed their ideas, he chooses to reflect Martin's question to other students who have not yet spoken their ideas.

Ann: Uh.. it seems like both are right. I know you gotta have a power source like a battery or things won't work, but maybe the more wires you have the brighter the bulb, so the ones with two wires will make the bulb light brighter.

Chris: I think Sara's idea is right. The other day when my dad and I were trying to fix the taillight on the car, I noticed there was only one wire to the bottom of the bulb.

Sara: Let's quit talking and see what does happen.

In working with his students and in conferences with the fellow educators and researchers with whom he works, Jones has learned to search for value in what the students bring to the learning situation. The Source-Receiver idea, expressed by Sara, is generally a useful intuition since even the energy company expresses electrical distribution as the flow of electricity from the powerplant to the consumer. Ann has suggested another generally useful intuition, "the more of one thing gives more of another." Even though these two ideas do not fully apply to the situations at hand, Jones is confident that the students will sort this out as they experiment with the battery, wire, and bulb.

Jones also knows that Chris failed to observe all of the relevant variables when he looked at the car battery. Since relating classroom work to out-of-class experiences is a priority for Jones, he notes that this context will provide a nice challenge once students have dealt with less complicated classroom phenomena. He will ask Chris to talk about it again after the students have additional shared experiences involving somewhat structured observations and inferences.

Martin has suggested the circular idea that will eventually be the precursor of "circuit." Just as with the other students, Jones does not signal Martin about the correctness of his ideas. This student's knowledge may be based on an incomplete understanding of something he has seen or heard, but not observed. Jones has learned that knowledge built on superficial experiences is less likely to generalize to new situations.

Jones: That's good that you all have brought so many ideas and experiences to the situation. What could you do to find out which of these ideas, if any, work?

Sara: Can we try it? Can we try the experiment?

Jones: Go to it! But, as you are setting up the situation, be sure you think about how your experiment will help you decide which of the ideas you have discussed so far seem to work. In the end you will need to be able to describe not only your ideas but also how the experiments you did tested your ideas.

Getting Started opens a giant box of issues. In the process of Getting Started, the students become aware of the variety of ideas they have about electricity. As their study progresses, some of these ideas will be rejected. Others will be modified as students begin to account for new phenomena. Additional contexts will cause students to further refine their emerging understanding. Though he is aware of the limitations of some of the students' understandings, Jones avoids thinking of the students' ideas as either "right" and "wrong." He knows which questions to encourage early in the study of electricity and which should be postponed. Jones thinks about phenomena which can be observed by the students. He applauds Sara's impulse to investigate, knowing the tentative, evolutionary nature of ideas developed from such idea testing investigations.

The Investigation:

Each group uses flashlight batteries, bulbs, and wires. Jones knows his students are capable of dealing with the variables in this situation so he elects to have them identify relevant factors and design investigations to test their initial ideas. Chris and Sara have teamed up. Chris holds a battery in one hand and a bulb in the other. A thumb holds one end of the wire to the top of the battery while the other thumb holds the other end of the wire to the bottom tip of the bulb. Sara holds the tip of a bulb directly to the top of a battery. Neither bulb lights.

Ann places one wire from the bottom of a battery to the tip of the bulb and another wire from the top of the battery to the threaded part of the bulb. Her bulb lights. Martin holds the same arrangement except that the ends of both wires are touching the bottom tip of the bulb. His bulb does not light.

Martin wishes Mr. Jones would just tell him the answer like his last science teacher did. He has always earned good grades when he knew exactly what to study. He is concerned that his grades will go down because instead of giving him answers, this teacher keeps asking him to think about everything. Jones holds high expectations for this capable person but is sensitive to the time the student will need to adjust to being expected to describe the phenomena and to justify his answers and ideas.

Ann, by contrast, is pleased to have a class where she actively explores ideas and justifies her thinking. She is beginning to recognize the limitations of her past experiences, how little equipment she has used outside of school. Though her initial ideas on pre-instruction quizzes have proven to be incomplete, she has performed exceptionally well on tests at the end of the first few units. Jones and the research team which occasionally observes his class have found that involving students in lab activities which answer student-posed questions has had a leveling effect in terms of making up for inequities in students' home environments.

Jones moves from group to group noting the varied explorations and the quality of the students' technique. This embedded assessment helps Jones monitor the students' development of skills in investigation. The check sheet on which he takes notes will become part of a longer record, the analysis of which will help Jones improve his teaching about investigation.

The building principal, on her way down the hall, stops by the classroom to admire the level of engagement and activity of the students and teacher in this "controlled chaos," as she calls it. Because of the efforts of Jones and other educators and researchers in the partnership, this school has improved on several measures of performance. As she leaves, the principal recounts the extra efforts it has taken to convince the rest of the school district to commit the necessary resources to support the new programs. The extra equipment and the time for teachers to plan has proven to be a worthwhile expense. Excellence doesn't come without a price.

Down the hall the principal passes the mother who heads the Schools' Foundation. Officers in the Foundation assumed leadership in developing understanding and support for reforms in mathematics, science, and technology education. In addition to written explanations providing a rationale for planned changes, these members of the community worked with the teachers to provide Family Nights when parents could experience the excitement and frustrations of exploring ideas. Change is a process that takes time so parents are just now beginning to value the growing depth of understanding, facility with reasoning, and investigation capabilities of their children. Each woman expresses appreciation for the invaluable support the other has provided for the teachers and students.

Meaning-Making:

Jones encourages the students to share their observations. Sharing requires the students to re-present their understandings. In this way a common understanding can be constructed, an understanding that may generalize across a broader range of experiences.

Jones: OK, so what did you find out? What factors must be present in order for the bulb to light?

Chris: Sara and I found that even though we know the battery is important and needed, you can't just connect the bulb to one end of the battery.

Jones: Do you agree, Sara? Did you find any way to light the bulb?

Sara: Yeah, but it was more like Martin and Ann said.

Jones: What do you mean? How was it like what Martin and Ann said?

Jones reflects her comment back to her, encouraging Sara to be more precise.

Sara: Well, Martin said you need a circle to get the bulb to light. When Chris and I tried their idea, we got it to light most of the time.

Martin: Except that to get it to light, you have to touch the wires to two parts of the light bulb, not just to the tip on the bottom. Mr. Jones, please just tell us the answer.

Jones: You're doing fine. You don't want me around for the rest of your lives to tell you when you are right or wrong. You all are finding out that you can learn from your own investigation and from talking with others about their investigations and experiences. That's how paid scientists learn too. I want you to continue to learn about the world around you even after you are out of school and away from teachers. I will say, however, what's been said so far is consistent with my experience too.

Jones coaches the students to think about their own experiences, to listen and share experiences with others, and to gain confidence in their skills of meaning-making together.

Jones: In the situations that light the bulb, what is important about the arrangement?

In learning and problem solving, Jones knows it is important to have learners identify perceptually salient characteristics by which they can later recognize when principles, findings, or conclusions will apply.

Sara: You need a circle.

Martin: But you also need to touch two parts of the bulb and both ends of the battery.

Jones used to be relieved when a single student suggested this essential part of the pattern. He now realizes that if he is patient enough, several students will share this observation.

Ann: Yeah, it's like you have to have both the plus electricity and the minus electricity to come from the ends of the battery to go to the bulb and have a reaction at the filament.

Martin: But, it has to go to the tip of the bulb and to the threaded part of the bulb.

Ann: Yeah, one wire to each, because the tip of the bulb is connected inside to one end of the filament and the threaded part of the bulb is connected to the other end of the filament.

Chris: How do you know that?

Ann: Cuz, I asked Mr. Jones if it would be okay to break open a bulb, so we did it, and I saw what was connected to what inside.

Sara: But how do you know there is a reaction from the two electricities crashing in the bulb. I think it is like Martin said. There is a circle from one end of the battery to one end of the bulb, through the bulb out the threaded part to the other end of the battery. Maybe that is how electricity flows, around the circle.

Jones: OK, so let's see what we've found out so far. It sounds like some of you are suggesting that we need to involve two connection places on the battery, two connection places on the bulb, and, that the whole arrangement has to form a circle. Did any of you find an arrangement that shows that any of these parts are unnecessary? Jones pauses to learn if the students agree of these essential parts.

The conclusions you have come to so far are very important. Most common electrical devices we encounter daily have two endedness. And most have one or more circles, technically called circuits. Notice that the words circle and circuit are very similar.

Jones has learned that technical terms are best understood when rooted in shared, prior experience. That is why he did not introduce the terms earlier in the unit as he once had done.

Martin: That's the word I was trying to think of. That was the word they used on TV.

Jones: Yes. That's probably what you heard, Martin. So, two endedness and a circle arrangement. Those important factors seem to be common for us all now. Those things we could see. Now what about these ideas that Ann and Sara are suggesting? Has anyone seen any evidence for one of these and not the other, whether two different electricities meet and react in the bulb or that electricity goes around in a circle through the bulb?.......No? Perhaps we'll have to keep thinking about that and see if we can come up with any evidence to support or reject one or the other.

Although Jones has read about electron drift theory, he has not seen any evidence for this idea that would be accessible to his students. There are other ideas that are more likely to be relevant and applicable to their lives so he chooses to ignore the more sophisticated idea unless a student mentions having read or heard about it.

Chris: But, I'm still confused about when I worked on the taillight. I know I saw only one wire to the back of the bulb holder.

Jones waits five seconds to see if there is anyone who addresses Chris's concern. Not getting an answer, Jones primes the discussion again. One of his goals for classroom interaction is to have students address each other's concerns and questions.

Jones: Can anybody help Chris out on that concern?

Sara: I think maybe the metal car acts like the other wire. The electricity might go from one end of the car battery through a wire to the bulb. Then, maybe it goes from the other end of the bulb to the metal part of the car and through the metal car back to the other end of the battery.

Chris: Ohhh, maybe that is why the other end of the battery goes through a big wire to the metal engine of the car. I noticed that the other day when we were looking at Mr. Jones' car.

Extending Activities:

From prior research and from classroom experience, Jones knows that a next big issue regarding current electricity will be whether the electricity gets used up by a bulb or flows through the bulb. He will use another preinstruction assessment, asking students to predict the relative brightness of two bulbs in series. This will initiate another instructional cycle of Getting Started, Investigation, and Meaning-Making. These cycles have proven useful even if the shape of the particular activities differ. For example, in order to explore this next idea, he has a particular critical experiment for every student to do. The students will not be engaged in an open investigation this time.

For another week or two, the emphasis will be on working qualitatively with ideas. At some point the students will make measurements, and at that time numerical data analysis will become integrated with the qualitative ideas. As numbers are introduced, it will be important for the students to revisit ideas and experiences that made sense earlier to see the consistency between concepts and formulas.

After students have shared a common set of experiences, each student will engage in a computerized assessment designed to diagnose problematic understandings or reasoning. The diagnosis will assist Jones in making instructional decisions about what ideas need to be addressed by further activities with the whole group or smaller groups of students. This diagnosis and prescribed instruction increases the probability that certain key ideas will get developed. It also makes students aware of areas where they need further study.

By experiences such as these, students' understandings of classroom situations are elaborated. Their understandings are extended into new situations which were not explored by the full class. They are reminded of contexts in which additional constraints need to be imposed.

At some point, the students will go back to the devices available the first day and show that they understand aspects critical to the working of these devices. Given batteries, bulbs, switches and wire, they will have an opportunity to wire a make shift house addressing problems like turning off lights in one room while being able to leave them on in another and some appliances requiring twice the voltage to operate them. Striving for this more authentic assessment seems to help students retain their understanding and bridge the gap to being able to see the world more like the professional.

Assumptions about the Cognition of Learners

Research on students' conceptual understanding suggests that students come to a learning situation with existing ideas. In the context of our story, "battery is the source, bulb is the receiver" is one dominant idea. Associated with this idea is "each bulb uses up electricity that comes from the battery." Another more generic reasoning pattern is "the more influence the more effect" which gets applied in the electrical context in the form of "the more wires, the brighter the bulb," "the more batteries the brighter the bulb," or "the more bulbs you use, the more electricity gets used." These are initial ideas that are predictably present at the beginning of a unit on electricity. When teachers and students are aware of initial understandings and reasoning, experiences can be designed with challenge and extend these initial ideas.

These understandings and reasoning are pervasive and often robust. Conceptual questions have been asked internationally with similar resulting understanding and reasoning exhibited (Jung, 1984, Viennot, 1979, Driver, 1985, White and Gunstone, 1992). Without implementing instruction that addresses students' understanding and reasoning, not by telling them that they are wrong, but by letting the students observe the limitations of their ideas, they will continue to exhibit their old ways of thinking in new contexts(McDermott, 1984).

One reason why the ideas are robust is that they often work in some circumstances so the student may come to believe that they are always valid. The limitation of students' ideas often resides in the contextual application of the ideas rather than in the ideas themselves. "The more batteries used in the circuit, the brighter the bulb" applies if the batteries are arranged in series, but not if they are arranged in parallel. "Heavier falls faster" works when dropping a coin and a feather from the ceiling, but not if a wooden ball and steel ball are dropped from that same height. However, if the wood and steel balls are dropped from a height of a hundred meters above the ground, the heavier steel ball will hit the ground sooner. Unless one wants to rely on knowing and remembering a vast number of observations, a deeper sense of the mechanisms influencing effects is necessary to accurately predict the relative fall times of various objects under various conditions. There is evidence that telling students that their thinking is wrong and that they need to think another way has much less effect than having them experience and articulate the limitations of their ideas. There are valuable aspects of students' knowledge and experience that they bring from their everyday experiences, aspects that can help them as they move toward a professional's view of the world. One goal of teaching is to help students build an understanding that incorporates knowing when (in what contexts) certain ideas apply and when they don't.

Students have ideas or beliefs about teaching and learning in addition to specific ideas specific to the discipline (Gunstone, 1991). "The teacher's job is to tell me what I need to know. My job is to study hard to remember what she told me" was a belief represented through the voice of Martin in the story. Instructional systems need to address these notions, if students are to make a smooth transition from their daily world where they occasionally may be expected to think and make decisions to the professional world where they regularly will be expected to think and make decisions. Our teacher, Mr. Jones, resisted the temptation to tell Martin the answer, but Jones also guided the learning situation so that Martin might begin to feel empowered by his success at investigating the ideas which he generated.

Learners exhibit a "confirmation bias." Seeking evidence which supports their existing ideas takes precedence over looking and accounting for disconfirming evidence. Even when students note discrepancies, they tend to discredit its source. Our students, for example, after noting disconfirming evidence can be heard to say "I can never do science right anyway" or "our equipment isn't working right." The ecology among their existing ideas may be so strong that it becomes difficult to modify one aspect without attending to the others. In an attempt to avoid being overloaded with perceptual cues, learners may avoid dealing with apparent discrepancies. For whatever reason, the knowledge system of learners tends to be conservative with respect to change, especially with respect to attending to and resolving inconsistencies between articulated expectations and classroom observations. In our story, Jones persisted, encouraging students through classroom conversations to recognize and resolve differences between their expectations which reflected their initial ideas and their new experiences which suggested a need for a reformed conception.

Curricular Activities

What is taught and what is done in the classroom, typically called the curriculum, has been traditionally embodied in "the textbook." As we take students' understanding into account, and as we attempt to reflect the activities of the discipline, our view of the curriculum becomes more dynamic. What we investigate and how we investigate it, in terms of the activities of the class, depends on the assessed needs of the students, on the resources available, and on the interests of the students and teacher.

We believe that the curriculum should address the understanding and reasoning of students. In our story, Jones used a preinstruction quiz and related discussion to help make students aware of their initial expectations and ideas. We find that asking our students to make predictions or initial interpretations, prepares them mentally to listen more critically to the ideas of others and to be more likely to note differences between expectations and the actual results of demonstrations or lab experiences. In the story, students had an opportunity to test and change and further develop their ideas.

After the initial investigation, Jones asked all students about a particular situation (two bulbs in series) because learning their ideas around that situation was critical to the teacher's choice of subsequent instructional activities. Thus, embedded in the curriculum are cycles of diagnosis of potential difficulties and prescription of activities designed to address those potential difficulties. The larger instructional cycle involved Getting Started, Investigation, Meaning-making, and Extending Activities. This cycle represents phases of identifying potentially relevant ideas, testing the ideas, resolving differences, and then trying the reformed understanding in new contexts from which the cycle repeats.

The curriculum should reflect activities consistent with intellectual practice of the discipline. Investigation (including questioning, predicting, experimenting, and interpreting results) involves the processes of the discipline called science. We foster and facilitate activities that incorporate aspects of scientific investigation. In the story, the students designed their own experiments to test alternative ideas about electricity.

Problems which might require further investigation provide opportunities to apply and extend ideas. Rather than assigning ten repetitious exercises using $V=IR$ and solving for voltage(V), current(I) or resistance(R), students might encounter and use the conceptual ideas behind Ohm's Law as they design circuitry to meet the voltage and current requirements of appliances in a home.

The issues involved in coming to new understandings and reasoning need to be revisited in subsequent activities. Arons (1990) recommends revisiting new ideas in no fewer than five contexts. Some memory research suggests spacing the review opportunities. (Loftus, 1980) In our situation, the two endedness and simple circuit idea will be revisited each day in the early part of the unit, then arise later in the house and appliance circuits, and even later in a subsequent unit which focuses on energy.

Good curricular activities correctly and appropriately represent the substance and nature of a subject and use a context that focuses attention on relevant aspects of the concept being developed. The activities must be comprehensible to the particular pupils being taught. (A lesson that works well with one group of students may bomb with a group that has had very different earlier experiences.) Finally, the activities should focus on a particular change in students' thinking so much so that students can articulate the puzzling questions which they are working to resolve. In order for teachers to create, know, and implement useful instructional activities, they need to understand the subject matter in a rich flexible way, and they need to have a knowledge of learners and learning (McDiarmid, Ball, and Anderson, 1988).

Teaching Strategies

A critical but supportive environment

To create an environment for reconstructing understanding and reasoning, we suggest using teaching strategies that foster a critical, yet comfortable, risk-taking environment. Students are more likely to attend to the results of a new investigation, if they consider those results in light of their initial ideas and expectations. (Jung, 1984) We want students to express their predictions or interpretations openly. We also want students to be critical of ideas that don't make sense to them personally. Part of the artistry of teaching is bringing these purposes together within the same classroom. Lampert describes her role as working "to bring students' ideas about how to solve or analyze problems into the public forum of the classroom, to referee arguments about whether those ideas were reasonable, and to sanction students' intuitive use of mathematical principles as legitimate" (Lampert, 1986).

We want to foster a willingness to make and correct errors rather than avoiding and denying them (Resnick, 1987). We also want students to be thinking, to be critical of conclusions that seem inconsistent with their experiences. In our story, Jones was neutral in his responses to students' suggested interpretations or predictions. He kept the argument focused on the phenomena and on ideas rather than on people and on whose ideas were right. Students seem to feel less threatened with sharing their initial ideas when they respond to ideas individually before sharing them in small groups.

This gives them a smaller arena in which to articulate their ideas and a preliminary opportunity to evaluate the viability of those ideas. Finally, the ideas may be written on the board, but by then they are usually owned by several members of the class.

When discussing ideas in the large group, we first allow people to cite evidence in support of a particular idea. We may ask people to hold their counter arguments or questions until after we have heard the supportive arguments. By the time we are ready for counter arguments, two things usually have happened. One is that several of the arguments begin to look viable. Another is that ideas are further separated from the people who suggested them. When we turn to counter arguments, we are now challenging the ideas, not the person. The students who originally suggested the idea are usually the first to be allowed to raise objections to it. Thus, we hope that the private understandings of individuals are developed in the arena of public evidence in support or against various ideas. When we are finished we hope there is a public consensus of understanding and reasoning. In our story, the group concluded that the circle and two endedness were both important principles related to the circuit phenomena.

Questioning in the discipline

When learning is viewed as accruing information, teacher as teller is an associated view of teaching. If learning is viewed as constructing understanding, the role of teacher changes to guide in the disassembling and reconstruction of understanding. Under the latter perspective, questioning becomes a key activity, initiated early in the course by the teacher, but progressively adopted by the students as they begin to take responsibility for their own learning. At the start of an investigation, the questions may center around descriptions of what will happen or what did happen. Associated with predictions are questions of "How do you know?" or "How did you decide?" Associated with interpretations or explanations are questions like "What is your evidence?" or "Why do you believe that?" The first are phenomenological questions and the second are related to the reasoning associated with that phenomenon. We have built a computerized DIAGNOSER that asks these associated questions in sets. They assist the teacher and student to maintain the importance of having a rationale associated with any pronouncement. Notice this same approach applies equally well in literature or social studies. What conclusion would you make about ...? How did you decide, or what evidence do you have to support that conclusion?

Questioning about learning

In building environments for conceptual change, there are also questions relevant to learners encountering phenomena during investigation. In generating new knowledge (or revising existing knowledge), there are at least two critical questions for the learner to be asking: 1. Do I identify any inconsistencies between what I am observing and what I would expect from what I already know? 2. If I observe an inconsistency, is the resolution of the inconsistency (between observation and what I presently believe to be true) of value? Is resolution worth the intellectual effort that it will take-to understand the limitations of my earlier thinking? These questions have to do with deciding whether to further engage in intellectual practice or to shunt it, in favor, perhaps, of being told. Sometimes it is not worth the effort or the differences are too vague to articulate and resolve. Most learners choose to engage in intellectual practice at some times and determine that it may not be worth the effort in others. We increase the chances that they will engage by bringing the inconsistencies into the public arena.

Questions associated with generating knowledge are a bit different from questions related to applying accepted knowledge. Consider looking at a set of data and attempting to identify and interpret the patterns in the data. What is nature trying to tell us? What factors are related to the observed effects? What is the quantitative relation between the variables? Now, consider applying what has been learned from answering the first questions. What are the implications of that relation, if we have certain known initial conditions? Emphasis in schools has been more on accepting conclusions from the past and applying them. In the reformed system, skills in generating knowledge (the first set of questions) are being emphasized as well.

Verbal Interaction

In the dominant questioning cycle, it is typical for the teacher to ask a question, the student to respond, and the teacher to evaluate the student's response. As an alternative, we work to have our students talk to each other about the issues and questions. We use what we have come to call a "reflective toss" (vanZee and Minstrell, 1991). After asking a thinking question, the teacher listens to a response from a student, and then, rather than evaluating it, the teacher reflects the response back to that or a different student. Notice in the story that Jones encouraged students to talk among themselves. Intellectual practice among professionals involves colleagues suggesting ideas and evaluating them as a team, rather than waiting for a response or input from a supervisor.

Perhaps no single finding from science education research has received as much attention as the lack of wait-time in the average classroom. The average teacher waits less than one second after asking a question before calling a student to respond. Similarly, after a student gives an answer, the average pause-time before evaluating the answer or calling on another student is typically less than one second (Rowe, 1974). It takes time to listen to a question and to develop an articulate response. The quality and length of answers increases with an increase in the wait or pause-time of a few additional seconds. Teachers and students need to consciously wait to respond for three to five seconds while all students have an opportunity to formulate or reformulate their responses.

Assessment of Understanding and Reasoning

Assessment, by focusing both teacher and students on what is known and not known, can guide instructional decision-making. Short quizzes or observations of discussions and lab work, may indicate concepts and skills which need further development by the full class or individual students. In the past, tests have been used largely as instruments for grading students at the end of a unit or a course, not as diagnostic instruments which help determine learners' needs. We feel the need to refocus assessment to be primarily in the service of instruction to guide learning.

In the service of learning, assessment becomes more embedded within the instruction. For example, in our story Jones administered a preinstruction, diagnostic quiz to identify what understandings and reasoning students had at the beginning of the unit. That gave him an initial reading of who had what ideas, and it gave his students some preview of the issues that would be involved in activities of the next few days instruction. In our classes we are using a computerized DIAGNOSER that assesses the sorts of understanding of phenomena and associated reasoning used by our students. This assessment is late in the unit when students might believe they understand the ideas; it allows them check their understanding. Our unit tests are considered assessments of understanding at a given point in time; the ideas and situations included in those tests remain open for further discussion during the rest of the school year.

The questions or situations used in the assessment ought to reflect significant ideas which students might use in their everyday lives. Our long range purpose for building the understanding and reasoning should be addressed by assessment tools. In the story, while Jones asked students to deal with flashlight bulbs and batteries, the ideas about circuitry and electrical devices that were learned with this equipment can be later applied to circuits in the home and car as well.

When students learn particular understanding and reasoning, they should also know the conditions under which those particular ideas are sufficient. For example, we want our students to understand and be able to interpret and explain various situations of objects being moved under the influence of natural forces like gravity and the pushes by the surrounding air (or another more viscous medium like water). We want learners to be able to identify when air resistance can be considered to be negligible and when that is not an appropriate assumption. What are the conditions under which a particular explanation is sufficient? What alternative explanation is more appropriate if those conditions do not exist? How might the conditions change from one sort to the other? What factors are involved? In mathematics, under what data conditions would it be appropriate to assume a straight line equation would describe the relation between variables. Too frequently, we preset the conditions for the learner. We teach them how to perform the needed action, but not how to identify when it is appropriate to apply that action. These considerations should be built into our assessment of learning as well as our instruction. Do our students know when it is appropriate to apply the ideas they are studying?

Our assessments should include questions that are situated in real-world problems. In the current vocabulary, learners ought to demonstrate performance in more authentic circumstances than the typical paper and pencil test in multiple-choice format. Jones' end-of-unit assessment involved teams of students setting up the circuits to address the needs of a pretend house. This assessment involves a practical situation.

In creating an environment for reconstructing understanding and reasoning, students' reasoning needs to be expressed and assessed. In his verbal interaction with students, Jones asked for the experiences and rationales that supported students' answers. Students should be expected to justify their answers based on observations and inferences. Even when a quiz uses multiple-choice questions, each question can be supplemented with an additional question asking students to "Briefly explain how you decided on the answer you chose." In large projects like the lighting of the pretend home, students could be asked to interpret the phenomena resulting from particular configurations of bulbs and wires. "What does it mean that the fuse gets hot when we have lights on in several rooms?"

Benefits and Concerns about this Environment

Benefits

Why would a teacher want to create an environment for reconstructing understanding and reasoning that incorporates the attributes described in this paper? As some teachers have become frustrated by the superficiality of students' understanding which often results from more traditional teaching, they have sought ways to change what happens in their classrooms. Those with whom we have worked report having found significant changes in their students' actions and performance once they began to focus on their students' understanding and reasoning. The level of conversation increased as students were encouraged to reduce the use of jargon and discuss issues and ideas. As students were expected to explicate their rationale, the length of written responses has increased. Questions related to the everyday world, which required a deeper understanding of scientific concepts and an ability to identify relevant variables, have been answered in thought-provoking ways. Students have begun to feel empowered as they come to believe that they too have valuable ideas about the world. In many cases, program enrollment has increased. Students are exiting the program demonstrating that they understand physical concepts as they arise in rich and varied contexts.

Teachers feel revitalized about their own teaching and learning. Not being responsible for presenting knowledge to students gives some teachers permission not to have to know everything. As a result, they may enter into investigations with their students. The authors confess to learning much physics from students as a result of complex and interesting questions raised during class discussions. The focus shifts to learning how we can come to know, how we can determine what might occur when a given set of circumstances are postulated.

Concerns

It seems appropriate that we share concerns that might be raised by this practice. Even when the students seem to be quite engaged in a classroom discussion, they may resist this approach to learning and teaching. Many students believe in the roles of teacher as demonstrator and teller and student as note-taker and memorizer. They feel uncomfortable with questions that extend beyond one day's exploration and the lack of closure that can extend for a period of time. It seems unfair to some students that they might be held responsible for ideas for the entire length of a course.

If the program is the only one in the system in which students are expected to be accountable for their learning, the teacher may encounter resistance from outside the classroom. Parents, and even other educators, may not understand or appreciate the approach and may resist its implementation. Some parents do not believe that students should make decisions for themselves on the basis of their experiences. They may challenge basic assumptions which underlie the course.

Even when this new approach is perceived as valid, it can be difficult to implement if a teacher is working alone. Most existing curriculum and assessment materials are not consistent with this approach and creating them can be time consuming. As national reforms in mathematics and science education result in pressure on publishers to modify their curriculum, this is likely to change. To challenge and reconstruct students' understanding and reasoning, teachers need to know students' existing ideas and be able to guide the development of more powerful concepts. By learning more about the results of research on teaching and learning and about fostering development of ideas, teachers can become better prepared to teach in ways suggested by this paper. While classroom discussions are fascinating, skills of leading discussions take time to develop. As the teacher becomes clearer about goals for a particular lesson, determining when to narrow the focus of a discussion and when to broaden it become clearer. All of these changes require time and commitment.

For us, the benefits of engaging students in meaning-making far outweigh the costs. As our approaches have evolved in the directions described in this paper, our own teaching has been revitalized. We have become actively involved in teacher leadership and research and development efforts. Our work has been supported by our administrators, and although some parents and students do not yet understand the environment we are creating, for the most part we have their confidence. We have a broader range of students and a larger percentage of the student body taking physics than ever before. When we compare our current students' performance with what we used to expect and accept, we believe that the our effort has been a worthwhile investment.

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