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Article Title: Conceptual Change Teaching And Learning: An Instructional Approach That Supports Metacognition

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Common to many of the strategies used to address conceptual change has been an elicitation of students' ideas on a topic, representation of students' ideas verbally, through illustrations or in written form, confronting students' ideas with the canonical views of science, and checking to see if students' ideas changed (Hewson & Hewson, 1988). This sequence of instruction ignores two assumptions of the Conceptual Change Model of Posner, Strike, Hewson and Gertzog (1982), namely the need for students to reflect on components of their conceptual knowledge as outlined in the conceptual ecology and the need for students to talk about their conceptions as well as with their conceptions -- to be metacognitive in the sense described by Kuhn, Amsel, & O'Loughlin (1988). Instruction in the classroom chosen for this study was intentionally planned to facilitate metacognitive discourse about the status of and justifications for students' conceptions. The teacher set out learning goals that required students to provide reasons underlying a particular conception and to reflect on their developing conceptual knowledge. Since conceptions are believed to survive and have meaning within the conceptual ecology, and since a change in a conception should be accompanied by a concomitant change in status (Hewson & Thorley, 1989), it is reasonable to assume that instruction directed at these metacognitive aspects of learning would be more likely to facilitate learning science concepts.

How the teacher in this fifth grade classroom (age 10-11) facilitated metacognition for students is the subject of this research. Student outcomes as a result of this teacher's instruction included dramatic changes in their understanding of the particulate nature of matter (water in this case) and the epistemic need for consistency when thinking about abstract objects such as particles. Changes in the students conceptions are attributed to the set of learning goals provided by the teacher. These goals encouraged students to talk about their learning and the teacher facilitated this through instructional activities that helped students become metacognitive. Characteristics of the learning environment created by this teacher and an analysis of the instructional activities

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CONCEPTUAL CHANGE TEACHING AND LEARNING: AN INSTRUCTIONAL APPROACH THAT SUPPORTS METACOGNITION

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INTRODUCTION

The difficulties' students experience in learning a range of science concepts has been documented for several decades (Duit, Goldberg & Niedderer, 1992; Pfundt & Duit, 1991; Novak, 1987; Helm & Novak, 1983). The persistence of these conceptions following instruction and the limited utility these ideas could play in terms of understanding science has also been recognized for a long time (Driver & Easley, 1978). Taken together, these findings raise questions for teachers and researchers alike concerning what to do about students' scientific conceptions. Current research efforts increasingly focus on questions about the social environment in which students learn science (Brown, Collins & Duguid, 1989), theoretical models of teaching and learning (Hewson, Beeth & Thorley, 1997) and appropriate interpretation of the ideas that students do express (Klassen & Lijnse, 1996).

Over the past three decades, research in conceptual change has produced more than 2800 reports describing the variety and extent of students' conceptions on science topics (Duit, 1993). The trend throughout many of these studies has been to document gaps in student learning. A more recent trend attempts to understand what students learn given the instructional contexts within which they are expected to learn (see for example Roth & Roychoudhury, 1992). Studies such as the Children's Learning in Science Project (1987) and the American elementary school classroom of Hennessey (Beeth & Hennessey, 1996; Hennessey, 1991a, 1991b, 1993a, 1993b) make significant contributions to understanding how students learn in classrooms devoted to students' conceptions. Included among these efforts have been attempts to establish metacognitive abilities assumed to be necessary for conceptual change learning to take place such as the PEEL Project at Monash University-Australia (Baird &

Mitchell, 1986) and the CASE project at King's College, London, England (Adey & Shayer, 1990; 1993). Findings from these studies have important implications for helping students learn to reflect on their scientific ideas in powerful ways.

THE STUDY

Analyzing teaching activities that facilitated and supported metacognitive reflection by students is the focus of this study. Students in this fifth grade classroom (age 10-11) changed their conceptions of water from inconsistent and idiosyncratic views to one consistent view of the particulate nature of water. What is important here is that these students have a consistent view of matter (e.g., water) at the particulate level. Conceptions of water at the molecular level and of the atomic character of hydrogen and oxygen were not elicited by the teacher in this classroom. Instead, she supported discourse that allowed students to talk about their ideas -- second order thinking (Kuhn, Amsel & O'Loughlin, 1988). The metacognitive aspect of what these students learned was as important as the science content they learned.

Instruction in this classroom was intentionally planned to helped students speak about their conceptions as well as with their conceptions. The continual focus on students current ideas and on pushing them to reflect on those ideas stands in sharp contrast to many approaches to science instruction. A more common pattern in many studies addressing conceptual change has been to elicit students' ideas on a topic, have them represent those ideas (e.g., verbally, through illustrations or in written form), confront students' ideas with contemporary views of the same phenomenon, and check to see if the students' ideas have changed (Hewson & Hewson, 1988). The learning goals of this teacher are represented in the following quote from Kuhn, Amsel and O'Loughlin (1988):

> Thinking about theories, and how evidence bears on them, in contrast merely to thinking with them, we have suggested, is a tremendously important distinction.
> . . . The person who only thinks with theories lacks any awareness or control of the interaction of theories and evidence in his or her thinking. The person who has achieved the ability to think about theories and how

> evidence bears on them has achieved a considerable degree of awareness of and control over this interaction. We have suggested that this ability is "metacognitive" in a very important, core sense of the term (p. 228).

Characteristics of the learning environment created by this teacher and an analysis of the instructional activities she presented to students are used here to answer the following research questions: 1) How did this teacher engage students in thinking about water at the particle level? and 2) How did this teacher's instruction help students develop a consistent view of water particles?

SITE DESCRIPTION AND DATA SOURCES

The parochial school selected for this study includes grade's kindergarten through sixth grade. The school is located in a middle class community of approximately ten thousand people. Agriculture and light industry are the predominant forms of local employment.

I participated in daily instruction throughout one academic year. Data collected to address the questions above included audio recordings of classroom discourse, observation notes describing instructional activities presented to students, student's written work, and informal discussions with the teacher.

Observation notes, transcripts of classroom discourse, and informal discussions with the teacher are used to document the sequence of instructional activities. Instructional activities presented to the students were placed on a timeline representing the chronological sequence of instruction. Data from classroom discourse and informal discussion with the teacher about her intended instructions were then added in parallel to this timeline. These three sources of information provided a graphical representation of what the teacher intended for students to learn and how the students responded to that instruction.

THE STUDENTS

Thirteen student's age 10-11 (fifth-grade) participated in this study, six females and seven males. All students enrolled in this class were within the normal ranges of ability for fifth grade students -- none were exceptionally gifted or lacking in basic skills as judged by the teacher (Hennessey, personal communication). Students in this school received instruction from the same science teacher each year until the end of grade six. Many of these students experienced science at this school in previous years.

PHYSICAL SETTING OF THE CLASSROOM

The classroom in which science instruction took place was modern and well equipped. Black slate lab stations with electric outlets, sinks, and gas jets bordered the classroom. Microscopes, analytical balances, and a human skeleton were on display and available for student use. A computer terminal was available at each lab station and a demonstration table and white board occupied one end of the classroom. In many respects, the physical setting of this classroom was similar to that found in high school science classrooms.

The classroom also included a carpeted floor, on which the students often gathered in small groups to discuss their ideas. Posters created by the students virtually covered the walls, ceiling, and demonstration table at the front of the classroom. These posters represented students' most recent thoughts on the content they were studying. The teacher saved all of these student posters. Frequently the teacher retrieved older versions of posters to remind students of their past ideas and to encourage them to talk about if, how, and why their ideas had changed.

Although this classroom is well supplied with equipment necessary for teaching science, there was an additional characteristic to this classroom that distinguished it from many others. The display of posters containing the students most current ideas indicated to me that their ideas were the subject of interest. This 'work in progress' impression of students scientific knowledge displayed on their posters is a sharp contrast to the more typical ‘finished product’ appearance seen in other classrooms.

THE TEACHER

The teacher in this classroom taught elementary science classes more than twenty years. Her weekly schedule with the fifth grade students included three instructional periods of 52 minutes each devoted to science instruction. She also taught these students one period each of health and computers. This schedule was quite flexible however, and the students were frequently exposed to four or five periods of science instruction. If the teacher determined that the students actively engaged in developing a particular concept, they pursued their interest in that topic on days designated for instruction in health or computers. The teacher's constructivist view of learning is reflected in the following written statement describing her philosophy of teaching, produced in response to being nominated for a national teaching award:

> Briefly, from a constructivist perspective, I perceive learners as actively constructing their own knowledge by using their existing knowledge to interpret new information in ways that make sense to them. As a result, learners build their own conceptual structures which subsequently fosters the development of some conceptions and inhibits the development of others.

The teacher in this classroom paid considerable attention to the "existing knowledge" of her students and to helping them "interpret new information in ways that make sense to them." Implicit in her statement above, but explicit in her stated learning goals, is the notion that students need to reflect on the consistency and reasons for their scientific ideas. Her pedagogy is founded on instructional activities that support and facilitate students as they learn to talk about their ideas in increasingly powerful ways.

The teacher's view of science discourse was reflected in six learning goals she presented to her students (see Table 1). These learning goals contain the criteria and the limits by which ideas are discussed in this classroom. Embodied with these goals is a very strong notion that students must develop the ability to communicate their ideas as well as evaluate the ideas of others. The learning goals most critical to this study are examining reasons underlying ideas (Goal #2) and recognizing when ideas are consistent (Goal #3). The teacher's instruction intentionally focused on supporting students' abilities to meet these goals as they constructed their understanding of the particulate nature of water. Metacognitive reflection was facilitated through a series of instruction that helped students speak about the reasons underlying their ideas and the learning goal that required them to apply consistent reasoning to their ideas.

Table 1
Learning Goals Presented to Students

1. Can you state your own ideas?
2. Can you talk about why you are attracted to your ideas?
3. Are your ideas consistent?
4. Do you realize the limitations of your ideas and the possibility they might need to change?
5. Can you try to explain your ideas using physical models?
6. Can you explain the difference between understanding an idea and believing in an idea?
7. Can you apply intelligible and plausible to your own ideas?

DATA INTERPRETATION

Implicit in the learning goals stated by the teacher are several fundamental metacognitive activities. First among these metacognitive activities is the recognition by students that they do have ideas (Goal #1) and that they need to communicate those ideas to others. Students would also need to think about and provide the reasons for their ideas (Goal #2). The teacher periodically reminded students that they needed to talk about their ideas with comments such as:

> Teacher: OK. Do you have ideas? Can you talk about them? Bring them out into the open. Why do you like your ideas? Why you're attracted to them?

It is notable that this requirement to explain why you liked an idea goes well beyond the mere propositional statement of an idea. The expectation of this teacher is that students should be able to provide the reasons underlying any ideas they put forward. Thus, this is not simply an exercise to elicit students' ideas so the teacher can categorize or judge them. This is an attempt to move students to the second order, metacognitive, level of thought. What was important to this teacher was that she needed to know the reason's students had for holding an idea. Knowing this information, she could then address the students' reasons during subsequent instruction (Hennessey, personal communication). For example, a student might state: "Water is made of particles." While this statement is correct, it tells little about the reasons underlying the student's idea and there is no indication of how well the student could apply this idea. What would be critical for the teacher, and instructive for the students, would be to examine the extent to which this idea is applied to water taken from different sources and in different states.

If the statement "Water is made of particles" is a robust conception the student must have some justifiable reasons for believing the idea to be true. If the student indicated that water is particulate -- how does the student think water particles are arranged? Does this student have a continuous view of matter or do they think there are spaces between the particles? If spaces exist, what could occupy these spaces and how would you know if this idea was correct? Do water particles change their shape -- when changing from liquid to solid for example? While answers to each of these questions could enlighten the teacher about the depth of a student's understanding, there is no assurance that a student would respond to these questions in a consistent manner. A consistent view of matter at the particle level, whatever those particles might be made of, would allow a student to begin examining these more interesting and important questions.

In the discourse exchange that follows, the teacher had already presented students with samples of water frozen into different shapes -- a tea cup of ice, a cylinder of ice, a cube of ice, etc. When asked about the water particles that made up the ice the initial responses from the students were that each was different at the particulate level. As a result of the students' responses she asked students to do and talk about three situations--cutting a piece of paper into ten pieces and then cutting one small piece into ten more, etc.; crushing a sugar cube into its smallest part; and removing a core from a common doughnut. The conversation that followed these events is presented below.

> Teacher: Let's take a look at our ice from yesterday. If we don't focus in on shape and we just focus in on what the ice is made out of <Student: It's the same> all of you used the same little structures to build [a model]. You know you used your hydrogen, your oxygen that wasn't a problem.

However, when we're talking about ice you had a hard time saying that if I cored a piece out of the ice all of a sudden it was going to be different. All right? So if you want to start explaining whatever this piece of doughnut is made out of, I mean we can't really draw it chemically up there because it's too big because it's got sugar and all kinds of other things in it so let's just do this. Here's the doughnut [draws a circle on white board]. So whatever this doughnut is made out of it's going to be molecules of some kind because it's a solid right? And if I take a core out of it and make this core gigantic over here [writes on the white board] whatever it's made out of it's going to be made out of molecules of some kind because it's a solid. How many kind of agree with that? Let's have some hands up [a few agree]. OK hands down. How many disagree with that [a majority disagree]? Can we come back and do one more thing here? Can I take this doughnut, whatever the doughnut's made out of, and say OK I don't know exactly what that molecule looks like so I'm going to draw a circle to stand for it. Whatever it's shape is I'm drawing a circle to stand for it. Could I say that this is a good way to draw many of them [doughnut particles]?

Many students: Yes.

Teacher: Because it is a [pauses]

Student: Solid.

Teacher: Solid. All right. Does it make sense to call this [whole doughnut] different from this [smallest particle of the doughnut]?

Many students: No.

From the students initial responses the teacher inferred that they were unable to distinguish between two levels of description -- the shape of an object at the macro level and the composition of the object at the particulate level. The teacher chose to address this conceptual problem with a series of instructional activities that challenged students' to differentiate between matter at the macro level and the particulate level. By selecting instructional activities that helped students differentiate between the macro and particulate levels (e.g., cutting a piece of paper into ten equal parts repeatedly) and then using bridging analogies' strategies similar to those developed by Brown and Clement (1989), the students were able to distinguish between two important levels of description. However, these students still had to overcome a second inconsistency in their thinking -- specifically that there could be differently shaped water molecules in each container of frozen water.

In all instances when students presented their ideas on a science subject the teacher probed for the reasons why that idea appealed to them. Over an extended period of doing this the teacher was able to determine the consistency of the students' conceptions. For example, when student's first discussed frozen water, their idea was that water frozen in different shaped containers contained water molecules of different shapes as well. If water was different at the largest level, the macro level, it must also be different at the particle level, the particulate level. The teacher addressed the students' ideas with a series of demonstrations that called for applying consistent thinking about matter when dividing it into its smallest particle. First she asked the students to cut a piece of paper into ten pieces, and then to cut one of the ten into ten more, etc. Next she crushed a sugar cube and asked students if there was anything but sugar in the cube and if they would be able to taste anything but sugar from the smallest particles. Finally, she used a cork borer to remove a core from a doughnut and asked if the doughnut was the same throughout. By 'same throughout' she meant to focus the student's attention on the paper, sugar, and doughnut particles -- even when you could no longer physically see them as the original materials.

Later, she confronted the students with examples of water taken from different sources. She asked if the water was the same at the particle level or different and the students responded that water from different sources was, to them, different. How she responded to the students is presented immediately below.

> Teacher: Some of you were having difficulty with [water from different sources]. The water is coming from different places on a macroscopic level, a large level that you can see with your eyes. Obviously it looks very different. The Yahara [River water] doesn't look like the drinking

fountain water <Student: I hope not>. OK, but when we went down to the microscopic level you said things but do you really believe what you said? What did you say about the microscopic level? What about the microscopic level of water from a lake? What is it made out of?

Student: H-2-O

Teacher: Something like that [writes chemical formula - H-2-O]. OK. What about the Yahara then?

Student: H-2-O.

Teacher: OK. And drinking fountain water or whatever. But you weren't satisfied. You were kind of like uncomfortable. I could see where you were coming from all right and maybe I need to address that before addressing this. [Teacher gets colored fluff balls to use as visual models]. OK, let's say this is the drinking fountain water [two white fluff balls and one red in a vee shape]. OK? All right? Do you agree that it is a good model for the drinking fountain water? <Many students: Yes>. What if we are going to talk about the Yahara?

Many students: Put some dirt in there. Put some more water in there [Student's suggest using colored fluff balls to represent contaminants to the water--green for garbage, brown for dirt, yellow for "body pollution"].

Teacher: OK. So what is the basic part of the water?

Many students: H-2-O

At this point the students indicated a consistent understanding of the chemical composition of water as containing one part oxygen and two part's hydrogen. The fluff ball representation of a water molecule arranged in a vee by the students is also consistent with contemporary illustrations of the three dimensional structure of water molecules. The students apparently knew this fact from experiences outside the classroom, possibly their exposure to science programs on television. Up to this point, the teacher had created a situation through her instruction in which all students shared a consistent description of water molecules at the particle level (Note: It is common practice for this teacher to require all students to agree on an idea as part of her instruction. Beeth (1993) offers a full account of this practice). Their consistent view of the particle nature of water represented a significant change in these students' conceptions, a change from idiosyncratic models based on macroscopic appearance to one that viewed water particles as having a consistent shape. A consistent view of water at the particle level provided these students with an anchoring conception in the sense proposed by Clement (1993). However, they remained inconsistent in their thinking about water from different sources.

The teacher indicated her understanding of this conceptual difficulty in her statement, "I could see where you were coming from all right. And maybe I need to address that before addressing this." The "this" referred to here is the students' initial idea that water particles could be different depending on the source of the water. She addressed this conceptual problem by first establishing the particulate nature of water and then confronting the student's views that water from different sources might be different at the particle level. The following segment of transcript illustrates this teacher's ability to call for and support consistent reasoning as these students think about frozen water as compared to liquid water.

> Teacher: But the water is still there, all right? It doesn't mean that all the rest of the stuff can't be. You know, things as big as a whale and as small as phytoplankton.
>
> Student: Take out the [colored fluff balls not representing water].
>
> Teacher: Is this the water [holds up a fluff ball not representing water]?
>
> Many students: No.
>
> Teacher: OK. So I take out everything that is not water. Even if I did the same thing with models of the Yahara, models of the ocean, models of the drinking fountain, models of the swimming pool, if I take out everything

not classified as water then all the rest of the stuff has to come out. Now some how, some way when you are dealing with water you are OK. But when we turn this stuff back to ice you get lost <Many student: huh [an expression of puzzlement]>. OK, what is the difference between a solid and a liquid?

Student: Solid is hard a liquid is runny.

Teacher: OK. Is this a solid or a liquid [model of water with molecules arranged in rows]?

Student: Solid.

Teacher: OK. Now what if I said this is drinking fountain frozen water. Is that all right?

Many students: Yes.

Teacher: OK. What if said now this is drinking fountain frozen water [model of water with molecules arranged in a circle]?

Many students: No.

Teacher: What if I said that [circular representation] is drinking fountain frozen water?

Many students: No.

Researcher: Why isn't that one [a good model]?

Jane: Because she said one was water and that was like in a straight line and now she says that they are in a circle and that's water too <expressed as a question>?

Researcher: What has to be the same Jane?

Jane: Well, if they're both water they have to be the same.

Researcher: OK. So whether it's water from the drinking fountain or water from the Yahara and it is frozen it has to be the same?

Jane: Yes.

Teacher: OK. Does it really make any difference this way [linear representation] or the circle or the way I had them before? <Many students: Yes>. Yeah they are different models. But could all three of them be the explanation of frozen drinking water? What do you think? Could this be a model of frozen drinking water the circle? OK. If I really believe that this is what frozen drinking water looks like, and then tomorrow when you come in here I say this is what frozen drinking water looks like [presents an alternative model], and the next day you come in here I say well this is what frozen drinking water looks like [presents a third model], what is going on here?

Jane: It is not constant. You are not consistent in what you are saying.

The need for consistency stated above by Jane is representative of the entire class. Although many students were actively participating in this dialog, Jane was the one who expressed the need for consistent ideas about water. Collectively, the students represented in this exchange recognized the need to think about water in a consistent manner regardless of its source. In particular, they generalized their conceptions of water to include water taken from any source and in solid or liquid states. They also learned to talk about their conceptions, specifically that conceptions needed to be supported by reasons and that conceptions needed to be consistent.

CONCLUSION

The teacher in this classroom approached science learning with a constructivist pedagogy rooted in seven learning goals. These learning goals shifted her role from one of evaluating her students' ideas to one of establishing and supporting the metacognitive abilities of students to obtain these goals. Her instruction was influenced by how students could or could not talk about their views of water and water particles. Throughout instruction, she supported a number of metacognitive abilities that helped her students learn to comment on their conceptions of water. It remains to be seen if these students would apply consistent thinking to other science content or in other disciplines.

Learning outcomes resulting from the teaching sequence described above included a positive change in students' views of water at the particle level. Students' views changed from idiosyncratic and inconsistent to views much more in line with those accepted by the scientific community. The teacher responded to her students' ideas by allowing them to discuss their ideas within the framework of her stated learning goals. When initially asked how water molecules were different in the various frozen shapes the students indicated that the arrangement of water molecules was a reflection of the macro structure of the ice. After having distinguished between the macro and particulate levels of description, the teacher then asked students to apply their understanding to water taken from different sources or in different states of matter. The distinction between what was observed at the macro level and how these students talked about entities such as particles mirror the kinds of conversations found in the scientific community. These students also learned to consistently apply their view of particles to explain a range of phenomenon (i.e., all water particles are the same regardless of their source or state of matter).

IMPLICATIONS

The instruction described above is prototypical of a classroom environment that facilitates and supports conceptual change learning. Students' ideas were exposed, as in many previous forms of conceptual change instruction, however this teacher then sought to encourage reflection on these conceptions through a series of instructional activities that required second order thinking by students. Instructional goals that required talking about conceptions were effective in bringing about some conceptual change for these students. The teacher was able to address various components of the conceptual ecology through her instruction. Students exposed to this instruction showed dramatic positive changes in what and how they thought about matter.

Instruction that facilitates the kind of discourse environment described above can provide students with the cognitive and metacognitive tools needed to engage in science discourse. As was demonstrated here, the ability of students to comment on their developing ideas has tremendous implications for the science content they learn and how they come to understand the discursive nature of science in the making.

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My research interests are in the field of Conceptual Change Teaching and Learning. In particular, I am interested to understand how elementary students learn science concepts given their existing knowledge of a science topic and their understanding of the nature of science as an intellectual process. My research is specifically focused on the role of metacognition in learning. Understanding instructional events that precede metacognitive discussions, and what learners were able or not able to do as a result of these discussions, is a major goal of my research.