Decision Making in the Practical Domain: A Model of Practical Conceptual Change

ALLAN FELDMAN
School of Education, University of Massachusetts, Furcolo Hall, Box 33070, Amherst, MA 01003-3070, USA

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ABSTRACT: The work of science teachers can be viewed from a variety of perspectives. In this article, teaching is seen as an activity in which teachers deliberate in the practical domain to decide on actions and goals. In the first part of the article, it is argued that, because practical reasoning is similar to scientific reasoning, a model of practical conceptual change can be developed that is analogous to the conceptual change model. The following conditions for the modification of a practical theory or paradigm are described: Teachers must be discontent with a current practical theory. They must find that the new one makes sense and that it is beneficial to their practice. Finally, teachers must see that the understanding of their practice that arises from acceptance of the new practical theory is illuminating or enlightening. In the second part of the article, two case studies of teachers are examined using the model of practical conceptual change. One is a case of a novice teacher whose grading policy is based on highly resilient practical theories. The other is a cross-case analysis of two experienced science teachers, one of whom accepted a radically new curriculum and another who rejected it. The article concludes with implications for the use of the model. *Sci Ed* **84:**606–623, 2000.

INTRODUCTION

To teach is to shape the lives of others and is, therefore, both a moral and political activity. It is also a practical endeavor because teachers must make decisions about what to do and how to do it to improve their students' lives. If teachers are to foster the common good within an increasingly multicultural society, they must be able to make decisions that support equity, social justice, and human rights. The present study examines research on teacher education practices that can help develop practical wisdom (Feldman, 1997) in novice teachers, which will help them make decisions that lead to a more just society.

This article is part of my effort to answer the question, "How do we, as teacher educators, come to understand what it means to teach and to be a teacher?" In previous work, I have shown that we do so by viewing teaching from different perspectives, each with benefits and drawbacks, and each associated with a variety of forms of wisdom (Feldman, 1997).

Correspondence to: A. Feldman; e-mail: afeldman@educ.umass.edu
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In this article, I look at teaching from the *teacher reasoning perspective* and, from that perspective, I construct a way of understanding teachers and teaching that I call *practical conceptual change.*

One of the drawbacks of viewing teaching from this perspective is that it limits our view. The teacher reasoning perspective puts little emphasis on what teachers know and how they know it (teacher knowledge perspective) or on issues of equity and social justice (sociocultural perspective). It also limits the importance of the notion of teaching as a way of being, as seen in work by Berlak and Berlak (1981), Stengel (1996), and Feldman (1997). As a result, the teacher reasoning perspective and the metaphor of practical conceptual change do not provide us with a complete understanding of what it means to teach and to be a teacher. I recognize that to gain such an understanding would require a superposition of the views from all perspectives, but there is much that can be learned from a careful look from each viewpoint. My goal in this article is to demonstrate what we can learn about science teaching by examining it from the teacher reasoning perspective.

Because most events in the world of practice are similar to ones that have happened before, teachers develop practical theories, or rules-of-thumb, to help them with decision making. The development of practical theories is based on experience and is similar to the construction of what are called prior or naive conceptions or misconceptions in science instruction. In this article, I use the conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982) as a metaphor to construct a framework for understanding how and why teachers change their practical theories. In addition, I test the framework's usefulness and validity for understanding how teachers construct and change their practical theories.

THEORETICAL FRAMEWORK

Conceptual change theory burst on the science education scene in 1982 with the publication of "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change" (Posner et al., 1982). In that article, the authors presented a model for the learning of scientific concepts that drew primarily upon two theoretical frameworks: one from the history and sociology of science (Kuhn, 1970) and one from developmental psychology (Piaget, 1977). The conceptual change model (CCM) was built upon the remarkable resemblance to Kuhn's descriptions of the workings of normal science and how scientific revolutions come about to Piaget's descriptions of assimilation and accommodation of knowledge by learners. Simply put, the process of doing normal science that Kuhn typified as accretion of knowledge within a paradigm is similar to assimilation, the way that Piaget described how individuals acquire knowledge without changing their underlying conceptual framework. In the same way, the scientific processes that result in the development of new paradigms can be considered to be similar to the accommodation of new knowledge by an individual, which is dependent on change in the individual's conceptual framework.

Posner et al. (1982) suggested conditions for the accommodation of new concepts that are similar to Kuhn's conditions for the acceptance of a new scientific paradigm. The argument is a straightforward syllogism:

Major premise: Accommodation is similar to a paradigm shift.
Minor premise: There is a set of conditions that must be met for a paradigm to change.
Conclusion: Therefore, there is a set of conditions for the accommodation of concepts.

Whether or not this follows logically or whether the similarity between a theory of the construction of knowledge in Popper's World 3 (Popper, 1972) and the growth of understanding in World 2 is more or less than coincidence, the 1982 article can be identified as

the beginning of a new paradigm for research in science education that has spawned a vast number of studies (see, e.g., the bibliography assembled by R. Duit).

Criticisms of the CCM

It is important to note that the conceptual change model and its Piagetian basis have been criticized for its overly cognitive orientation (Pintrich, Marx, & Boyle, 1993) and its lack of attention paid to knowledge growth in social situations (O'Loughlin, 1992). Although its authors modified the CCM (Strike & Posner, 1992), it still remains a model of individual cognitive conceptual change.

The same could be said of the metaphor of practical conceptual change that I develop here. However, this is not the case because it is a metaphor for reasoning within the practical domain. As teachers reason about their work, they include in their deliberations social, cultural, moral, and political concerns that were missing from the original formulation of the CCM. Therefore, it must be responsive to the situations in which the practice is situated.

Teacher Education and the CCM

As a model for understanding learning, the CCM is a metaphor for the mental and social processes that result in new understanding. As a metaphor, it has recently been applied to the preservice education of science teachers. This has occurred primarily in two ways. One has been to provide novice science teachers with knowledge about instructional methods to help induce conceptual change in their students (e.g., Stofflett & Stoddard, 1994). The other has been to use conceptual change instructional methods to help novice teachers accept and understand constructivist educational philosophies (e.g., Northfield, 1992).

In this article, I extend the metaphor of the CCM further into teacher education. I do this by focusing on teaching from the teacher reasoning perspective, which lies within the practical domain (Feldman, 1997). The teacher reasoning perspective has a large and varied literature associated with it. The work of teacher educators and researchers of teaching has been heavily influenced by Schön's (1983) conception of the reflective practitioner and by related models of teacher reasoning such as Fenstermacher's (1986) practical arguments and Sanders and McCutcheon's (1986) practical theories. I draw upon that work later in this article.

The teacher reasoning perspective goes beyond the notion of expert teachers being those who are highly familiar with a knowledge base on teaching, to the idea that teaching is a moral activity. A teacher makes numerous choices each day (Clark & Lampert, 1986) that are decided based, in part, on some set of morals. That is because teaching is in itself a social and political activity and, therefore, entails the intervention of the teacher into students' intellectual and personal development (Tom, 1984).

The teacher reasoning perspective, while allowing that many of the problems that teachers face are technical in nature, acknowledges that most of the decisions teachers make can have some effect, good or bad, on the lives of their students. These decisions are made in response to practical problems—problems "about what to do . . . whose final solution is found only in doing something, in acting" (Gauthier, 1963, p. 1). The solutions to practical problems differ significantly from solutions to factual or technical problems. Factual questions have answers that are right—the correct solution to the problem—or wrong—not a solution. Practical problems are phrased in the form, "What should be done?" as contrasted with "What do you know?" or "How do you know it?" Once phrased in this form, practical problems can be seen to be normative, or ethical questions.

Origins of the Teacher Reasoning Perspective

The teacher reasoning perspective has as its basis Aristotelian ethics. In *Nichomachean Ethics* (Irwin, 1985), Aristotle distinguished among several different types of reasoning: *techne*, *episteme*, and *phronesis*, which correspond to some extent with what we think of as technical, scientific, and practical reasoning. While technical reasoning is concerned with production or design, and scientific reasoning is concerned with knowledge production, practical reasoning is a way in which a person attempts to make good decisions and to act on them. For example, John Elliott has defined practical reasoning as "a form of reflection concerned with translating universal[1] values into concrete forms of action in a particular situation" (1987, p. 162). It is a cognitive and social activity, a form of reflective deliberation that people use to decide what action to take, or which goal to choose, given the situation and the person's values (Carr & Kemmis, 1986). It is a process by which the one deliberating chooses an action to take to resolve a practical problem by taking into consideration, through reflection, the moral and ethical aspects, issues of equity and social justice, as well as, the context of the situation.

Practical Arguments and Practical Theories

In this section, I look at two ways of understanding practical reasoning: the practical argument, developed by Fenstermacher (1986); and the practical theory, described by Sanders and McCutcheon (1986). Fenstermacher suggested that the practical argument serve as a way for teachers and others to understand their actions and decisions (1986). The practical argument is an extended form of the practical syllogism. The idea of the practical syllogism as a parallel to the more familiar "logical" syllogism was introduced by Aristotle in *De Motu Animalium* (Nussbaum, 1978). In *De Motu Animalium*, the practical syllogism serves as an explanatory model for human activity. The practical syllogism, just as the logical syllogism, consists of a major premise, a minor premise, and a conclusion. The logical syllogism serves as a way to validate and explain the conclusion, which is new knowledge. Practical syllogisms have similar dual functions for their conclusions: actions or goals. They serve:

> . . . as a model of explanation generally, and, in the case of human rational agents, as a schema for the justification of action, [and] often also for conscious deliberation. (Nussbaum, 1978, p. 207)

Although the practical syllogism has the same form as the logical syllogism, they differ in several ways. First, the logical syllogism is used for validation while the practical syllogism serves to justify. The practical syllogism cannot validate its conclusion. If it were to validate, it would show that it is founded on truth or knowledge. The conclusion of the practical syllogism is an action (or goal) that is dependent on the beliefs and intentions of the actor and is neither true nor false. The practical syllogism rationalizes or explains the chosen action. In the scientific syllogism, the conclusion necessarily follows from the premises: if the premises are true, then the conclusion is true.

If the major and minor premises of the logical syllogism are assumed to be true, then a

[1] Elliot's use of the term "universal values" does not require the person engaging in practical reasoning to accept the existence of a single moral code that is independent of culture. However, the person who engages in phronesis must have an internalized set of values if practical reasoning is to occur. This is made explicit by Nussbaum (1986).

true conclusion follows from the two premises. The major premise of the practical syllogism is a statement that refers to a desire for some good that can be fulfilled through an action. The minor premise pertains to the circumstances in which the action will take place. It describes the restrictions and limitations on the possibilities of action that can be taken in order to fulfill the intention or desire of the major premise. The conclusion that follows is an action (or goal) that will fulfill the desire given the particularities of the minor premise (Wiggins, 1987). In *De Motu Animalium,* Aristotle gave several examples of simple practical syllogisms:

> . . . when you conceive that every man ought to walk and you yourself are a man, you immediately walk. . . . Again, I ought to create a good, and a house is a good, I immediately create a house. Again, I need a covering, and a cloak is a covering. I need a cloak. What I need I ought to make: I need a cloak, I ought to make a cloak. And the conclusion "I ought to make a cloak" is an action. (Nussbaum, 1978)

Countless examples of these practical syllogisms can be written that refer to educational problems. The generic form would be:

Major premise: I would like my students to attain a certain educational goal.
Minor premise: The context of my teaching situation is as follows . . . which restricts the actions that I can take in the following manner . . .
Conclusion: Therefore, I choose to take the following action . . .

What Fenstermacher did in the practical argument was to extend the practical syllogism by allowing for multiple minor premises to help incorporate the complexities and contingencies of teaching. While it should be clear that the practical argument is not a description of how teachers actually reason, Fenstermacher and colleagues demonstrated that it can serve as a model for analyzing teachers' actions and understanding their behaviors.

Sanders and McCutcheon examined the idea of practical theories in their study, "The Development of Practical Theories of Teachers" (1986). Practical theories are the conceptual structures and visions that help provide teachers with reasons for actions (Sanders & McCutcheon, 1986). They are rules-of-thumb based on experience and consisting of "a repertoire of practices, strategies, and ideas" (Sanders & McCutcheon, 1986, p. 50) that help teachers incorporate into their work their best practices and those of others (Nussbaum, 1986).

Practical theories have certain characteristics. First, they are indefinite. They have no specific limits and are not confined to a particular context because of the nature of practical problems. Since practical problems are context-bound, any practical theory must be mutable, indeterminate, and particular. The form of the practical theory does not govern its use: the context determines the utility of theory. Thus, a second characteristic of the practical theory is that the utility of practical theories is determined by the context. The particularities of the situation in which the practical theory can be applied act in a normative way to assess the correctness of the practical theory (Nussbaum, 1978). A third characteristic is that they need to be stated in a way that allows them to act as authorities against which the appropriateness of particular decisions can be assessed. When formulated in these ways, practical theories aid in moral learning, save time, and are resistant to the passion of the moment (Nussbaum, 1978).

Finally, practical theories arise from life histories and from ethical and moral lessons. These ethical and moral lessons are found in literature, religion, and the popular media (Nussbaum, 1995). Practical theories are shaped by life experience, professional experi-

ences, the stories of others, and reflection on personal experiences and the experiences of others. Any teacher, whether novice or experienced, enters the classroom with a set of practical theories that has arisen through these avenues and are changed over time either through practice-centered inquiry like action research or, more haphazardly, through experience.

Practical Paradigms

Practical theories arise from all aspects of experience. Student teachers as well as experienced teachers enter the classroom with a set of practical theories that derive from many influences, including the years spent in the classroom as students. As a result, practical theories can be difficult to change. For example, Zeichner and Liston (1987) found that, even though the teacher education program at the University of Wisconsin–Madison was developed and enacted around the idea of teachers as reflective practitioners, there was little change in the practical theories of the student teachers over the course of the year. The tenaciousness of some practical theories is due to the nature of practical theories themselves. Because they are not isomorphic with the outside world, there is a loose fit between these theories and practice. They are modified by practitioners to fit particular contexts in the field as they gain experience. As a result, it is possible that a practical theory could go through multiple modifications, resulting in a new rule-of-thumb. However, the more tenacious practical theories resist significant modifications. Some examples of extremely resistant practical theories are: "Do unto others as you would have them do unto you," "Do not kill other people," and "Parents should care for their children." Somewhat less tenacious are: "Students must wait their turns" and "Only students who raise their hands will be recognized."

When the actions suggested by these practical theories do not result in reaching the desired goal, the person applying them might choose a different action instead of modifying the practical theory. It is possible that the practical theory is so durable that the person will unsuccessfully attempt to reach the goal numerous times by applying the no longer appropriate practical theory. Even when reflecting on the situation, the person could overlook the inapplicability of the practical theory and continue to choose actions based on that practical theory. When viewed in this way, these more tenacious practical theories bring to mind the characteristics of paradigms as described by Kuhn in *The Structure of Scientific Revolutions* (1970). I, therefore, refer to these sets of somewhat more permanent practical theories as practical paradigms.

Practical paradigms are analogous to the scientific paradigm described by Kuhn in that a community shares them. In some ways, they become the ethos of that community into which newcomers are indoctrinated. For example, Tabachnick (1980) found that, even though intern-teachers':

> . . . early experiences in schools were shockingly disillusioning . . . after a year's experiences, interns seem to be creating a reality that replaces, or at least suppresses, their early disillusionment. They find reasons to accept teaching behavior previously thought to be ineffective or inappropriate. (p. 133)

The year's experience has acted to inculcate the interns into the world view of schooling; a world view that includes numerous practical theories and resistant practical paradigms.

Practical paradigms are also analogous to Kuhn's paradigms in that they are in a sense equivalent to "concrete puzzle-solutions which . . . can replace explicit rules as a basis for the solution of the remaining puzzles . . ." (Kuhn, 1970, p. 175). The practical par-

adigm serves as a template for problem solving into which the particularities of the situation are molded. When working within a practical paradigm, the practitioner selectively identifies those aspects of the context that allow him or her to use that practical paradigm even though it is inappropriate and should either be modified significantly or discarded completely.

To summarize, practical paradigms are quite tenacious; teachers do not easily modify them. They are shared by a community and are supported by other teachers, students, parents, and administrators. They may be applied in situations for which they are inappropriate, and their existence can cause teachers to be extremely selective in their observations of the situation and analyses of the problems.

Teachers create hypotheses based on experiences, test them, and accept or reject them (Schön, 1983). Some are modified and elaborated for new situations and circumstances, and others are rejected and replaced with different practical theories. Furthermore, as with the development of new scientific theories, the development of practical theories appears to be analogous to Piagetian assimilation and accommodation. This leads to the following question, "Is there a set of conditions, similar to those for the accommodation of a scientific theory (Posner et al., 1982), that can help us to understand why some practical theories are tenacious and act like Kuhn's paradigms, while others are put aside by better practical theories?"

PRACTICAL CONCEPTUAL CHANGE MODEL

In the preceding section, I defined practical reasoning and described some of the ways that one can draw parallels between practical and scientific reasoning. When that parallel is extended to Kuhn's work on scientific revolutions, it appears that we can speak of practical theories—in the form of maxims, commandments, or common sense—that are generally accepted and resilient to change, and think of them as practical paradigms (Feldman, 1992).

Conditions for the Accommodation of a Practical Theory

I now draw an additional parallel. Similar to the way that the originators of the conceptual change model noted the resemblance between Kuhn and Piaget's theories, I do the same for practical theories/paradigms and Piagetian learning theories and ask the question, "What are the conditions for practical conceptual change?"

I suggest that the following can be the first step in identifying those conditions that will lead a teacher to go through a sort of "paradigm shift" that leads to the accommodation of a new practical theory:

First, in the same way that a learner must become dissatisfied with her understanding, a teacher may become *discontented* with a practical theory because she recognizes it as ineffective, unsuccessful or because it leads to dissonance or dilemmas in practice. It is important to note that often dissonance or dilemmas are due to the teacher's perception that something is morally, ethically, or politically wrong in her practice.

Posner et al. (1982) argued that for a learner to accommodate a new conception, she must find it intelligible. I would like to suggest that a new practical theory must appear *sensible* for it to be accommodated by the teacher. By this I mean that it should be comprehensible and reasonable in particular situations and consonant with the teachers technical and normative goals so that the actions or goals that emerge from it "make sense."

The conceptual change model also claims that a new conception must be plausible for it to be accommodated. For a new conception to be plausible, it must "at least appear to

have the capacity to solve the problems generated by its predecessors" (p. 256). The practical analog of plausibility is *beneficialness.* That is, the new practical theory must lead to better (in a normative sense) actions or goals for it to be accommodated.

Finally, Posner and colleagues added that for the new conception to be accommodated, the learner needs to find it fruitful. By this they mean that the concept "should have the potential to be extended, to open up new areas of inquiry" (p. 258). I suggest here that for a new practical theory to be accepted that transcends the current "paradigm," it should be *illuminating* or *enlightening.* I use illuminate and enlighten in the sense of providing new understanding of practice situations. For the teachers, this new understanding, which can arise from the particularities of one situation, can be used to modify the new practical theory to the particularities of different situations.

This is the crux of my argument: Teachers make numerous decisions each day that are within the practical domain. Their decision making can be modeled using the ideas of the practical syllogism, argument, and theories. If we want teachers to change their practice, which is what is called for in the current reform efforts, then they must accept new practical theories that are consonant with the reforms. There is a great deal of empirical evidence that demonstrates that teachers' practice is not easily transformed. Using the conceptual change model as a metaphor, I have suggested that teachers may accept new practical theories, consonant with reform, if they are *discontent* with their old practical theories and they find the new ones *sensible, beneficial,* and *enlightening.*

METHODS OF THE STUDY

This study consists of two distinct parts. The first is the analytical review of the literature on conceptual change theory in science education and science teacher education and of the literature on practical reasoning in teaching. Through a synthesis of the two sets of literature, I develop a practical reasoning analog of the conceptual change theory. In the second part of the study, I revisit data that I collected in two previous studies (Feldman, 1992, 1997). In one, I used clinical and in-depth interviewing techniques (Seidman, 1991) to probe the practical theories of two novice teachers. The other was a comparative case study of two experienced teachers involved in a curriculum development effort. That study was embedded in an evaluation study of the curriculum development project. For the majority of the evaluation, I used ethnographic methods (including observations, audiotaping, and videotaping of classes and workshops); interviews of teachers, focus groups with students, and a series of survey instruments on teachers' opinions of the curriculum; students' attitudes towards physics; concept webs; and a card-sorting task with which to probe teachers' conceptions of the discipline of physics; and interviews of the development team. I coded qualitative data using preconceived categories based on the development team's goals for the curriculum, and emergent categories. Survey data were analyzed using EXCEL.

I reanalyzed the data from these studies to see if I could identify instances of resilient practical theories that are similar to the "misconceptions" of science learning. I used both predetermined and emergent coding categories to analyze the data. The predetermined categories are the conditions for practical conceptual change that I identified in the first part of this article. I determined the emergent categories inductively from the data, following the methods of the development of grounded theory (Strauss & Corbin, 1990).

In the next two sections, I report on the results of the reanalysis. The first, which relies on one of the case studies from the 1992 study, demonstrates the way that the concepts of practical theories and paradigms can be used to understand the actions and choices of a novice science teacher. In the following section, I use the conditions for practical concep-

tual change as a way to understand the actions of the two experienced teachers in the 1997 evaluation study.

THE GRADING POLICY AS PRACTICAL PARADIGM

In this section, I review the case of a novice teacher who appeared to have a highly resilient practical theory that acted like a practical paradigm (Feldman, 1992).

Frank was an intern teacher in a college preparatory parochial school. His assignment was two chemistry classes, each with approximately 30 students. About 6 weeks into the term, he sent "deficiency notices" home to parents that stated that their children could expect a grade of D or F in his class. The students were concerned about the low grades, especially during their junior year, because of the effect that might have on their college plans. Guidance counselors responded to the students' concerns, then the department chair, who was Frank's resident supervisor, then the vice principal, and finally the principal of the school. Just before the first quarter's grades were to be sent home to the parents, Frank was dismissed from his internship position by the principal for refusing to follow the school's grading policy.

During this time, Frank was using a practical theory that guided his grading policy. To Frank:

> . . . a grade is supposed to be what students earn . . . [and] as far as what is an A and what is a B and a C, I think that came from my upbringing and background: that an A is outstanding, that a B is very good, that a C is average.

In other words, he was operating under a practical theory that students need to perform at a certain level in order to get a certain grade. This theory was supported by his beliefs about teaching and learning that constituted a sort of "conceptual ecology" in the practical domain. First, it was clear to him what levels of performance and what benchmarks constituted these different grades. Second, as he told me in an interview, he had no doubts about what and how he was teaching, which was "very much by the book," and that he did not want to change the level at which he was teaching to make it into a "rinky dink class." While he told me that students' grades depended upon the students' efforts and how effective the teacher is, he had strong beliefs about the abilities of these students and about the ethos of the school:

> . . . the students were generally not above-average students and that the school was very much de-emphasizing academics. [It] was a sports-oriented school, and a social-party-oriented school, and . . . that it was not an academically oriented school.

Frank's practical theory appeared to be highly resistant to change. He was under a great deal of pressure to change what he was doing so that his students would get higher grades. In addition, he was receiving advice from the principal, vice principal, science department chair, other teachers, guidance counselors, students, and his intern-teaching supervisor from the university. However, from my interviews with him, I learned that he listened to this advice selectively, accepting that which supported his practical theory and rejecting that which disagreed (Feldman, 1992). Frank stuck to his guns and did not modify his practical theory. He either ignored suggestions that would have had him change it or denigrated the people who made those suggestions.

It might appear that what we have in Frank is pure stubbornness, that he dug in his heels and would not budge from his position. But, in a sense, to call someone stubborn is

to describe his actions, albeit in a normative fashion, rather than explain them. In the same way, we could explain Frank's behavior by saying that he was acting on his convictions. But a conviction, as can be seen in its dictionary definition—"a strong persuasion or belief" (Merriam-Webster, 1994)—is an example of a practical theory. The idea that Frank was using a practical theory to guide his actions and that his practical theory has characteristics similar to a scientific paradigm can help us understand why he was stubborn or why he was stuck to his convictions.

It appears that the practical theory that was Frank's grading policy was a practical paradigm. It was tenacious to the utmost: Frank stood by it even though it cost him his internship position. To Frank, it was immutable. His practical theory had been defined throughout his life and could not be changed. He had a community, albeit small, that shared it. He applied it in a situation where it was clearly inappropriate, and it caused him to be blind and deaf to all who sought to help him change his practical theory.

CURRICULUM DECISION MAKING AND PRACTICAL CONCEPTUAL CHANGE

I now turn to the cases of two experienced teachers. The data that I reanalyzed came from the evaluation study of the Minds-On Physics (MOP) curriculum development project. MOP was developed at the University of Massachusetts, Amherst with funds from the National Science Foundation (NSF). The development team consisted of four physicists with a record of research in physics education. The goal of MOP is to engender expertlike problem-solving abilities in students by providing them with deep conceptual understanding. MOP is based on a constructivist philosophy, takes a "less-is-more" approach, and urges that students work in collaborative groups as their teacher guides them. In the remainder of this section, I use the practical conceptual change model to understand why these two men made significantly different decisions about the implementation of MOP.

Bob Jones and Dave Smith were both in their twenty-ninth year of teaching. Each teaches in an old "mill town" in New England. The two towns have similar diverse populations. The majority of the students come from white working-class families. There are growing numbers of minority students (Latino, Southeast Asian, and African American) and a small middle-class population. Because multiple levels of physics are taught in each school, both men saw their honors classes as most appropriate for MOP. When observed, it was clear that honors students in both schools were quite capable of working in the style of MOP—collaborative group work with the teacher acting as facilitator and guide. Both men see themselves as physics teachers, having had that as their primary teaching responsibility for many years. Jones has an undergraduate degree in chemistry from a well-known engineering college. Smith was an undergraduate at the state university where he double-majored in physics and education. Both men have master's degrees: Jones has a master's degree in education and Smith has a master's degree in computer science.

Both men also volunteered to test the implementation of Minds-On Physics. They attended a 1-wk workshop on constructivism, "less-is-more" philosophy and how to teach using the MOP materials. At the end of the workshop, both were skeptical about the use of MOP. Despite these similarities, it was evident by mid-October that they were in very different places with regard to use of MOP. While Jones' classes seemed to be immersed in the materials, doing three to five MOP activities per week, Smith's classes had used a total of five.

This section demonstrates how the idea of practical conceptual change and the conditions for practical conceptual change can help to account for the differences that were seen in the implementation of the curriculum. I show that Mr. Jones went through a type of

paradigm shift that I call practical conceptual change and radically altered his practice, while Mr. Smith sought ways to incorporate MOP into his existing teaching practices.

Discontent

Both Jones and Smith decided to become part of the MOP project and to use the MOP activities in their teaching of physics. For Smith, this occurred after he attended a 1-day workshop on constructivist teaching in physics given by two of the MOP Principal Investigators (PIs). Jones decided to join the project after I talked with him about it and he had the opportunity to talk with one of the PIs. Why did Smith and Jones decide to become a part of the MOP project?

Jones told me that he had been looking for new ways to teach physics. Although by many measures, he was successful in his teaching—his students did well on standardized tests, they were accepted at competitive colleges, and they came back to tell him that he had prepared them well for their college study of physics—he was not satisfied with his teaching methods:

> I'd been looking for a long time for some way to get kids to interact during the class period rather than just sit because the lecture wasn't working. You get those kids who pay a lot of attention but you get those kids who you lose . . . I couldn't think of an alternative approach.[2]

Jones had taught in a traditional didactic style for his entire career but was concerned that there were many of his students who had difficulties with physics that were not being addressed. He saw MOP as a way to make physics more fun for his students and to help him move from teaching that stressed memorization to focusing on the importance of underlying concepts.

It is not clear that Smith had the same level of discontent. He did want to change some aspects of his teaching, and the constructivist approach that he was exposed to in the 1-wk workshop was appealing. However, he had some hesitations about constructivism, especially if it meant "discovery learning," and he was not at all sure that there was anything significantly wrong with his practice. Instead, he thought of MOP as a way to learn about new ways of teaching that he could incorporate into his existing style.

Making Sense

When Jones left the summer workshop at the end of the first week of August, he had planned to begin the school year in his usual manner. That meant that he would begin his physics classes with an introductory 2-wk unit on measurement, the metric system, and analytical techniques. However, by Labor Day, he had decided to use the MOP curriculum exclusively. When I asked him why he had made that decision, he gave several reasons. First, when he looked at the materials without reading them carefully, just shuffling through them, he saw that they looked a lot like what he was already doing:

> The emphasis is on graphs, graphing techniques, interpreting the graphs in physical ways, using graphs to solve problems. My whole approach to teaching physics has been right from the graph, tying equations to graphs, having kids draw a graph for every single equation. . . . That caught my eye right away. The first thing that you do with the MOP activities is getting into graphing. I liked the looks of that.

[2] All of the teachers' quotations are from interviews conducted as part of the MOP evaluation.

Second, again from his casual inspection of the materials, he suspected that MOP was rigorous physics:

> When I read the problems at the end of the sections, they were hard physics. It wasn't a watered-down kind of thing. I knew that if they were going to ask those kinds of questions at the end of each block, they would need to provide really solid physics in the middle somehow.

Third, MOP was also consonant with the distinction that he made between teaching students methods for problem solving and teaching for conceptual understanding. He saw that the MOP activities developed conceptual understanding to prepare students to solve problems. Fourth, he saw this being consonant with his interest in preparing students for college. Finally, Jones believed that the only fair way to try out a new curriculum is to use it as intended.

What Jones had done was to look carefully at the MOP materials to see whether it made sense to him and for his students. He saw the emphasis on graphs and graphing as being in line with his conception of teaching physics. He also believed that high school physics should take a rigorous approach to the discipline. His inspection of the materials convinced him of that, and he had been impressed by the physics knowledge displayed by the curriculum development team, each of whom holds a doctoral degree in physics. Finally, he decided to use the curriculum in the manner intended by the development team because he thought that was the only way to give it a fair test. What this suggests is that Jones had determined that the curriculum made sense in his situation and that it was a sensible decision for him to try it out in his class.

It is important for me to point out that there was at least one aspect of the MOP curriculum that concerned him: the "less-is-more" approach with its major emphasis on mechanics. In one of my interviews, we spoke of this and, in doing so, he convinced himself that the MOP approach was sensible:

> I know that it doesn't matter what I'm teaching as long as the students are thinking. It doesn't matter. The only thing that matters is that they are thinking and are engaged in physics, actively attacking the ideas. If I can keep them doing that, they will be okay in college physics.

Jones believes that it is important for students to *truly understand* physics. Because he knows that it takes a large amount of time to uncover misconceptions and induce conceptual change, he is willing to limit the number of topics covered in his honors physics class, and therefore it makes sense to him to use the MOP curriculum.

While Jones found the MOP curriculum and approach sensible for his situation, this did not seem to be the case for Smith. In general, he did not see the goals of MOP as being consonant with his goals for high school physics. He did see MOP as a method that would successfully develop deep conceptual understanding of physics. However, he felt that goal was primarily for students who would be continuing with their study of physics in college, while he saw that "two out of three kids are not physics people." He sees his course as a survey of physics and as a way to expose students to different topics as a way to interest them in science. In other words, he sees the MOP curriculum as the type of course that makes sense for those students who have already expressed an interest in studying science, while most of his students were not bound for careers in science.

Given his goals for his students, Smith did not think that the MOP "less-is-more" philosophy made sense:

> I am not comfortable with this "less-is-more" philosophy. I do not know how much less is acceptable. That is a major problem for me. I may be losing on both ends [problem-solving skills and content coverage]. I'm not sure that my role is to prepare students for college physics. This is a survey class . . . I need to catch the students' attention. . . . How many of my students won't go into science in college because they haven't had more experience in high school?

It is important to note that Smith did not simply reject MOP because of the dissonance in goals. He weighed the potential benefits of the program against what he was already doing as an experienced physics teacher. He saw that the MOP activities could engender deep conceptual understanding of physics and that some of the techniques used in MOP—such as the use of multiple representations for problem solving and an emphasis on free-body diagrams—were a welcome addition to his honors and AP physics courses. Because Smith did not believe that a full immersion in MOP made sense for his students, he tried to use the curriculum on a piecemeal basis. He found that did not work well because each activity relied on other activities for cognitive coherence. In essence, what he discovered was that the MOP activities could not be used in that way, that they just were not flexible enough for it to make sense for him to use it in his classes.

Beneficialness

As might be expected, Jones found the use of MOP to be highly beneficial to him and his students. He found the MOP approach superior to lecturing and that it is:

> . . . more fun for the students. They like to work with one another, talking with other kids in the group. It makes them think differently, to look more deeply into things . . . these kids are never asleep, never daydreaming, or looking out the window.

He found the use of MOP to be an effective way to get students to change their minds about physics concepts:

> You can't tell people the right answers and get them to change their minds . . . You can't force people to change their minds. That is why lecture is a terrible way to teach.

Jones believes that the primary purpose of his honors physics class is to get his students ready for college:

> My primary goal is get [my students] ready for college, and that doesnt just mean physics. In fact, what I say, my actual line is, "I want to get your mental set ready for college, for a college environment. If I can teach you physics too, then that's an extra."

Jones found that MOP was consonant with his desire for a method of teaching physics that accomplished his goals of teaching conceptual understanding, problem solving, and preparing students for college. He saw MOP as a way to respond to all three goals and that it is:

> fun . . . I really enjoy it . . . I found out that I didn't know as much physics as I thought I did . . . and that I always relied too much on memorizing ways to solve certain kinds of problems rather than thinking about the underlying concepts.

In fact, Jones felt that all students would benefit from the MOP approach and has begun to develop MOP-style materials for his grade 9 general science classes.

As might be expected, Smith found little benefit in the use of the MOP materials or methods. Again, as with Jones, the question of whether it is beneficial or not has to do with how well Smith sees MOP helping to meet his goals. He is not sure that the development of deep conceptual understanding is the appropriate goal for high school physics if it means sacrificing content coverage, especially if he has no guarantee that these instructional methods will prepare his students as well when it comes to problem-solving skills. He believes that it is a disservice to students not to provide them with experiences in a wide variety of topics in physics. He also believes that to spend most of the year on mechanics, which MOP appears to require, would mean giving up a lot. For many of his students, this is the only physics course that they would ever take. To not cover more topics would deny them the opportunity to experience, for example, electricity and magnetism, light, sound, or thermodynamics. In addition, he feels that these topics are often what get students excited about science. By not including them in the high school course, he feels he could possibly be doing harm by preventing students from seeing what the study of physics could mean for them.

Again, I must reiterate that Smith's beliefs are not quite this simple. He does believe that it is important to develop deep conceptual understanding of physics concepts, but not if it conflicts with his goals of producing a scientifically literate populace and of "turning on" students to science. He was concerned that MOP was having the opposite effect because he saw his students' frustration and disenchantment with the MOP activities. So, Smith sees a limited benefit of MOP—increased conceptual understanding for those students who would continue with the study of physics—and possible harm to the others, who make up more than two thirds of his students.

Illumination and Enlightenment

While the "less-is-more" approach and the use of collaborative group work with the teacher as facilitator are important components of the MOP approach, its basis in constructivist theory may have the greatest potential for illumination or enlightenment. As it turns out, Jones' and Smith's level of acceptance of constructivism paralleled their acceptance or rejection of MOP.

In each of the three interviews that I did with Jones and Smith, I asked them the following two questions:

- Are you familiar with the term *constructivism*? If so, what does it mean to you?
- Do you consider yourself a constructivist teacher? If so, give an example of what a visitor to your class might see that is an example of constructivism.

In interview I, Jones basically said that he had no idea what constructivism is. By the second interview, Jones had a definition of constructivism that was in-line with that of the development team. He referred to uncovering prior conceptions and then using instructional methods to change students' conceptions. By the final interview, it appeared that Jones not only "knew" what constructivism was, but had internalized his own understanding of it, and saw his use of MOP as a way to operationalize his belief in a constructivist model of learning.

During the first interview, Smith indicated that his understanding of constructivism was that it was equivalent to some sort of discovery learning model in which students discover for themselves the laws of physics. By the second interview, his conception of construc-

tivism had begun to change. Even though constructivism still left "a bad taste in his mouth," he was aware that it had something to do with students constructing their own understandings of physics concepts. In my final interview with Jones, he no longer talked about it in a negative way. He referred again to discovery learning, but now to say that is not what constructivism is. In addition, he talked about working through problems, putting pieces together, and students making sense out of information. Even more telling is his answer to the second question. In the first interview, he told me that he did not like the term constructivism. In the third interview, he told me that he hoped that all teachers considered themselves constructivist teachers.

From this, it can be seen that, for both Jones and Smith, their knowledge of constructivism and what constitutes constructivist practice grew through the year. It appears that, over the course of the year, this was an enlightening experience for Jones. Constructivism was a way of understanding what made sense about MOP and why he thought it was beneficial. For Smith, there does not appear to be the same sort of synergy. While he went from a disdain of constructivism to embracing it, he did not see that a constructivist educational philosophy necessarily leads to an acceptance of what some call constructivist pedagogy, such as "less-is-more" curricula, collaborative group work, and writing across the curriculum.

Practical Conceptual Change

In this section, I have used interview and observation data to determine whether the rubrics of discontent, sensibility, beneficialness, and enlightenment can be used to understand why these two teachers had such different responses to the MOP curriculum. Before I assess the usefulness of the construct of a practical conceptual change theory, I point to some evidence suggesting that Jones did go through some type of "paradigm shift," while Smith sought to assimilate MOP into his existing way of teaching physics.

For Jones, it is clear that MOP had become his curriculum. The MOP material and approach were central to his teaching, and the vast majority of class time was spent with it. He completed all the activities that the development team had assembled, asked for more, and used them in his classes. Jones is fully committed to the use of MOP materials. He told me that in the next year he expected to be teaching honors and Advanced Placement (AP) physics, and general science, and that he would again use MOP straight through, activity by activity, with the honors physics. For his AP course, which focuses on mechanics and electricity and magnetism (E & M), he said he would use selected MOP activities to limit the time spent on mechanics so that he can devote significant amount of time to prepare his students for the E & M portion of the AP exam. And, as I noted before, he has begun to prepare MOP-like activities for his general science class.

This suggests that he has gone through a significant change in the curriculum materials and methods that he uses. But in addition, he supplied me with evidence that his way of thinking about teaching physics had also changed:

> My old idea of teaching was tell students stuff. My new approach is listening to them and guiding them—modifying their thinking rather than telling them. I find it hard to do that. Every once in awhile I find myself in front of the blackboard with a piece of chalk in my hand, and I say, "Whoa—I don't want to do that." The old teacher I was had chalk in hand all the time. Now I rarely do. If something goes on the blackboard, the kids do it.

And probably even more telling, "I will never lecture again in my life."

Smith sought ways to add MOP to what he was already doing. He told me that he went

through a period of what he called "soul searching" as he, and his fellow physics teacher, tried to negotiate a curriculum that included MOP and met their goals. This turned out to be quite difficult for him to do because of the conflict between the need to expose students to a wide variety of physics topics and the need to focus on only a few if deep conceptual understanding is to be attained. One of the ways that he dealt with this dilemma was to acknowledge that physics can be a vehicle for teaching problem solving and critical thinking, but that he sees it being a shared responsibility of all the teachers in the school:

> Should I have the responsibility of being the only person at [my high school] to get kids to think? There are 4 years of opportunity for that, and I have other things to do. Jones was saying that he was willing to write off a lot of physics to get kids to think clearly. I'm not sure I'm the only one who is responsible for doing this for kids.

Jones had hoped that by incorporating MOP activities into his survey of physics, he would be able to "get [students] to see things in ways they haven't before." Unfortunately, this did not work. He found that one activity by itself would not have the effect that he wanted:

> One [activity] will result in a marginal change, you can't then go off and do something else. You need to have the discipline to do 8–10 [activities] for each concept. I didn't have that discipline.

He was disappointed with MOP because it was not flexible enough for him to incorporate into the existing curriculum that he has negotiated with his students in his community over the years. And, because he could not incorporate it into his "paradigm," he eventually rejected it.

DISCUSSION AND IMPLICATIONS

There are several findings that have come out of this study. First, I developed analogs in the practical domain to the conditions needed for conceptual change. For example, if a teacher finds that a resilient practical theory that she holds becomes ineffective or unsuccessful, or that it leads to dissonance or dilemmas in practice, she may become *discontented* with it. For her to take up a different practical theory, she needs to find it *sensible*; that is, it should be comprehensible and reasonable in particular situations. It also should be at least as *beneficial* as other practical theories that may seem sensible in the same situation. Finally, the application of a new practical theory should be *illuminating* or *enlightening*—as a result of applying it in the situation, the teacher should now understand her practice in ways that were not available to her before.

Second, an analysis of the data from the previous studies indicates that novice teachers can maintain resilient practical theories that are resistant to change even though it leads them to act in ways that appear unfair, arbitrary, or even cruel. It also appears that supervision and reflection can result in a process similar to Piagetian assimilation in which the teachers continue to use the same practical theory but adjust their understanding of their educational situations so that the practical theory continues to make sense and is of benefit to them and at least some of their students, without, however, addressing the issues that led to discontent in the first place. From this, it appears that clinical methods similar to those used successfully to promote conceptual change in science may not be effective in the practical domain. Vásquez-Levy (1993) had mixed results with them, and my previous attempts to evoke changes in practical theories through probing interviews (Feldman, 1992) and dilemma analysis (Feldman, 1990) were not successful.

Third, the conditions for practical conceptual change can be used to understand why teachers decide to act in certain ways. We saw in the cases of Jones and Smith that discontent alone does not necessarily lead to the accommodation of a new practical theory. Jones found the constructivist theory and methods of MOP to make sense, to be beneficial, and to enlighten his understanding of physics teaching and learning. Smith, however, felt that MOP did not make sense and was not beneficial enough given the goals that he had for his students. Therefore, he chose not to accept a new practical theory that would lead to a major shift in curriculum and pedagogy. This was the case even though he was discontent enough with his current practice to seek new ways of teaching and eventually accepted constructivism.

This, then, leads to the question of implications for teacher education and educational reform. It appears that many novice teachers are like Smith—one of the reasons that they give for wanting to become science teachers is that they have the desire to help students get excited about science and to provide them with experiences that engender conceptual understanding and problem-solving abilities. However, when observed in their first years of teaching, they are often seen to be using the same didactic methods that they earlier claimed "turns kids off." Clearly discontent with aspects of their own education in science, and exposure to constructivism in methods classes may not be enough to induce practical paradigm shifts. The practical conceptual change metaphor suggests that teachers need to be discontent, not only because their goals are not being met, but to also be discontent with their goals. They could then engage in practical reasoning about their goals and change them in a way that enables them to see that new ways of teaching make sense and are beneficial to their students and to them.

There is some evidence that, like Frank's grading policy, teachers' goals are highly resistant to change and are constrained by the structures of schooling, both "real" and mythical (Tobin & McRobbie, 1996). A possible way to encourage change is to help teachers become part of communities of practitioners. My analysis of novice teachers engaged in collaborative action research suggests that teachers' ongoing interaction with nonevaluative "critical friends" or participation in collaborative inquiry with groups of teachers engaged in sustained conversation (Hollingsworth, 1994) may provide the conditions for teachers to change their "practical theories." In other words, the promotion of democratic communities of teachers in which long and serious conversations (Feldman, 1999) can take place could lead to the types of practical conceptual changes that promote increasing equity and social justice.

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