Teaching for Conceptual Change: Confronting Children's Experience

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For nine winters, experience had been the children's teacher. Every hat they had worn, every sweater they had donned contained heat. "Put on your warm clothes," parents and teachers had told them. So when they began to study heat one spring day, who could blame them for thinking as they did?

"Sweaters are hot," said Katie.

"If you put a thermometer inside a hat, would it ever get hot! Ninety degrees, maybe," said Neil.

"Leave it there a long tune, and it might get to a hundred. Or 200," Christian added.

If Deb O'Brien had begun her lesson on heat in the usual way, she might never have known how nine long Massachusetts winters had skewed her students' thinking. Her fourth-graders would have learned the major sources of heat, a little bit about friction, and how to read a thermometer. By the end of two weeks, they would have been able to pass a simple test on heat. But their preconceptions, never having been put on the table, would have continued, coexisting in a morass of conflicting ideas about heat and its behavior.

However, like a growing number of educators at all levels, O'Brien periodically teaches science for "conceptual change." Her students, allowed to examine their own experiences, must confront the inconsistencies in their theories. In the process they find the path toward a deeper understanding of heat, have a great time with science, and refine their thinking and writing skills.

O'Brien began with the simple question, "What is heat?" Using journals and the chalkboard to record their ideas, the students, with O'Brien's help, wrote down their "best thinking so-far" on the subject of heat. Heat came from the sun, they wrote. And from our bodies. But when Owen spoke about the heat in sweaters, everyone else agreed. Sweaters were very hot. Hats, too. Even rugs got "wicked hot," the children said. Sensing the first of many naive conceptions, O'Brien stopped them and said the magic words in science, "Let's find out."

For two whole days the testing went on. Experience, that most deceptive of teachers, had to be met head on. With their teacher's help, Christian, Neil, Katie, and the others placed thermometers inside sweaters, hats, and a rolled-up rug. When the temperature inside refused to rise after 15 minutes, Christian suggested that they leave the thermometers overnight. After all, he said, when the doctor takes your temperature, you have to leave the thermometer in your mouth a long time. Folding the sweaters and hats securely, the children predicted three-digit temperatures the next day.

When they ran to their experiments first thing the next morning, the children were baffled. They had been wrong. Now they'll change their minds, and we can move on, O'Brien thought.

But experience is an effective, if fallible, teacher. The children refused to give up. "We just didn't leave them in there long enough," Christian said. "Cold air got in there somehow," said Katie. And so the testing went on.

Conceptual Change And How It Grew

Since the late 1970s, the notion of "conceptual change" has been a pedagogical football among science educators. Arguing that reading and observing scientific principles will not alone move the mountain of" alternative frameworks" about science that children bring to the classroom, that even hands-on activities allow such thinking to go undetected, teachers are beginning from square one, helping children construct their own models of scientific principles.

If children base their thinking on what they have seen and felt, then their experience must be structured to challenge their erroneous beliefs. If alternative views of scientific principles are not addressed, they can coexist with "what the teacher told us" and create a mishmash of fact and fiction. When studying astronomy, for instance, if one brings up the common belief in astrology, children can learn every available fact about the planets and still go away thinking that Venus somehow controls their destiny. But if each child is given a chance to test his or her own model of the universe and find its limits, then a deeper understanding, without the naive conceptions, can result.

As early as the 1920s John Dewey emphasized science as inquiry, and Gerald Craig in his landmark dissertation spoke eloquently in favor of teaching science as investigation.[1] Yet the texts and curricula of the 1950s told a different story. Science texts were reading books, punctuated by predigested demonstrations of various facts embedded in such obvious questions as, "Does air have weight?"

When the orbiting Sputnik I beeped to the world that the U.S. space program was second best, the golden age of science education began. Millions of dollars were made available for writing and implementing new science curricula. The National Defense Education Act (NDEA) of 1958 provided matching federal dollars for equipment purchased by schools. Probably most important, the new emphasis on science education gave scientists, psychologists, and educators the opportunity to combine efforts on a single task: improving science and mathematics education for all children.

Drawing on the world of such psychologists as Jerome Bruner, Robert Gagne and Jean Piaget,[2] the emphasis in science education finally caught up with what Dewey, Craig, and others had been saying since the 1920s. Science is an inquiry-oriented subject; subjects should be taught and ultimately learned according to the structure of the discipline; children and how they learn should be at the center of the teaching of any subject.

Since the early 1960s science educators have tried to follow these tenets through times of financial feast and famine. The plethora of programs --- from the 1960s: Science A Process Approach (SAPA), Science Curriculum Improvement Study

(SCIS), Minnesota Mathematics and Science Teaching ProJect (MINNEMAST), Elementary Science Study (ESS), from the 1970s: Conceptually Oriented Program in Elementary Science (COPES), Science 5/13, Nuffield; and from the 1980s: Great Explorations in Math and Science (GEMS), TOPS, Activities in Integrating Math and Science (AIMS) --- all subscribe, with mild variations, to the basic philosophies described above. Children are the focus, and science is viewed as a combination of content, process, skills, attitudes, and values.

These alphabetic programs, later published by commercial firms, made a modest impression on the market. Their ideas and activities were incorporated into such commercial texts as Space, Time, Energy, and Matter (STEM), but even these books have made no more than a ripple in the ocean of school science. The latest generation of texts once again pays lip service to science as an inquiry-oriented discipline, but the books themselves resemble their ancestors of the 1950s more than they do those produced during that brief "golden age." Today's texts, which have the greatest influence on how science is taught in American schools, have come almost full circle, and teachers who rely primarily on them are little closer to teaching science as inquiry than were their counterparts in the 1920s. In too many classrooms across the U.S., science is skill taught as a cohesive set of facts to be absorbed, and children are viewed as blank slates on which teachers are to write.

But in the last 20 years such people as David Ausubel, Joseph Novak, Rosalind Driver, John Clement, and others have begun to ask different questions about children's learning.[3] Cognitive psychology and neo-Piagetian philosophy agree that knowledge, for both children and adults, grows and changes in very interesting ways. Learners bring their idiosyncratic and personal experiences to most learning situations. These experiences have profound effect on the learners' views of the world and a startling effect on their willingness and ability to accept other, more scientifically grounded explanations of how the world works. Teachers who take a personal, adaptive view of knowledge are known as constructivists because their model of learning posits that all knowledge is constructed by the individual in a scheme of accommodation and assimilation.

Deb O'Brien is such a teacher. Her students, actively constructing their conceptual understanding of heat and its behavior, eagerly tackled their surprising data with yet another experiment.

The Investigation Heats Up

When the shock of the room temperature readings on the bundled-up thermometers wore off, the children went at it again. If, as they insisted, cold air had seeped inside the clothes overnight, what could they do to keep it out? While O'Brien would have preferred to focus on one variable at a time, the children's discussion brought out other naive conceptions. Remembering attics and cars, some of them said that closed spaces were hot. "How could you test that?" O'Brien wondered. Neil decided to seal the hat, with a thermometer inside, in a plastic bag. Katie chose to plug the ends of the rug with hats. Others placed sweaters in closets or in desks, far away from the great gusts of cold air they seemed to think swept through their classroom at night. With their new experiments snugly in place, time-that old heat maker -was left to do its job.

On Wednesday morning the children rushed to examine their experiments. They checked their deeply buried thermometers. From across the room, they shared their bewilderment. All the thermometers were at 68 degrees Farenheit. Confused, they wrote in their journals.

"Hot and cold are sometimes strange," Katie wrote. "Maybe [the thermometer] didn't work because it was used to room temperature.

Owen didn't know what to write, and Christian wrote simply, "I don't know why."

Meanwhile, O'Brien kept her own journal. This was one of her first attempts at teaching through conceptual change, and she wondered how long she should let these naive conceptions linger.

"The kids are holding on to and putting together pieces of what they know of the world. But the time we are taking to explore what kids think is much longer than if I told them the facts." If she told her students that hats didn't make heat, she knew that most would parrot her statement just to please her. Lacking the evidence to prove that fact, however, they would continue to prefer their own conceptions of their teacher's answer.

Surprises await the teacher who expects children to give up their conceptions at the first sign of a discrepancy. Stubbornness, a trait not limited to children, causes students to grasp at straws, O'Brien found. When the temperature inside a sweater rose even one degree, the students cheered and shouted, "Finally!" And if, as was more often the case, the thermometer stayed at room temperature, well, then, perhaps the thermometer was broken. Or perhaps the cold air got in somehow. Or maybe they just hadn't let the sweaters sit long enough. Christian wanted to seal a hat and thermometer in a metal box and leave it for a year. Then the temperature would be sure to rise.

Should she tell them the difference between holding heat and emitting heat, O'Brien wondered. Should she devise her own experiment on insulation? She decided to let the conceptions linger through one more round of testing. And so the sweaters, hats, and even a down sleeping bag brought from home were sealed, plugged, and left to endure the cold.

The Sleep of Reason

While we often assume that reason is the guiding light of science, the history of scientific thought shows otherwise. When confronted with contradictory evidence, scientists are sometimes as puzzled as children. Through further testing, they seek additional evidence. If the results continue to disprove what they once thought, scientists often behave very much like children: they argue among themselves, they cling to their old theories, and they devise experiments that will reinforce the traditional way of thinking. As Thomas Kuhn showed in *The Structure of Scientific Revolutions,*[4] scientists are capable of holding contradictory theories about scientific concepts. Scientific communities, such as O'Brien's classroom, can take this a step further by dividing into camps that simultaneously believe several different explanations of the same event, often for many years' duration. When it comes to confronting the errors in one's thinking, scientists of all ages seem equally susceptible to certain barriers.

In theory, at least, when confronted with-evidence that contradicts existing assumptions, rational observers will accommodate their thinking to fit the latest observations. A theory, says the philosopher of science Irme Lakatos, is judged on how well it solves problems.[5] If a theory generates problems that it can't solve or explain, Lakatos says, it is rejected in favor of a new theory that solves those problems and offers promise of further investigation. Even fourth-graders seek answers that can be explained by their theories. But the substitution of one theory for another is not as easy as erasing the chalkboard. Certain preconditions for conceptual change must exist if the barriers in the path to understanding are to be overcome.

We suggest several barriers to conceptual change, barriers strong enough to laugh in the face of discrepant events. Among schoolchildren the strongest of these obstacles is likely to be stubbornness, the refusal to admit that one's theory might be wrong. Children who are not often asked their opinions are especially reluctant to admit the errors in their thinking and will find ways to adjust old ideas before assimilating new ones.

Lakatos cites the varying strengths of scientific concepts as reasons why some beliefs are changed and others are not. "Hard-core ideas" take precedence over "protective-belt ideas," Lakatos posits. In the face of discrepant evidence, believers will change their "protective-belt ideas" in order to protect their hard-core beliefs, much-as astronomers devised endless variations on cosmological theories, adding epicycles, altering distances, and so on just to keep the earth at the center of their cosmos. Katie was willing to believe that "hot and cold are sometimes strange," surrendering her belief in the consistency of temperature in order to build walls around the idea of "warm clothes." When children are unable to call on scientific knowledge to explain a piece of contradictory evidence, they will often call the discrepant event "magic." As many teachers know, tenacity in children makes scientists look downright flexible.

Another barrier to conceptual change is language. A teacher seeking conceptual change should be cautious about vocabulary. The difficulty of mastering new terms in addition to a new way of thinking about a concept can cause children to cling even more tenaciously to their old beliefs. Even the vernacular usage of nonscientific terms, such as "warm clothes," can cause confusion. There must be a reason why everyone calls them "warm," O'Brien's students conjectured.

Perception itself can block conceptual change as well. We tell children that "seeing is believing," but in science that often isn't true. Touch is an even more deceptive sense. Though O'Brien's thermometers had stayed at room temperature, each night the children kept warm beneath their blankets, just as each winter they had put on warm hats and sweaters and actually felt the warmth that the thermometers refused to register. A few days of surprising results in the classroom are not likely to change such deeply "felt" thinking. Teachers and students learn firsthand the inadequacy of empiricism as a theory of knowledge. As Eleanor Duckworth so aptly put it, "The critical experiments themselves cannot impose their own meanings. One has to have done a major part of the work already, one has to have developed a network of ideas in which to imbed the experiments." [6]

O'Brien and some of her abler students could have imposed their findings on the class saying, "Look at the thermometer. Room temperature! Now do you believe that sweaters don't make heat?" Textbooks attempt to do just this, presenting events and critical experiments from the history of science up to the present day. But, to paraphrase Louis Pasteur, understanding favors the prepared mind. If the learner has done a major part of the work already and has developed Duckworth's "network of ideas in which to imbed" the new idea, an enlightened view is more likely to evolve. If not, the experience may mean nothing.

While children and adults face many of the same barriers to learning, a few of the obstacles to conceptual change are developmental. Children in the middle elementary grades are only beginning to use concrete operations. As Piaget's research showed, when confronted with new evidence, children in these grades tend to revert to the earlier stage --- in this case the preoperational stage, characterized by an inability to conserve concrete properties, such as size and weight, and by difficulties in measurement and logical reasoning.

Children at this stage of development swear by their feelings in the face of the evidence and, having limited experience with the scientific method, trust their lifelong convictions more than they trust a thermometer. They particularly susceptible to what researcher Judith Tschirigi calls "sensible reasoning" .[7] Such reasoning Tschirigi says, often takes precedence over Piaget's "concrete reasaoning in." Children will modify their experiments to accommodate their beliefs long before they will change their beliefs to fit the evidence.

Because children's minds are still "under construction," they must be treated with care where conceptual change is concerned. As O'Brien learned, expecting students to exhibit conceptual change after having observed a few discrepant events is bound to be frustrating for both teacher and students. A teacher who chooses to let students tackle their own misconceptions is well advised to consider Lev Vygotsky's "zone of proximal development," .[8] also known as a child's "construction zone." Such developmental factors as memory, skill acquisition, and reasoning ability affect a child's capacity to incorporate new knowledge into existing schemes of thought, Vigotsky said.

The "construction zone" encompasses what a child is developmentally ready to consider. Any new information or skills needed for conceptual change may lie outside the zone if the child is developmentally unprepared to learn them. O'Brien's students who cheered when the temperature inside the "warm" clothes rose a single degree evinced such unpreparedness. They failed to recognize that the single degree was an insignificant rise and may even have resulted from a misreading of the thermometer. Conceptual change can take place only within the "construction zone." Since children's scientific skills are constructed more slowly than many buildings, conceptual change in science will not happen overnight. Unfortunately for teachers, there are no prefabricated units to be assembled in mental constructions , though many science texts would seem to suggest otherwise.

Finally, science itself has "critical barriers" to understanding, which present difficult hurdles to children and adults alike, according to David Hawkins. [9] Along with the seemingly innate problems involved in understanding size, volume, weight, and elementary mechanics, Hawkins identifies the concept of heat as containing some of these critical barriers. The perception of things as "hot" and "cold" conflicts with the scientist's conception of heat as a measurable quantity contained by all objects, Hawkins says. Since scientists held misconceptions about heat for hundreds of years, Hawkins reminds us, understanding heat is a hurdle that will not be cleared by students in a single two-week unit.

Fighting The Good Fight

With so many obstacles standing the way, conceptual change in science might seem not merely difficult to achieve, but impossible, especially based on a few measly discrepant events. Yet certain teaching strategies have been devised that can help teachers overcome these obstacles.

When discrepancies between children's thinking and the evidence are laid on the table, the teacher assumes a crucial role. Far from being a passive observer, the teacher can actively promote new thinking patterns through a variety of methods.

1. Strcssing relevance. Because children so frequently assume new information to be "stuff we learned in school," the teacher must connect new concepts to the child's everyday life. In the case of heat, O'Brien asked her students about times when they had felt heat coming from an object. She asked them if they could think of anything that trapped heat, that kept things warm without heating them. She asked them to think about animals that have "warm coats" and to consider whether those coats make heat. She asked them whether a handful of fur would stay warm if removed from the animals. Unless children appreciate the relevance of their experiments to their everyday life, they may just brush off a discrepant event as "some weird thing we saw in science."

2. Making predictions. Children who are asked to predict the results of their experiments are more willing to change their thinking than are children who function as passive observers. This neglected aspect of elementary-science instruction is essential because it asks students to link their new knowledge with what they already know in order to form hypotheses. Through ample writing in journals, O'Brien's students predicted temperatures and gave reasons for their predictions. Even though they were often wrong, they had the chance to incorporate yesterday's thinking into today's task. The use of journals in O'Brien's class also facilitated what Piaget called "reflective abstraction"[10] --- the chance to reflect on one's thinking, without which development does not occur.

3. Stressing consistency. Although nearly everyone lives quite comfortably while embracing a wealth of ideological and political contradictions, a teacher should encourage children facing new patterns of thought to be consistent in their thinking. A child can state categorically that the thickness of a sleeping bag "causes the heat inside and that pressure "causes the heat inside" a rolled-up rug. Yet that same child can maintain that hats, which are neither thick nor compressed, will be hot for no reason at all.
The teacher should tactfully draw attention to the inconsistencies in children's thinking and ask them to consider how two contradictory statements could both be true. While some children will blithely ignore the illogic of contradictions, many will confront inconsistencies and change their thinking as a result. The development of logical, consistent thought is thus a by-product of teaching aimed at conceptual change, and developing an orderly view of the world can prevent the compartmentalization of knowledge that occurs when students think that nature works one way at home and another way at school. Katie reflected such inconsistency when she wrote that "hot and cold are sometimes weird." If she is encouraged to seek consistency, however, she will not be satisfied until she has seen some order in the world around her.
If one concept is to replace another, then certain conditions must prevail.[11] First, the old way of thinking must be challenged by direct observation, by a discrepant event. Next, a new explanation for the phenomenon in question must arise, an explanation that is understandable (take care with vocabulary) and plausible. Finally, the new explanation must lead to further testing. If these conditions can be created in the classroom, conceptual change can occur.

Bringing It All Back Home

Overcoming resistance to conceptual change in children is clearly an ongoing struggle. Children will not easily surrender their carefully constructed schemes of thought to the onslaught of new evidence, no matter how convincing it seems. Dedicated teachers using a variety of strategies, including infinite patience and the willingness to let children swim upstream toward an elusive understanding, can help their students overcome these barriers. But reluctance to change one's way of thinking is not limited to scientists and students.

Despite massive evidence suggesting that students learn by doing, by manipulating, by experimenting, the great bulk of science teaching is still based on textbooks. Some independent teachers have pursued conceptual change in their science classes, but doing so presents a number of monumental questions to curriculum builders, school administrators, textbook authors, and anyone whose-job description includes monitoring the "coverage" of curriculum in any subject area.

- Is mere "coverage" of curriculum material-a viable or reasonable goal?
- What is "growth. in science, and how will we assess it?
- What content should teachers know in order to be able to recognize and then challenge children's naive conceptions?
- How can teachers adapt texts and curriculum to meet the constructivists' challenge about how children learn?
- Are there appropriate grade levels for various science topics, and what content areas are appropriate at which levels?

Any teacher who has really tested his or her effectiveness by checking students' understanding of concepts faces a startling dilemma. Teaching science in a constructivist mode is slower and involves discussion, debate, and the recreation of ideas. Rather than following previously set steps, the curriculum in a constructivist classroom evolves, depends heavily on materials, and is determined by the children's questions. Less "stuff" will be covered, fewer "facts" will be remembered for the test, and progress will sometimes be exceedingly slow. It is definitely a process of uncovering rather than covering.

The alternative is to cover the prescribed material, knowing full well that the students may be masking their lack of conceptual growth by solving the teacher rather than learning the content. In order to survive, students learn to give teachers what they want, whether memorizing and regurgitating book definitions of terms, completing lab reports in a certain format, or filling in the correct blanks on an exam.

Successful students have always done these things, and we suspect that they always will. It is their path to survival in schools. Nevertheless, their doing so presents teachers with an age-old dilemma: Do we cover the material, knowing full well that what we cover will be understood superficially at best --- accommodated, but not assimilated? Or do we forget about coverage and work to help children test their untutored conceptions against the real world through challenging questions, predictions, and experiments, knowing that we will be sacrificing breadth for the sake of depth? We suspect that these questions will be central in the coming decade. Moreover, further study is needed to find out more about the social aspects of learning, about how students use their conceptual understanding outside the classroom, and about how their experience grows into scientific models that they find satisfactory.

One thing is certain. We need to study more deeply the views held by children, to learn the purposes they serve, to learn their innate structures, and to learn how they are formed and used. Perhaps then we will be better able to understand role as teachers.

Putting Students In The Hot Seat

For the third day in a row in O'Brien's classroom, the children rushed to their experiments as soon as they arrived. The sweater, the sleeping bag, and the hat were unwrapped. Once again the thermometers uniformly read room temperature. O'Brien led the disappointed children to their journals. But after a few moments of discussion, she realized that her students had reached an impasse. Their old theory was clearly on the ropes, but they had no new theory with which to replace it. She decided to offer them a choice of two possible statements. "Choose statement A or statement B," she told them. The first stated that heat could come from almost anything, hats and sweaters included. In measuring such heat, statement A proclaimed, we are sometimes fooled because we're really measuring cold air that gets inside. This, of course, was what most children had believed at the outset. Statement B, of O'Brien's own devising, posed the alternative that heat comes mostly from the sun and our bodies and is trapped inside winter clothes that keep our body heat in and keep the cold air out.

"Write down what you believe," O'Brien told the class. "Then stand in this corner if you believe A and in that corner if you believe B. If you're not sure, stand here in front."

Pencils went to lips, and eyes studied the ceiling. Finally, after much thought, the statements were recorded in the journals. Students approached the chalkboard, ready to turn right or left. Katie turned left toward the B corner. Owen stood in the center for a moment, then followed Katie. Neil turned right and dung to his "hot hat" theory. Christian stood in the middle. One by one, the students took a stand. And when the cold gusts of approaching recess blasted through the class room, O'Brien counted noses. A few children had joined Neil. Stubborn, perhaps, but O'Brien had to admire the strength of their convictions. Christian and one other child stood undecided in the center, while the rest of the class stood proudly with Katie and Owen, convinced by their own testing that "warm clothes" aren't really warm and that the heat that seems to come from them actually comes from the warm bodies they envelop.

"How can we test this new theory?" O'Brien asked. Immediately, Neil said, "Put the thermometers in our hats when we're wearing them." And so the children went out to recess that day with an experiment under their hats. As Deb O'Brien relaxed during recess, she asked herself about the past three days. Had the children really changed their minds? Or had they simply been following the leader? Could they really change their ideas in the course of a few class periods? Would any of their activities help them pass the standardized science test coming up in May? O'Brien wasn't sure she could answer any of these questions affirmatively. But she had seen the faces of young scientists as they ran to their experiments, wrote about their findings, spoke out, thought, asked ques tions --- and that was enough for now.

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Unlike other academic areas, when it comes to learning science, children develop experience based preconceptions about the world and how it works before they even enter a classroom. These naive concepts can be useful in helping them develop in a complex world, but can ultimately result in incomplete or incorrect knowledge about the natural world. In order to correct and reshape these pre-developed conceptions about science, we must first identify where the misconceptions lie, then work with students Children will modify their experiments to accommodate their beliefs long before they will change their beliefs to fit the evidence. Teachers should stress relevance, prediction, and consistency when resolving discrepancies between beliefs and evidence. Includes 11 references. (MLH).Â Explains the difference between children's sensible reasoning and Piagetian conceptions of concrete reasoning. Children will modify their experiments to accommodate their beliefs long before they will change their beliefs to fit the evidence. Teachers should stress relevance, prediction, and consistency when resolving discrepancies between beliefs and evidence. Includes 11 references. (MLH). Teaching for Conceptual Change: Confronting Children's Thinking Phi Delta Kappan http://www.mdk12.org/instruction/success_mspap/general/projectbett er/ science/s-52-53.html. Teaching for Conceptual Change http://www.mdk12.org/practices/good_instruction/projectbetter/ science/s-52-53.html. Enhancing Learning Through Conceptual Change Teaching National Association for Research in Science Teaching http://www.educ.sfu.ca/narstsite/publications/research/concept.htm. REFERENCES. Chi, M. T. H., & Roscoe, R. D. (2002).