Implementing inquiry-based instruction in the science classroom: A new model for solving the improvement-of-practice problem

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Getting student teachers and traditional in-service teachers to regularly implement inquiry-oriented pedagogical practices in their science classrooms is more difficult than it appears. The general thinking among many science teacher educators tends to be that teacher candidates and traditional in-service teachers who learn how to conduct scientific inquiry will, in fact, teach science using an inquiry approach. Unfortunately, experience has shown that merely learning about scientific inquiry in methods courses and professional development workshops does not automatically translate to implementation of inquiry-based instruction. A number of important and neglected external factors influence whether or not and to what extent inquiry is implemented in the classroom. Unless these impediments are confronted and resolved, it is highly unlikely that even teachers who possess a good understanding of science inquiry will regularly implement inquiry-based instruction in their classrooms.

One of the leading goals of the science education reform movement in the United States is getting teachers to effectively and regularly employ inquiry-oriented pedagogical practices in science instruction (AAAS, 1990; NRC, 1996, 2000a; NSTA, 2003). Unfortunately, even after years of reform efforts, widespread progress has not been made in this area. If the science education reform movement is to make significant improvements in the way science is taught in schools, a better understanding of the relationship between the way teachers are educated and how they perform in the classroom must be had. How American school students learn science will depend strongly upon adequate teacher preparation and professional development that is based on a knowledge of the relationship between teacher understanding of scientific inquiry and the social context of teaching. Teacher candidate preparation and professional development for traditional in-service teachers must provide instructors with the ability and disposition to teach science via inquiry, as well as a means for dealing effectively with confounding factors such as personal teaching concerns, concerns about students, instructional and curricular concerns, and strongly-held didactic teaching philosophies. Such factors can at times be more influential than any intrinsic beliefs developed from a formal education (Young, 1991). It is the author's contention that failure of teacher preparation models to take into account the social context of teaching has, to date, left the science education reform movement languishing. A new model is desperately needed to help solve the long-standing improvement-of-practice problem.

The Improvement-of-Practice Problem

For more than a century there have been repeated calls to improve the procedures used in the preparation of science teachers so that they would more effectively provide students with experiential learning. To this end John Dewey (1904) noted with great concern that there was inadequate consideration of the proper relationship between theory and practice as far as the preparation of teachers was concerned. He expressed his concern that too much time and effort were being spent on "methods," and far too little expended on the theory that might guide practice in a more enlightened fashion. Dewey later (1916, 1938) repeated his call for reform. His pleas for changes in teacher preparation, however, fell on deaf ears. Teachers graduating from colleges and universities continued to teach using expository methods. For many science teachers today, didactic teaching remains the status quo despite growing evidence that "teaching by telling" is not highly effective in inculcating the content knowledge and process skills that are part and parcel of good science instruction (Costenson & Lawson, 1986; McDermott, 1993; NRC, 2000a, 2000b, 2005).

Shortly after the USSR launched Sputnik in 1957, broad-based work was begun in the United States to change the practice of science teachers and thereby improve the scientific literacy of American students. Up to that time the practice of many (if not most) teachers concentrated on imparting content knowledge. Pedagogy often consisted of drill and practice, and assessment focused on fact-laden tests. Under the sponsorship of the National Academy of Sciences, thirty-four psychologists and research scientists met at Woods Hole, Massachusetts, in September 1959, "to examine the fundamental processes involved in imparting to young students a sense of the substance and method of science" (Dow, 1991, p. 33). Jerome Bruner, a psychologist who headed the ten-day conference, strongly promoted conceptual learning and de-emphasized rote memorization. All the attendees appeared to agree that there should be a greater emphasis on inquiry practices, thereby including a spectrum of cognitive approaches – logic, intuition, and creativity. Other topics of discussion at the meeting included the evolving stage theory of cognition, child growth and development, and pedagogical strategies for promoting the "new science" following insights of psychologists Kurt Lewin and Jean Piaget. The discussion revolved around such questions as intellectual ability at various developmental levels, and what implications this might have for pedagogy. One major problem overlooked by the reformers was consideration to create an effective implementation model. Their model did not include such things as personal, social, and political factors that could support or impede progress toward the goal of revised classroom practice.

Failing to see the possible problems associated with implementation, Jerrold Zacharias, a physicist present at the Woods Hole meeting and now chair of the President's Science Advisory Committee, plunged blindly ahead to reform public school science in America. From 1962 through 1963 he hosted a series of meetings at MIT's Endicott House to hear the thoughts of educational theorists and practitioners. Zacharias was an outspoken critic of those who begged to differ with his views on educational practice, "and some of the nation's best-known educators left those meetings shaken by the encounter" (Dow, 1991, p. 41). There were many academicians to whom Zacharias listened, but most of these were university science faculty with little knowledge of what was happening in the nation's elementary and secondary schools. This latter group agreed among themselves that the dissemination of "predigested" summary information was intellectually and pedagogically wrong, that education of youth should consist of students taking a critical look at evidence in a detached manner, and drawing conclusions of their own. Knowing how to employ facts, concepts, and relationships was just as important as knowing them. According to the reformers, students should draw their own conclusions from evidence, much like a scientist working with data. Based upon this and similar efforts, large-scale curriculum development projects such as PSSC Physics, BSCS Biology, and CHEM Study were initiated. Years later, Dow would carefully document how deficiencies in planning and implementation, a lack of concern for suitable teacher preparation, and even a regard for social and school issues, resulted in the overall failure of the 1960s science education reform movement. These projects had run their course by the mid-1970s and the status quo of teaching using traditional expository methods had returned. Still, the science education reform movement was not dead.

The National Commission on Excellence in Education, writing in *A Nation at Risk* (1983), recommended that the "teaching of science in high school should provide graduates with an introduction to (a) the concepts, and processes of the physical and biological sciences; (b) the methods of scientific inquiry and reasoning; (c) the application of scientific knowledge to everyday life; and (d) the social and environmental implications of scientific and technological development." Subsequently, the National Research Council, the American Association for the Advancement of Science, and the National Science Teachers Association have indicated that science should be taught using inquiry-based instructional practices (AAAS, 1990; NRC, 1996, 2000a, 2000b, 2005; NSTA, 2003). The NRC in *Inquiry and the National Science Education Standards* dedicated a whole chapter to making the case for teaching via inquiry. Ideally, science teacher candidates will be educated in ways that are well aligned with the *NSTA Standards for Science Teacher Preparation* that place a strong emphasis on inquiry practice. As will be seen, this alone constitutes inadequate preparation for teachers to regularly implement inquiry-based instruction in their classrooms.

A large amount of research, reviewed by Costenson and Lawson (1986), and later by the National Research Council (2000a, 2005), has shown that helping students construct intellectual understanding through inquiry is the most effective way of getting students to accurately learn content knowledge, a wide array of intellectual process skills, and appropriate scientific dispositions. Further, they indicate that expository methods of teaching are comparatively ineffective in overcoming preconceptions, teaching a range of intellectual process skills, and inculcating appropriate values and attitudes. According to the NRC (2000b, p. 116), there is now a broad consensus about how learning occurs. "The report synthesized research from a variety of fields, including cognition, child development, and brain functioning. It also drew on research across content areas, with important contributions from the research on science learning." The report strongly supported the use of inquiry-based instructional practices. Still, many instructors of science continue to use expository methods.

Mary Kennedy (1991, p. 662) clearly enunciated the need for a new form of instructional practice if, indeed, teacher educators and professional development providers are going to have a significant influence on the way teachers teach. It would pay dividends to keep her words of wisdom in mind:

> "The improvement-of-practice problem boils down to this: if we know that teachers are highly likely to teach as they were taught and if we are not satisfied with the way they were taught, then how can we help them develop different teaching strategies? And how can we create schools and policies that will support the use of these strategies?
>
> How serious is the improvement-of-practice problem? I judge it to be very serious. We are caught in a vicious circle of mediocre practice modeled after mediocre practice, of trivialized knowledge begetting more trivialized knowledge. Unless we find a way out of this circle, we will continue re-creating generations of teachers who re-create generations of students who are not prepared for the technological society we are becoming."

Even after a century of demand for change, and after making clear the importance of teaching with the use of inquiry, there remains a significant difference between how many school instructors teach science and how university science educators say they should do so. With strong arguments for and evidence in favor of the inquiry approach, as well as repeated calls for improvement in science instruction, why don't more new and established science teachers use inquiry-oriented teaching methods?

Established Models for Implementing Inquiry-Based Instruction

Over the course of the years, informal models to explain why it is that science teachers fail to implement inquiry-based pedagogical practices in their classrooms have been proffered. Predominant among these models is an idea captured in the following quote:

"An unprepared teacher is likely to teach in the way that he or she was taught. When a powerful teacher education process does not intervene, new knowledge does not have an opportunity to transform teaching across generations. Yet prospective teachers cannot profit from these insights if they have no opportunity to encounter them" (Darling-Hammond et al., 1995, p. 21).

The National Research Council in *Inquiry and the National Science Education Standards* (NRC, 2000a) recently propounded an implementation model that suggests what it takes for science instructors to be able to teach using inquiry practices. The NRC has in effect suggested that the reason for teachers failing to implement inquiry-oriented instruction has to do primarily with the lack of adequate preparation. The NRC (p. 87) argued, "For students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry-based methods. Yet most teachers have not had opportunities to learn science through inquiry or to conduct scientific inquiries themselves. Nor do many teachers have the understanding and skills they need to use inquiry thoughtfully and appropriately in their classrooms." The NRC implementation model further posits that four factors account for teachers' understanding of scientific inquiry: (a) having learned science through inquiry, (b) having learned to teach science through inquiry, (c) having been lifelong inquirers, and (d) having followed a professional development plan that has inquiry-based instruction as its focus. Understanding of scientific inquiry is then positively correlated with implementation of inquiry-based instruction. The supposed NRC implementation model is shown diagrammatically in Figure 1.

Even though understanding of scientific inquiry is a prerequisite for implementing inquiry-based instruction in the classroom, it is not the only factor that influences its implementation. The NRC model is deficient to the extent that it fails to account for the human condition and the social context of teaching. As Kennedy (1991, p. 11) noted, "Although it is all too easy to do, let us not lose sight that causal laws in the social sciences refer to people." Unfortunately, this is what the NRC model appears to do; it makes the same mistake as the science education reformers did in the 1960s. The NRC model fails to take into account confounding variables - those factors that tend to be negatively correlated with the implementation of inquiry-based instruction.

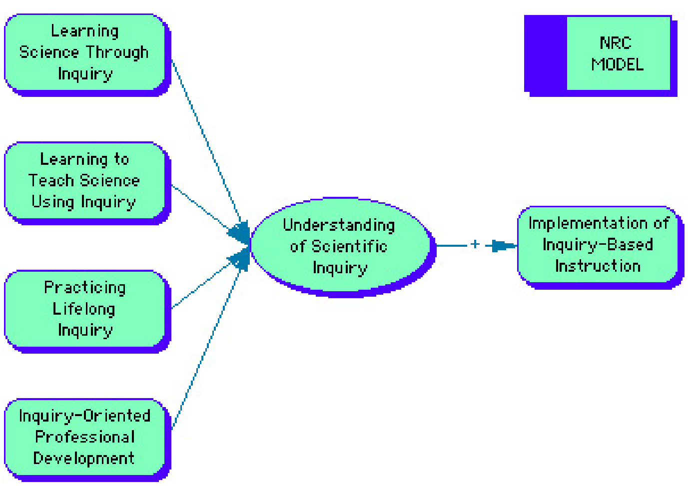

Figure 1. *The implementation model of the NRC. This model suggests that teachers' understanding of scientific inquiry, as well as those educational experiences that lead to this understanding, are positively correlated with implementation of inquiry-based instruction.*

Costenson and Lawson (1986), during interviews with teachers dedicated primarily to the lecture mode of instruction, identified ten major confounding factors to explain why these teachers failed to include inquiry practices in their teaching. While Costenson's and Lawson's 1986 work is now nearly two decades old and refers to biology teaching, these points are broadly applicable to all science teaching today. The following list encapsulates the major impediments teachers cited as the reasons teachers fail to regularly employ inquiry-oriented practice in their classrooms:

- *time and energy* – It is difficult and time consuming to produce high quality inquiry lessons; it is difficult to sustain the high level of energy required to use active learning.
- *too slow* – Inquiry takes more time than teaching by telling; the school curriculum requires coverage of broader spectrum of content than is possible with inquiry.
- *reading too difficult* – Students have difficulty translating textbook knowledge into active inquiry.
- *risk too high* – The school administration does not support inquiry practice due to a lack of sufficient content coverage; the teacher might be perceived as not doing his or her job.
- *tracking* – Classrooms filled with lower-performing students do not contain the right type of population needed to conduct inquiry effectively.
- *student immaturity* – Students are too immature and waste time in unstructured settings; they do not benefit from inquiry-oriented teaching.
- *teaching habits* – Established expository teaching habits are hard change after long periods of use; teachers do not have knowledge and skills required for inquiry teaching.
- *sequential text* – The textbook constitutes the curriculum; chapters are not skipped because too much important material is included in each.
- *discomfort* – It is uncomfortable not to be in control of the lesson; being uncertain of the outcomes that might result from inquiry-oriented teaching is disturbing.
- *too expensive* – Inquiry requires active engagement, and many classrooms are not equipped with sufficient teaching materials suitable for hands-on learning.

None of these ten teacher-identified confounding variables is included in the NRC model. In addition, there are other important considerations missing. Such things as the explosive growth of textbook contents, the quality of student teaching experiences, the lack of teacher mentoring, the unintended effects of high-stakes testing and No Child Left Behind legislation attended by calls to return to "direct instruction" (Cavanagh, 2004). All play a crucial role in determining whether or not inquiry is implemented in the classroom.

With regard to the factors identified by the NRC as positively correlated with teachers' understanding of scientific inquiry, not all are equally important or even necessary. For instance, teacher candidates who have been prepared with the knowledge, skills, and dispositions necessary to support sustained inquiry practice can successfully employ inquiry without ongoing professional development. Additionally, even novice science teachers – so long as they are well prepared – can implement inquiry without having been lifelong inquirers. As a result of these limitations, the NRC model is incomplete at best, and inaccurate and misleading at worst. A more complete and accurate implementation model is called for so that teacher candidates and in-service teachers can be properly prepared or retrofitted to teach science employing inquiry in an effective and sustained manner.

A New Model for Implementing Inquiry-Based Instruction

The NRC model for implementing inquiry-based instruction, while appearing logical, does not address factors that confound the implementation of inquiry-based instruction. This model therefore cannot serve as the basis for the "powerful teacher education process" called for by Darling-Hammond. If a more complete implementation model is developed, curriculum planners, instructional developers, teacher educators, professional development providers, and in-service teachers can be provided with a better understanding of the relationship between pertinent educational factors associated with the implementation of inquiry-based instruction. In educating/reeducating teachers, efforts can be made to galvanize them to resist confounding factors.

The author proposes for the first time a hypothetical model to explain more completely and accurately the observed disconnect between teacher preparation/professional development and teacher performance. This new model replaces the four positively correlated factors of the NRC model with three somewhat different factors essential for the implementation of inquiry-based instruction: knowledge, skills, and disposition. In addition, educational experiences (e.g., student teaching and professional development) are also incorporated. Finally, the new model groups the 10 negative factors identified by Costenson and Lawson into four major (if somewhat overlapping) groups that are all negatively correlated with implementation of inquiry-based instruction: personal teaching concerns, concerns about students, instructional and curricular concerns, and didactic teaching philosophy. The new model is depicted in Figure 2.

Experience has shown that there is a significant relationship between the dependent variable in this model (implementation

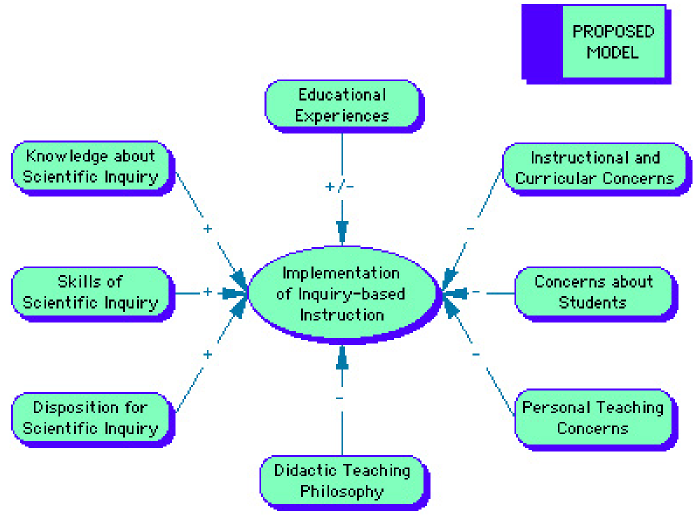

Figure 2. *The proposed model including confounding variables to more fully explain the degree to which science teachers implement inquiry-based instruction in their classrooms. This model suggests that teachers' understanding of scientific inquiry is not the only factor that affects the implementation of inquiry-based instruction.*

of inquiry-based instruction) and the multiple independent variables (understanding of science inquiry in three different dimensions, didactic teaching philosophy, personal teaching concerns, concerns about students, instructional and curricular concerns, and educational experiences). Other contributory factors might also negatively or positively influence the degree to which inquiry-based instruction is implemented. These factors could be grouped together in the model and appear as "specification error." They are, however, not included in Figure 2. According to this new model, when positive correlates exceed the negative correlates, inquiry teaching takes place. When the opposite occurs, little if any inquiry teaching occurs. This more complete implementation model, then, appears to explain the disconnect between teacher preparation and implementation of inquiry practice.

While no empirical evidence has been provided or cited by the author to validate the proposed model, it seems that reason and anecdotal evidence support it. Nonetheless, it would behoove science education researchers to conduct a path analysis of this model to determine if empirical evidence can be found either to support or reject the hypothesis. This would prove to be a daunting task due to the complexities associated with operationally defining and accurately measuring each of the model's factors. Another, but admittedly less satisfactory way, to test this model would be to create a teacher education/professional development program based on the assumptions of the model, and then determine to what extent that program's graduates actually implement inquiry-based teaching practices.

Failure to employ a real-world model for promoting and implementing inquiry-based instruction will impede any solution to the improvement-of-practice problem. As history has shown, the difference between educational practices that are influenced by a well-thought-out model and those that are not, can be profound in both their implementation and effects. The difference will be to the extent that an educational process is conducted blindly under the control of unexamined traditions or take into account personal, social and political factors.

"A Powerful Teacher Education Process"

If teacher preparation is to have a significant and lasting impact on teacher candidates' performance, teacher educators must keep in mind that candidates' beliefs and experiences have a strong influence on their decision-making processes as new teachers (Short, 2003). In the teacher preparation process, it is not at all uncommon to find little emphasis placed on teacher candidate thinking and great emphasis placed on methodology and materials (Schubert, 1991). As a result, there is more than adequate data to show that many teacher education programs contribute little to change prior beliefs about teaching and learning (Kennedy, 1991). A similar case can be made for the professional development of traditional in-service teachers.

The proposed implementation model calls for an educational process that might be thought of as analogous to the teaching of bicycle riding. Much can be gleaned from a study of the metaphor of teacher candidate as neophyte bicyclist. A parent (teacher educator) wishes to teach a child (teacher candidate) to safely ride a bicycle (teach via inquiry). Consider the following line of reasoning. In order to learn how to ride the bicycle, the child must be outfitted with the following: (1) a knowledge of how a bicycle is ridden (the parent describes the process of riding), (2) the skill of riding the bicycle (learn the process through practice), and (3) an understanding of the utility of bicycle riding (pointing out the benefits of doing so). In addition, the child needs to be 4) forewarned of the dangers associated with riding a bicycle, and (5) forearmed with the rules of the road as they apply to bicyclists. The metaphor of teacher candidate as neophyte bicyclist is quite apt; the parallels between learning to teach using inquiry and riding a bicycle are numerous. As conscientious teacher educators seeking to promote the use of a complex educational process, should we do anything less for our teacher candidates than a parent does with a son or daughter learning to ride a bicycle? The preparation process for new teachers must provide candidates with the required knowledge, skills, and dispositions related to inquiry practice. Candidates must be forewarned about teacher concerns and other dangers to their intended inquiry practice, and they must be forearmed to respond appropriately to attacks on that practice.

Initial Teacher Preparation – The inquiry practice of science teacher candidates will strongly benefit from preparation programs that follow a seven-step educational process (Wenning & Short, 2004) aligned with the proposed implementation model. This process, as several case studies have shown (Short, 2003), is effective in preparing physics teacher candidates to employ inquiry-oriented pedagogical practices in their classrooms. Teacher candidates also benefit from a program that includes aspects that serve to forewarn and forearm candidates so that they can start their teaching careers with the use of inquiry-based practices and continue doing so effectively throughout their professional lives. The following steps could well be incorporated into undergraduate physics teaching methods courses:

- <u>Prepare teacher candidates to use inquiry-based instruction</u>: Ideally, the model teacher education process includes a systematic treatment of inquiry practices incorporated in several physics teaching methods courses taught over the course of several years. The educational process also includes student teaching and first year teaching in the educational process. The seven-steps of the inquiry learning process promulgated by Wenning and Short are the following: introducing, modeling, promoting, developing, practicing, deploying, and supporting inquiry-based teaching practices.

  Introducing inquiry consists of having teacher candidates visit the classrooms of expert high school practitioners of inquiry and comparing what they observe there with the commonly didactic teaching taking place in the university classroom. The differences in teaching styles are readily observed once students know what to look for.

  Modeling inquiry consists of having teacher candidates play the role of high school students in a science methods course in which several exemplary inquiry lessons are taught by the university instructor.

  Promoting inquiry consists of helping students come to know the reason for and benefits derived from the use of inquiry practice in the science classroom. Discussions of readings taken from *Inquiry and the National Science Education Standards* and other sources form the bulk of the promotion.

  Developing an inquiry lesson plan using the Lesson Study approach modeled after the description by Stigler and Hiebert (1999) is the next step in the educational process. Students create a model inquiry lesson plan under the critical eye of an experienced inquirer.

  Practicing inquiry comes next by teaching the lesson study lesson plan to high school students. The approach consists of teaching, revising, and then reteaching the lesson. This activity is then followed by a series of inquiry-oriented lessons that students develop and implement on a rapid-fire basis so as to gain greater experience working with inquiry.

  Deploying inquiry comes with the start of student teaching. Teacher candidates prepare and teach inquiry lessons with the advice and assistance of their cooperating teachers.

  Supporting inquiry teaching continues throughout student teaching and the first years of professional practice by continuing contact between the novice teacher and high school and university mentors.

  This seven-step inquiry learning process has been shown to develop a strong understanding of inquiry practices and pedagogical processes related to inquiry-based instruction (Short, 2003). Integrated with this seven-step process are activities that help teacher candidates develop a strong philosophical disposition toward teaching via inquiry.

- Forewarn teacher candidates about potential impediments to inquiry-based instruction: Teacher candidates are made aware of the fact that there will be resistance to the implementation of inquiry. The ten main influences working against teaching via inquiry and identified by Costenson and Lawson (1986) are reviewed and discussed. Not among this listing, but today perhaps the most striking form of resistance to inquiry that teacher candidates will experience, comes from the high school students themselves. This is especially so for student teachers who take over courses that have previously been taught didactically. It's not uncommon to hear students complain under such circumstances that they "would rather be told" what they need to know rather than to have to construct knowledge from experience.
- Forearm teacher candidates to resist impediments to inquiry-based instruction: Teacher candidates are made aware of the wide variety of very real threats arrayed against inquiry practice. They address each of the arguments posed against inquiry based on the work of Costenson and Lawson (1986), as well as recent attacks against it by strong proponents of the No Child Left Behind initiative (Cavanaugh, 2004). Teacher candidates are galvanized with personal and professional resources with which to identify, confront, and resist or change confounding factors.
- Support teacher candidates and mentor novice teachers as they use inquiry-based instruction: Student teaching takes place using cooperating teachers who are open to and supportive of teacher candidates using inquiry-based practices even if they themselves have a didactically-oriented teaching philosophy. Better yet is to place student teachers with cooperating teachers who are strong proponents of instruction incorporating inquiry. Provide ongoing support to novice teachers during the transition period from the university through the first year of teaching. It should be well noted that a very significant fraction of novice teachers are lost to careers other than teaching during the first few years of classroom experience. To what extent this occurs as a result of conflicting messages between what teacher candidates are told in their university science teaching methods courses and what they experience in their own classrooms is unknown with certainty. Nonetheless, providing novice teachers with the transitional support they need for conducting inquiry is, without a doubt, a factor in solving the improvement-of-practice problem.

In-Service Professional Development – If the teacher reeducation process is to have a significant and lasting impact, it must take into account the fact that many experienced science teachers are likely have somewhat entrenched didactic teaching philosophies. Professional development probably will always be less effective than teacher preparation unless it identifies, confronts, and resolves the problems associated with expository teaching. Professional development activities must be of high saliency and prolonged if expected practices are to become the "coin of the realm." Activities should include placing teachers in the role of students as well as that of teacher so that they can see both sides of the coin. These practices must be backed up with sustained periodic mentoring by professional development providers. The improvement-of-practice problem for in-service teachers must, at the root, influence teaching philosophies. It is from philosophies that beliefs arise, and beliefs give rise to decisions. Decisions bring about actions, and actions have consequences. Hence, to influence outcomes, professional development providers need to give attention to teaching philosophies.

Turning Educational Theory into Practice

As noted educational philosophers John Dewey and James McLellan once stated, "The value of any theory is, in the long run, determined by practical application." (1895, p. 195). Years later, educational psychologist Kurt Lewin similarly stated, "Nothing is more practical than a good theory" (1951, p. 169). These dicta hold considerable truth when applied to the current situation. Our understanding of the relationship between theory and practice is critical if teacher educators are to make significant progress toward the goals of reforming teacher preparation and professional development. It is instructive to note how wide the gap is between theoretical sufficiency and practical efficacy as far as teacher preparation and professional development are concerned. Without reasonable theoretical underpinnings, it is likely that today's teacher preparation and professional development processes will continue to be less than entirely effective. To paraphrase Dewey's question, are teacher educators still spending too much time and effort thinking about "methods" and far too little time reflecting on the theory that might guide their own instructional practice in a more enlightened fashion? If we fail to turn educational theory into practice, our work will ultimately and always be a series of ad hoc initiatives that result in failure to make appropriate progress toward the goal of improving how teachers perform in their classrooms. Only if teacher educators establish a clear agenda based on an adequate theory base for teacher preparation and professional development can we hope to achieve our goal of solving the improvement-of-practice problem. The measure of our success will be found in the extent to which in-service teachers have adopted, are guided by, and utilize the methods of scientific inquiry in their pedagogical practice.

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