Action Research as a Research Methodology for the Study of the Teaching and Learning of Science

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What is Action Research?

Increasingly, action research has become a part of funded educational research and curricular development projects. There have been two main arguments for this. The first is that it reduces the time lag between the generation of new knowledge and its application in the classroom. If teachers are the researchers, the time lag may be reduced to zero. The second is that teachers represent a highly educated population who, with proper training, could act as classroom researchers. This offers are at least two potential benefits. One is that it could reduce the cost of doing research or development. Teachers would be researchers doing inquiry as a part of their normal practice, with little additional compensation or release time. The other is that teachers spend large amounts of time in schools working with children and are experts at what they do. The inclusion of teachers as researchers in funded projects is a way of utilizing that expertise.

At the same time, there are significant concerns about the use of action research as a research methodology. First, how is the success of action research measured? If it is done by looking for a product such as an addition to the knowledge base on teaching or learning, then issues related to the validity and reliability of the research arise. Can teachers generate sufficient warrant to support propositional statements that arise from their research? Can they avoid or overcome the bias that is inherent in doing research on their own practice? Other products, such as changes in teachers or students, are possible, but difficult to measure. For example, it may be claimed that the teachers' practice has improved, that they have reached better understandings of their educational situations, or that they have feel empowered through their involvement in action research. It also may be claimed that students find themselves in situations that are more supportive or challenging, or that they have learned more or differently as a result of their teachers' action research.

A second set of concerns relates to the ways in which the worlds of university-based research and teaching in kindergarten through grade 12 intersect. Chief among these are questions that relate to the setting of a research agenda. Who sets the agenda? What tensions may arise between the goals of the principal investigators (PIs) of a funded project and the teachers' goals that relate to their own professional development or their "need to know (Feldman, 1994a)" that their work has had the desired effect on their students? There are issues that arise because of possible differences between the structure of funded projects and teachers' work and lives. These may be as mundane as the constraints imposed by school schedules, funding timetables, and the isolation of teachers. They also may arise from conflicting assumptions of what constitutes research or from the "contradictions of control (McNeil, 1988)"that can arise from the top-down,

center-periphery management of action research configured as a grass-roots activity (Feldman, 1995c).

Finally, there is the issue of how teachers learn to do action research, and how others learn how to teach them how to do it and how to facilitate it. Must every project that attempts to use action research start from the beginning, or is there a way to build upon the successes and failures of others?

In this chapter, we address these issues by examining action research from three perspectives. The first is an overview of what it means to engage in action research as a methodology for investigating teaching and learning in science education. In that section, we make explicit various conceptions of action research and provide readers with our definition of it. The second perspective is that of an individual (Minstrell) engaged in action research in his classroom to improve his teaching, his students' learning, and to advance knowledge of the teaching and learning of physics. The third perspective is that of a facilitator (Feldman) of action research done by others. By providing views from these three perspectives, we intend to address these concerns and issues and help readers develop their understanding of what action research is and can be, so that it can be used as a methodology for the study of teaching and learning in the sciences.

Conceptions of Action Research

In writing this chapter, we are aware that action research is charged with meaning. In other words, our readers bring with them their conceptions of it. While some have abandoned the label because of these connotations and, instead, call this methodology "teacher research" or "practitioner inquiry," we have decided to continue to use it. Because of this, we find it necessary to make explicit some of the conceptions that readers may have of action research.

For some, their conceptions depend upon whether they put the accent on "action" or on "research." When the accent is on action, there is an assumption that when teachers do action research in their classrooms, their primary purpose is to modify their practice in some way. This may mean that the collection and analysis of data are used to guide the development of an action plan. Others do action research by changing the system through action as a way to determine what works and does not work in the classroom, and why. When research is accented, action research is seen as a modification of traditional educational research that incorporates teachers in a non-trivial way. The teachers may pursue their own research agendas, aid in research initiated by university researchers, or be alpha- and beta-testers as in industrial product testing models.

There are other conceptions that readers may have of what action research is and is not, and should be or should not be. To some, it is tied to a desire to do good in the world, through direct social action (e.g., McTaggart, 1994). Others come to it from a critical theory perspective that sees teachers' engagement in action research as an emancipatory process (Carr & Kemmis, 1986). Still others assume that action research, as

a form of research, is separate from the political sphere and is concerned primarily with knowledge accumulation (e.g., Borg, Gall, & Gall, 1993).

Action research has become linked to both pre- and inservice teacher education too. Increasingly, one finds a form of action research as a required component of preservice teacher education programs (Noffke, 19XX). It also is seen as a way to encourage the professional development of teachers either by providing them with skills that will allow them to be reflective and inquiring practitioners (e.g., Gore & Zeichner, 1991), or through the knowledge that they will acquire from the completion of action research projects in their classrooms (e.g., Fals-Borda & Anisur, 1991).

Clearly there are many ways in which readers conceive of action research. We have made some explicit here, not to suggest that certain of them are "misconceptions" and others "true," but rather as a reminder that action research, as a social and political endeavor with a history that stretches throughout this century, has multiple meanings and is understood in different ways by different people in different contexts. After saying that, we proceed to explain what we mean by action research.

A Definition of Action Research

By action research, we mean teachers researching their own practice of teaching. It is an inquiry into their teaching in their classrooms. Because this research is focused on the work of teacher-researchers, it is developmental in nature and has two main purposes. The more immediate of the two is the improvement of their teaching practice in order to improve their students' learning. That is, when teachers engage in research on their teaching, they do so to get better at what they do. The second purpose is to seek an improved understanding of the educational situations in which they teach so that they then can become a part of the knowledge base of teaching and learning. From this operational definition of action research, it should be seen that it is a research methodology, a paradigm within which research is done, rather than a set of specific research methods. It is characterized by the focus of the research--the teaching done by the researcher--and the goals of that research--the improvement of teaching and learning and a better understanding of the researcher's educational situation.

Doing and Facilitating Action Research

By defining action research in this way, we raise several questions that are embedded in the issues that we have raised already. First, action research appears to be a local and highly contextualized form of research. It is done by a teacher on his or her own practice in his or her own classroom. Does this result in research that is highly biased and from which it is difficult to generalize to other cases? Second, because it is highly contextualized, teachers choose problems to investigate that are of interest or concern to them. What if the teachers' agendas do not match those of the projects' PIs? Third, the goal of action research is greater understanding that can be linked to improved practice. This makes it an interpretive rather than an explanatory form of research (Bruner, 1996). Interpretive scholarship, which is ubiquitous in the humanities, has been accepted in the

social sciences only recently and has made few inroads into the natural sciences. This then raises the question of whether this methodology would be accepted by the large number of scientists who are a part of the science education research community.

We explore these issues through reference to our own professional experiences with action research. Minstrell will present a case of a physics teacher engaged in action research. In it, he will provide a narrative of his more than twenty years of doing research in his classroom on how his students learn physics and how that has affected his teaching and other professional practice. Feldman will relate his work with various groups of teachers engaged in action research to these methodological issues and will suggest possible remedies.

The Products of Action Research

One of the most significant questions about action research concerns its products and how it can be determined whether they are of importance. There are several different types of products of action research: the generation of knowledge about teaching and learning, increased understanding of practice, and improvements in teaching and learning. These products differ significantly in how they are evaluated. Typically, teaching and learning are evaluated relative to specific benchmarks or standards. These benchmarks may be determined as a result of research, or they may relate to social and political norms. And, depending upon what the benchmarks look like, an evaluation relative to them may be rather straightforward and traditional, such as a standardized examination or a Flanders-type checklist (Flanders, 1970), or quite complex if, for example, one is seeking evidence of deep conceptual understanding or constructivist teaching (see, for example, several chapters in this volume, including the one by Tobin).

Changes are other possible outcomes for teachers who engage in the process. These changes include an increase in the teachers knowledge and in their stances toward their work. From 1990 to 1993, Feldman studied teachers engaged in action research to understand the ways that knowledge and understanding are generated and shared in collaborative action research (Feldman, 1994b; 1996). During that time, he worked with a group of physics teachers in the San Francisco Bay Area who call themselves the Physics Teachers Action Research Group (PTARG). PTARG is a group of seven high school and community college physics teachers (Andria Erzberger, Sean Fottrell, Larry Hiebart, Tim Merrill, Annette Rappleyea, Lettie Weinmann, and Tom Woosnam) who have undertaken a collaborative systematic inquiry into their own teaching for more than six years. The group began as an occasional meeting of physics teachers in the Bay Area to discuss the teaching of physics and to hear presentations from physicists on current research.

In his analysis of the group's meetings, Feldman was able to demonstrate that knowledge about physics, teaching, and learning, and what Shulman calls pedagogical content knowledge (Shulman, 1986) was generated and shared among the teachers (Feldman, 1995b). It also was apparent that the teachers began to see themselves as researchers as well as classroom teachers. They began to make presentations at meetings of the American Association of Physics Teachers (AAPT) and have published as a result

of their action research (Erzberger et. al., 1996). Similar changes in stance occurred among teachers who did action research as a part of the California Scope, Sequence, and Coordination (SS&C) Project (Feldman, 1995c). All of the teachers found that they were capable of improving or understanding better the implementation of new curricula in their schools. Several presentationed papers at national and state conferences for the first time, and one mentioned that being called an action research "fellow" had had a positive impact on his conception of himself as a professional. These changes in how they viewed their practice can be called empowerment, and it has been seen in other studies of teachers engaged in action research (Hollingsworth, 1994; Cochran-Smith & Lytle, 1993).

While improvements in teaching and learning are the ultimate goals of educational research, and growth in teachers' knowledge, as well as their empowerment, can be ways to achieve these goals, there is the assumption that funded research will result in a product that enhances the knowledge base for teaching and learning. For this to happen, knowledge must be generated. Whether the knowledge is in the form that Shulman (1986) has called propositional, case, or strategic it must be warranted in some way (Phillips, 1987).

Knowledge is generated by doing research. If action research is to generate knowledge, it must be a legitimate form of research, and the results must be seen to be valid. Is action research research and is it a valid form of research? As Feldman has worked with teachers doing action research, whether the physics teachers in PTARG, the science teachers in California in the SS&C project, or the teachers enrolled in a graduate seminar on action research (Feldman, 1995a; Feldman, Alibrandi, et. al., in press), they have explored the question of the validity of action research. During his investigation of PTARG, it was Andria Erzberger who voiced most often the question, "Is this really research?" At one point she asked, "How do I know if my students are learning any better? How do I know if I've changed? How do I know if the students have changed (Feldman, 1994a)?"

Feldman has attempted to answer Erzberger's questions about whether action research is research by referring to Lawrence Stenhouse's definition of research: systematic critical inquiry made public (Stenhouse, 1975). Because this definition goes beyond the idealized notion of research as quantifiable hypothesis testing that produces generalizable propositional statements, it allows for human inquiry activities that are interpretive as well as explanatory to be labeled as research. Using this definition, the scholarly work of social scientists who use the ethnographic methods of anthropology or the clinical methods of psychology as well as that of historians, philosophers, and literary and art critics can be recognized as legitimate forms of research.

Returning to action research, if Stenhouse's definition is accepted, action research is a legitimate form of research if it is systematic and critical inquiry made public. In Feldman's work with teachers doing action research, they have tried to make it so by the teachers systematizing their inquiries and by subjecting them to critique from within and from outside (Feldman, 1996; 1995c; 1995a). However, several factors make this difficult

for the teachers to do. First, because action research is inquiry into one's own practice, the distance between inquiring subject and object of study has been reduced to zero; they are the same person. Second, the action research is inherently non-reproducible. Teaching situations change continuously and no two classes are similar enough to control variables in experimental designs. It also must be noted that there are times when a teaching technique that would be considered the "experimental treatment" has enough inherent strengths that ethical issues are raised if it is withheld from a "control group" of students. And, third, the methods of the social sciences that can be used to mimic scientific experimental designs can lead to frustration and obfuscation because of temporal, spatial and social constraints on the teacher action researcher (Feldman & Atkin, 1995).

While these factors suggest that action research cannot meet the demands of traditional research, this turns out not to be the case because the goals of action research are often interpretive rather than explanatory. Because most action research is concerned with seeking understanding or meaning, teachers do not need to demonstrate that what they have learned are viable explanations for all cases. Rather, they need to show that what they have learned is true in the particular case of their teaching in their classrooms. To do this, they can use a variety of techniques borrowed from the social sciences that improve on the verisimilitude of their research. These include triangulation, the consideration of alternative perspectives, testing through practice, practical compatibility, and ethical justifiability (Feldman, 1994a).

Triangulation consists of collecting data that represent several views of the same situation. For example, when action researchers try out a new teaching idea, they can write an account of what happened. The account is based on what the teacher remembered while in the role of teaching the class. This can be triangulated in a variety of ways. The teacher can audiotape or videotape the class. Other teachers may be asked to sit in on the class to record their observations. Students can be interviewed formally or informally after the class for their perspectives. The students could be asked to write their own reflective notes on the class. These methods have been used by all of the teachers whose action research Feldman has facilitated. Moreover, it is possible to get a variety of outcome measures, such as traditional and alternative forms of assessment.

While triangulation is done to gather a variety of data from different views, the data can be interpreted from a variety of different perspectives, too. This is particularly useful in trying to understand students' responses to classroom situations. For example, a teacher may observe that students do not cooperate with one another when they are asked to work in groups. This may be interpreted as students competing rather than cooperating in response to their desires to be accepted to competitive colleges. But this also may be interpreted as a failure of the students to understand the purpose of, or instructions for, the activity, or the teacher's failure to communicate. New data can be collected, or existing data reinterpreted, to check these hypotheses.

Action researchers, like engineers and others in the applied sciences, can test their ideas by putting them into practice. The teachers develop new ideas about teaching, or reconfigure others, and try them out. Action researchers can evaluate the effectiveness of

their new instructional methods or materials through outcome measures, or they can use ongoing formative assessments within the context of the teaching situation. Although this formative testing through practice cannot "prove" that a particular instructional method works, it can demonstrate that it did not work in its present form and requires modification. This is what the PTARG and CA SS&C teachers have done.

In addition to testing ideas about teaching to see whether they affect students' learning, action researchers can test whether their ideas are practical and compatible with their teaching situations. They get an immediate evaluation of the implementability of the suggested improvement. Some ideas can be rejected out-of-hand; for example, minuscule budgets may prevent the use of sophisticated technology in a particular classroom. Other ideas may need to be modified because of large class size, multiple presentations, or the socioeconomic status of the students.

Finally, because teachers can have profound effects on the lives of their students, the results of their action research must be justifiable ethically. Therefore, the self-evaluation of teaching practices through action research should pass tests of accessibility and equity, and should promote the health and well-being of the students and others in the schools (Altrichter, Posch, & Somekh, 1993).

Teachers who engage in action research can take steps to ensure that their data are trustworthy through triangulation, they test their ideas through practice in their own classrooms, they check that their findings are practical and ethical, and they share what they have learned with other teachers, as ways of "publishing" what they have learned and of opening it to the scrutiny of their peers. In this manner their research is systematic and critical inquiry made public. In the next section of this chapter, we present an example of one teacher doing action research. In it, we look at how Jim Minstrell has done systematic critical inquiry in his classroom, and made it public.

Doing Action Research: An Example of Action Research in One Teacher's Classroom

Much of the experience of being an action researcher occurs alone in one's own classroom. Consistent with that tradition, this section will be written in the first person. In it, one of us (Jim Minstrell) will recount how he arrived at, and developed gradually, the methods and learning perspectives that he has used during more than two decades as an action researcher attempting to understand his students' thinking and the effects and practice of his teaching in the context of classroom activities in science and mathematics. More recently, he has been working with networks of teachers who are engaging collectively and independently in their own action research to improve their students' learnings.

Why Classroom Research?

At some levels I have known that I was interested in questions of human learning since I was in the eighth grade. When studying science, we were "forced" to memorize

steps of "the" scientific method. I remember voicing my disapproval during a class discussion that "nobody thinks like that."

During my first few years of teaching, I was told by my administrators and by my students that I was "one of the best teachers" they had had, and I wondered precisely what "learning" effects I had had on my students. The students did well on my tests as long as I kept the questions close to the procedures that I had "trained" them to do. But, when I slipped in questions that required a deep understanding of the concepts and reasoning I supposedly had been teaching, I was disappointed. I became more curious about the nature of learning in the classroom.

After only four years of teaching, I had the opportunity to participate in research at the national level with Project Physics (Rutherford, Holton, & Watson, 1970). While the methods used by the researchers in that project were very sophisticated and served the needs of a large curriculum development project, they were not useful to my interest in improving my effectiveness as a teacher in my own classroom. Although the results seemed too far from my issues of learning in my classroom, the experience initiated my interest in research.

Six years into my teaching career, I began working part time at the University of Washington with Professor, Arnold Arons, a colleague and mentor through whom (not from whom) I learned a lot about science and about the capabilities and difficulties of developing conceptual understanding. In working with our university students (mostly teachers and prospective teachers), Arons used to coach me to keep my hands in my pockets and make the students show me what they did, or what they would do, about the problem. Prior to that, my inclination was not unlike many well-meaning teachers whose approach is: "Here, let me show you how to do it," from which the students learned little more than how "smart" I was.

Arons also coached me to listen to what the students were saying, reminding me that I had two ears but only one mouth and to use them in that proportion. In addition to my learning much about physics, I changed my perspective from a focus on me as a deliverer of knowledge to a focus on my students and what they were learning. My critical questions as a teacher became: "What is the understanding of my students?" and "What experiences can I put before the students to cause them to have to rethink their present understanding and reconstruct that understanding in order to make it more consistent with a broader set of phenomena?"

This has evolved into my line of classroom research and has affected my teaching greatly. When I finished my doctoral dissertation, I applied for a grant to buy part of my time so that I could stay in my high school classroom and conduct research on the teaching and learning of my students. That has become the natural, and practical, setting within which I conduct a line of research. At the same time, my primary responsibility has been to teach, or, more correctly, to be responsible for my students' learning. Now, in the classroom, I always wear both the hat of a researcher and the hat of a teacher. Each perspective helps me to direct, and to make sense of, the results of the other.

My Classroom Based Action Research

How better could I understand my students' thinking, their conceptual understanding, and their reasoning in the natural setting of the classroom? What effects, if any, did my teaching have on their learning? How could I effect better learning? Will my results be of use beyond my classroom?

In the early stages of my action research, my activities as a researcher were informal. They amounted mostly to anecdotes that, to me, represented evidence of either the learning I intended or the learning that did not occur. I looked for correlation between gross measures like grades in my class (e.g., high school physics) and possible predicting variables like grades in other courses (e.g. geometry) and more "standardized" measures (e.g., "the Classroom Test of Formal Operations" (Lawson, 1977).

Sometimes, I was testing an intervention as short as a particular lesson and, at other times, the effects of aspects of an entire year's program. At times, I could conduct a controlled experiment. At others I was gathering data and attempting to interpret the results.

Gradually, there evolved a line of investigation in my classroom that focused on describing my students' initial and developing understanding and reasoning about the content of the courses I was teaching. Later, that line of investigation evolved into designing and testing instructional interventions explicitly adapted to address students' difficulties in understanding and reasoning.

Data Gathering in My Classroom

After I began to listen to my students more carefully and to solicit their ideas, I needed to gather data systematically. I enlisted the help of my students and their parents who, at the beginning of the school year were asked to consider and sign consent forms for participation in my studies. I warned my students that I might be doing some atypical teaching and assessment during my research to understand and address their thinking. I bought a small, battery-run audiorecorder that I kept on my desk in the classroom. Later, I bought a videocamera and recorder that I set up when I anticipated discussions that might be informative to other teachers. While students interacted in small groups, I carried the audiorecorder with me and turned it on when I came to an interesting discussion or when students came to me with questions or ideas they had about the phenomena under investigation. During large group discussions, when it appeared that an informative discussion was likely to develop, I started the recorder and let it run throughout the class period. After the discussion, if I felt there were not research quality data, I erased the tape and prepared it for another class.

On one such occasion, early in my experience as a classroom researcher, the audiorecorder was running when we were beginning the study of force and motion. I had asked the students about the forces on a book "at rest" on the front table. The students drew and wrote their answers on paper quietly. While I was walking around the room, I

noticed that two answers, involving whether the table exerted a force dominated. One suggested that the table exerted an upward force, and the other suggested no such upward force. When our discussion began, I drew those two diagrams on the board and took a poll. There was an observer in the class that day, so I asked him to record the number of students who raised their hands during these brief surveys. The answers were divided approximately evenly between those who thought that the table exerted an upward force and those who thought that it did not.

I asked for volunteers to support one or the other of these positions and discovered that the difference revolved around whether one believed that passive objects like tables could exert forces. I decided to test this by putting the book on the outstretched hand of a student. We took a poll on the students' beliefs about this situation. Nearly everyone thought that the hand exerted an upward force. I inquired about the difference between the two situations, and the students argued that the hand was alive and that the person made muscular adjustments to support the book, especially when I stacked several additional books on top of the first one. The observer recorded the number of students who raised their hands. The teacher side of me wanted the students to be able to see the similarities between the situations, but it was clear that the students were seeing the differences. Again thinking about how I would address their concern, I pulled a spring out of a drawer, hung it from hardware, and attached the book to the spring. The spring stretched until the book was supported. I asked again for diagrams and took another poll, recorded by the observer. Nearly all of the students believed that the spring must be exerting an upward force. I countered by asking whether the spring was alive or how this situation was like the book on the hand. The students did not believe that the spring was alive with muscular activity, but that it could stretch or deform and adjust in a way to support the book. And, how was this different from the table? They suggested that the table was rigid: did not stretch or deform like the spring. "Ability to deform or adjust" now seemed to be the difference between these situations and my target situation of the book on the table. I put on my teacher hat, darkened the room, pulled out a light projector, and set it up so that the light reflected off the table top onto the far wall. Using this "light lever," I alternately put heavy objects on and off the table, and we noticed the movement of the light on the far wall. The students concluded that the table must be bending also. With my teacher hat still in place, I summarized by suggesting that force is a concept invented by human kind. As such, we are free to define force in any way we want, but the scientist notes the similarity of "at rest" in several situations. Then, wanting to be consistent, he thinks of one explanation that works for all of the situations: the explanation involving balanced forces. This means that the scientist's definition of force will include "passive" support by tables as well as "active" support by things like hands or springs.

The description of this action research became the material in my first published research article (Minstrell, 1982a). The situation has been analyzed since by other researchers and incorporated into curricular materials (Camp et.al., 1994). It is important to note that, in this discovery mode, the "hats" of researcher and teacher are being interchanged quickly in efforts both to understand the students' thinking and to affect their learning.

It was a memorable lesson for me and for my students. It made them think differently about whether actions are active or passive and about the idea of force. These lessons that students keep referring back to later in the year, or in subsequent years, I have come to call "benchmark lessons," a metaphor from the geographical survey reference bench marks that one finds cemented into rocks (diSessa & Minstrell, in press).

This interplay between conducting research focused on students' understanding, and making adjustments in instruction to address their understanding, is similar to the design process of engineering as well as the investigatory process of science. Prototype lessons are planned, tried, altered, and tried until the product is a lesson that works within the design constraints of addressing the students' concerns and the target learning of the curriculum. As a teacher-researcher, I was at the same time a scientist, trying to understand students' thinking, and an engineer, trying to develop a product lesson that works within the constraints.

This interplay places demands on me to be creative in designing and redesigning relevant experiences that bring into question some of the initial ideas of the students. In that way, I test my models of their thinking. I also need to know the subject matter well so that I can appreciate the issues from the students' view and how those issues relate to the formal discipline. Then, I need to know the curriculum possibilities well so that I can choose or redesign activities.

Description of My Students' Thinking

With more experience as an action researcher, I became more systematic in my methods. To find out what students are thinking, I designed and set problematic situations before them at the beginning of most units of study. These tasks were typically in the form of pre-instruction quizzes, but only the students' honest effort, not the "correctness" of the answer, counted for credit (Minstrell, 1982b). Students were asked for an answer and reasoning for how the answer made sense. From the sorts of tasks I set and from the answers and the rationale students gave, I inferred their conceptual understanding. In this research approach, I was using methods similar to the interviews conducted by cognitive scientists except that I was interviewing my whole class (Bruer, 1993). As a teacher, the activities I set out in class tended to be driven by the class as a whole, rather than by an individual learner. Still, the method allowed me to "know" the tentative thinking of most of the individuals in my class as well as the thinking of the class in general.

The above procedure allowed me to "discover" aspects of my students' thinking. For example, before I started a dynamics unit, I used the University of Massachusetts Mechanics Diagnostic (Clement, 1982) to identify ideas my students seemed to have about the forces that objects exerted on each other during interaction. Even though most high school students were able to repeat the phrase "for every action, there is an equal and opposite reaction," they did not apply the idea to objects interacting. I found that most students initially attended to surface features and argued that the heavier, or the stronger, or the most active object, or the one that inflicted the greater change in the other object, exerted the greater force. Often, that was as far as I could go in terms of learning

about students' thinking, creating the hypothesis, and then instructing with that thinking in mind.

However, as time and opportunity allowed, I also attempted to "verify" my hypotheses about students' thinking. I designed problematic situations that contained those features specifically, and, based on my assumptions about the students' thinking, I predicted the outcomes. If they responded according to my prediction, I had some degree of confirmation that my assumptions about their thinking were correct.

Notice that the procedure is consistent with science as a method. As a researcher, I was generating and testing hypotheses about students' thinking. As a teacher, I wanted to know generally what the thinking was so that I could choose or design more relevant activities, benchmark lessons that might have a better chance of changing students' conceptions, e.g., by incorporating a broader set of phenomena, constructing new conceptions or new models that likely would be more consistent with formal scientific thinking.

The results of these more systematic approaches to identifying students' ideas have appeared in a working document accumulating facets of students' thinking (Minstrell, 1992). Are students' facets of thinking consistent from one situation to another? If one looks at the data from the perspective of principled formal physics, the answer is a clear no. However, if one looks at the surface features of problems, students' thinking is much more consistent (Minstrell & Stimpson, 1986). To the extent that we can triangulate students' understanding from test results, discussions, laboratory activities, and written work, we establish the reliability of our findings. The facets developed from classroom research provide a set of potential hypotheses of students' thinking in most topics of physics. As a classroom teacher, I use these facets to diagnose the ideas of students and to prescribe my instruction based on the diagnosis. The facets and facet-based instruction have been incorporated into a computerized diagnoser for physics instruction developed by me and my colleagues in the psychology department at the University of Washington (Levidow, Hunt, and McKee, 1991; Hunt & Minstrell, 1994).

Testing the Effects of My Instructional Intervention

Being a teacher and wanting to see that I have an effect on the learners in my class, I write or adapt an instructional activity that is designed to perturb the assumed thinking of the students. To test for effects, I needed to identify the students' initial thinking first. The facets are helpful in designing a pre-instruction quiz or survey to do that. Then, I used an instructional intervention, designed specifically to address the students' thinking. This usually amounted to a series of lessons, including the benchmark lesson, that took a few days for the students to work through. Repeatedly, the issues, questions, and ideas that were voiced in the initial problematic situations were revisited. Finally, at a later time, I set another task before the students in order to assess their resulting thinking, looking for apparent change. Out of this process I and my fellow teachers have developed a physics pedagogy program, an evolving set of activities that can be used by teachers to help them focus on their students' learning of critical ideas

about the physical world. The classroom measured effectiveness of these research-based products provides our source of validity for the research.

Summary: Lessons from Doing Action Research

Most of my current research is directed at modeling students' thinking and testing the effectiveness of interventions to change that thinking. It is no accident that most of my current teaching involves guiding students' modeling of physical phenomena. The methods of the research are eclectic. Sometimes, they are chosen to be consistent with the rhythm of the classroom. Occasionally, they interrupt the flow. Although somewhat constrained by the context of the classroom, the research methods I choose are associated with the questions involved in the research and are not necessarily unique to the classroom.

Many of my findings can add to the general knowledge of learning and teaching and are not limited to my classroom only. My "rule of thumb" has been that if about 10 percent or more of my students exhibit a similar sort of thinking, then I need to acknowledge and describe the conceptions and reasoning they are using, and I need to design instruction to address that thinking. These findings have been generalizable beyond my classroom. Although one might think that there would be as many different ideas as there are students in the classroom, this is not the case. Usually there are between two and eight approaches to thinking exhibited by the class when confronted with a particular situation. When we present similar sorts of situations, I see the same behavior replicated in the classrooms of other teachers. And, in most cases, the lessons that work to perturb the problematic thinking in one classroom also work in another. Thus, these findings are considered generalizable.

Teaching is a complex, problem-solving activity. There is no single way to do it. Some goals are predictable, and some emerge during classroom activities. Adopting the perspective of the researcher as well as the teacher in my classroom has given me professional vitality. Feeling free to do the research allows me to inquire into my own questions about teaching and learning. When I see learning, I can feel success as a teacher. When learning does not happen, I do not need to cover it up to preserve my self-esteem. Instead, I have another problematic situation to investigate as a researcher. Wearing both the hat of the teacher and the hat of the inquiring researcher allows me to produce more effective learning environments for my students and for the field of science education.

To be a teacher-researcher takes time. My personal development has taken years. I was fortunate to have survived competition for research funding that bought a portion of my time to enable me to think about issues of teaching and learning in my classroom. I also benefited from university colleagues who have challenged me to improve my research techniques. Finally, I have benefited from working with students, administrators, and especially teacher colleagues who have allowed me to investigate their classroom

environments. They have been instrumental in testing the validity and reliability of apparent findings.

Conducting action research has allowed me to maintain a line of personal inquiry in the context of the classroom, where most formal learning takes place. I am able to test my own hypotheses about learning and about teaching for more effective learning. Now I am working with several teachers, and we question each other, redesigning and testing instructional activities. Many of them claim, as I do, that conducting action research in their classrooms has revitalized their professional lives. All of us agree that taking on an inquiry perspective about our classroom activities has yielded significant changes in our teaching and, more importantly, in the learning of our students.

My action research and my actions as a teacher have become one. I can no longer teach without conducting research in the same instructional setting.

Facilitating Action Research

In his narrative, Minstrell has described how action research can result in a teacher's professional development, increased learning by students, and additions to the knowledge base on teaching and learning science. However, Minstrell's experience with action research is unique. He has been able to develop his own research agenda and carry it out through years of inquiry in his classroom in collaboration with colleagues in colleges and universities throughout the world. When action research is selected as a research methodology to be used by teachers as a part of funded projects, problems can arise that were not inherent in Minstrell's situation. In this section of the chapter, we explore these methodological concerns in relation to Feldman's experience as a facilitator of teachers' action research.

Setting the Agenda

The first of these methodological concerns is how the research agenda is set and who sets it. Tensions can arise between teachers and the project directors when the teachers are asked to do action research to meet the needs of a research agenda that they did not help to determine. These tensions arise because the teachers' reasons for engaging in the research do not match the goals of the funded project.

There are three ways that Feldman has seen this occur:

- Teachers' own research questions can push aside the agenda set by the project principal investigators.

- The project can call for teachers to do documentation or evaluation when they would prefer to focus on their professional development.

- The teachers' primary concern can be to satisfy their "need to know" that their teaching has the desired effect on their students' learning (Feldman, 1994a).

For example, in the original PTARG project, which was funded by the Spencer Foundation (Feldman, 1993), the teachers were aware of the goals of the project when they agreed to join it. However, as they engaged in collaborative action research, the problems and concerns that they had about their own practices, including their "need to know," pushed aside the PI's agenda.

During the academic year that PTARG was part of the Spencer Foundation funded research project, each of the teachers received a small honorarium for their participation ($500), a modest dinner was provided for each meeting, and several of the teachers were provided with travel funds to attend and make a presentation at meeting of the American Association of Physics Teachers. In addition, the teachers and Feldman invested significant amounts of time in the project during that year. Was this a good use of the resources? If measured against the goals of the funded project, the answer would be no. It should be clear that while the PTARG teachers agreed to be a part of the project and were aware of its goals, they were reluctant to participate fully in it. Eventually they did, but the outcomes were significantly different from those that the PI had expected, and as soon as the funded-year ended, the teachers abandoned that agenda for their own. This raises two issues: The first is whether we can expect teachers to engage enthusiastically in research that is not of primary concern to them. The PTARG teachers indicated to Feldman that they would and, in fact, did follow through with what they agreed to do. But this appeared to be more because of a feeling of professional obligation than of interest. This raises the question of why they joined the project in the first place if they had little interest in the stated goals. When asked, the PTARG teachers responded that it was a way for them to learn more about their own practice and to improve it by interacting with other physics teachers in ways that were not possible in their schools (Feldman, 1993).

Once in the projects, the teachers were aware of the commitment that they had made. In fact, the PTARG teachers told Feldman, in separate interviews, that they would have followed closer to the PI's agenda if they had been pressed to do so. This raised a second concern, one that has political and ethical dimensions: Given the hierarchical differences between university researchers and school teachers and the teachers' feelings of professional obligation once they agree to participate in a funded project, what can, or cannot, the directors of the projects do to keep the teachers focused on the project's agenda? And possibly even more important, is it necessary to make sure in some way that the teachers truly buy into the goals of the project before they are accepted into it?

A similar conflict of goals occurred in the action research component of the CA SS&C Project (Feldman, 1995c). Over the course of two years, twenty-four teachers engaged in action research on the implementation of SS&C in their high schools. In the original proposal for the CA SS&C Project, the action research component was envisioned to be a way for teachers to assist in the overall evaluation of the project and to generate knowledge about how students learn when science is taught in a coordinated manner. Only three of the teachers' action research projects could be considered evaluative in any way, and none was designed to generate knowledge about students' learning. In addition, these three evaluation studies were not done to satisfy the needs of

the PIs' or the National Science Foundation, the agency that funded the SS&C project, but rather to satisfy the teachers' own "need to know" that the effort that they were putting into the reform of their teaching was having the desired effects on their students. All of the others were concerned with either curriculum design and instruction or with structural problems in the school, the school district, or the region in the implementation of SS&C. It is important to note, however, that the action research component did meet the PIs' goal to create a mechanism that would provide teachers with information about the implementation of SS&C in other schools (Feldman, Mason, & Goldberg, 1992; 1993).

Structural Concerns

Feldman's work with the CA SS&C Project led him to identify methodological concerns that arose from the structure of the overall project and of the action research component. These included:

- a constrictive timetable.
- conflicting conceptions of what constitutes research.
- contradictions of control.
- the physical isolation of the teachers.

The first three of these flaws relate to what Feldman has called the institutionalization of action research (Feldman, 1995c). By this, he means that an organizational institution had been created and given legitimate status to promote a cause--the implementation of SS&C in California.

It is apparent that the institutionalized nature of this action research and the fact that these teachers are practicing professionals have impeded the research process. First, because the action research was embedded in the larger project, the timetable of the CA SS&C Project determined the pace of the action research. From the analysis of the action research component, it appears as if one academic year is not enough time for teachers to complete an action research project that is expected to generate new knowledge or be useful for program evaluation purposes. In fact, it appears that the first year is a time for sorting through priorities, coming to an understanding of the research process, and redefining the goal of the research. A second year would have been needed to proceed with the project. This is even more apparent when compared with Minstrell's action research biography, which began with his involvement with Project Physics in the late 1960s, developed through the 1970s, and resulted in his first publication in 1982.

A second impediment was due to the institutionalized nature of the action research, too. No distinction was made between research for professional development or

curriculum implementation and research for the purpose of program evaluation. To many of the teachers involved and to the directors of the CA SS&C Project, action research was seen as a way for teachers to evaluate the program at their schools. The teachers who attempted to do this found that it was a task well beyond the resources available to them. Related to this was an unforeseen conception that many of the teachers held of research in educational settings. While it may be expected for them to hold a conception of research similar to what is presented as "the" scientific method in introductory science textbooks, many thought of educational research as the collection of data about students to report to governmental agencies for accountability purposes.

Third, there were the contradictions of control (McNeil, 1988) inherent in this project, which was designed to be a site-based curriculum development effort, but was situated in a government initiative with its top-down, center-periphery, information transfer and control. While this had little effect on the day-to-day activities of the teachers in the CA SS&C Project, it had significant repercussions for the teacher leaders in the project (Kota & Feldman, 1993) and made the action research fellows unsure of what it was that they could focus on as problematic in their implementation of SS&C.

Finally, there was the geographic spread of the teachers involved. During the first year, most of the teachers were isolated physically from one another. They were spread throughout the entire 1000-mile length of California, although most of them were concentrated in the San Francisco, Los Angeles, and San Diego. This isolation led to two significant problems: The first was that the action research fellows did not know that their lack of time and other resources were not unique to them. The second was that they were not able to get the frequent critical feedback that would have allowed them to move ahead with their inquiries. Again, a look back at Minstrell's experience reinforces this. During much of his development as an action researcher, he had a supportive collegial relationship with Arnold Arons at the University of Washington.

Constraints of Schooling

In addition to the methodological concerns that arise from the structure of the funded project, there are those that are due to the constraints imposed by the structure of schools and of teachers' work. Chief among these are the lack of time to engage in any professional development activities other than those that are the normal part of teaching. In his work with PTARG and his teaching of a graduate seminar on action research, Feldman has developed a model of action research that is an enhancement of normal practice and relies on the use of sustained conversations in collaborative settings (Feldman, 1996; 1995b; Hollingsworth, 1994).

In enhanced normal practice, teachers engage collaboratively in action research through three mechanisms: anecdote-telling, the trying out of ideas, and systematic inquiry. In this context, "collaborative" refers to a group of teachers--or other practitioners--who form a group within which they work together to engage in action research on their individual practices. When the teachers gather together, they share stories of practice. One teacher may tell an anecdote; the others listen. The listeners

respond with their own anecdotes, with questions that ask for details, or with questions that take a critical turn and explore the nature of teaching and learning in schools in the context of the anecdote told. This is not a transmission model; rather it is a conversational exchange in a particular situation that relies on the teachers' expertise and experiences--what Searle calls the "Background," "the set of skills. habits, abilities, etc., against which intentional states function (1984, p. 68)."

As might be expected, ideas about practice are exchanged and generated in the anecdote-telling process. The teachers go back to their classrooms and try out these ideas. They then return to the group with new anecdotes that describe how these ideas were enacted and how the students responded to them. Again, the other teachers in the collaborative group respond to the anecdotes with their stories and with new questions. In this way, through both the taking of actions and through conversation, there is an improvement of practice and a better understanding of the teachers' educational situations.

The third mechanism of enhanced normal practice, systematic inquiry, is similar to classroom action research (Altrichter, Posch & Somekh, 1993; Calhoun, 1994; Sagor, 1992). It relies heavily on the collection and analysis of data in the modes of operation of the university. In the model of enhanced normal practice, systematic inquiry begins as the result of the uncovering of dilemmas or dissonances in practice that can be resolved only through a more detailed, systematic look at the practice situation.

As can be seen, sustained conversations are a significant part of enhanced normal practice. These conversations aid in research because they promote the exchange of knowledge and the generation of understanding through dialectical meaning-making processes. Again, it is important to note that this is not a transmission or conduit model in which words are the intermediaries between people that result in the transfer of thoughts, knowledge, or feelings (Reddy, 1979). Conversations play an important part in action research because they are critical inquiry processes. They are inquiry processes when the participants enter into conversations for the purposes of exchanging and generating knowledge and understanding, and when people enter into them to make defensible decisions about goals or actions. In this latter case, the participants are engaging in a form of practical reasoning, such as Aristotelian phronsis (Irwin, 1985). Conversations are critical inquiry processes because of the ways in which understanding grows among the participants (Gadamer, 1992). In conversations, the participants move between the conversational situation, their immediate understanding, and a more global understanding of what is being said, listened to, reflected upon, and responded to. Thus, conversations are analogous to the manner in which text is interpreted critically (Gadamer, 1992). When we come to understand a text, it helps us to understand its meaning in new ways. In the same way, conversation is a critical process that leads to new understanding and the new understanding shapes the conversation. It follows then, using Stenhouse's (1975) definition of research as systematic critical inquiry made public, that conversations, which can be mechanisms for critical inquiry, serve as a research method when systematized through the anecdote-telling mechanism of enhanced normal practice (Feldman, 1995a).

The Teaching of Action Research

Finally, there are the issues of how teachers learn to do action research and how others learn how to teach them to do it and how to facilitate it. It appears that learning how to do action research, as with learning how to do any type of research, is accomplished best by doing it. Therefore, if teachers are expected to have some level of expertise in action research when they do it as a part of a funded project, they should have had some experience with it already. What this means is that if projects are to incorporate teachers as action researchers, they must recruit teachers who have had experience with action research or another significant research experience, or there should be the expectation that the teachers' initial use of action research will serve mainly to teach them how to do it.

The same would hold true for those who teach teachers to do action research and facilitate it. Therefore, it is important for projects to include people with expertise in the teaching and facilitating of action research unless time is allowed for project personnel to gain that experience.

Summary: Lessons From Facilitating Action Research

When teachers engage in action research as a part of funded projects, methodological issues arise that relate to teachers' resources, goals, structures of the projects, and the constraints of schooling. Through our experience and inquiries into action research, we have developed the following set of suggestions for those who would like to include teachers' action research as a part of a funded project:

- Give it time. It appears that it may take up to one year for teachers to learn how to do action research. Then a second year would is needed for the teachers to look critically and systematically at their teaching.

- It is a group activity. Teachers get the most out of doing action research when it is done collaboratively with other teachers. It also appears, both from Feldman's experience with PTARG (Feldman, 1993) and his teaching of an action research seminar (Feldman, 1995a), that groups of teachers that transcend school boundaries may be more effective than groups within schools. His data suggest that when teachers collaborate with teachers from other schools, they are both less constrained by the cultures and structures of their own schools and more likely to find other teachers who can become invested in the idea of being teacher-researchers.

- The research questions should be generated by the teachers involved, or in collaboration with the PIs. The ownership of the questions can result in more ownership of the research.

- The methods, both quantitative and qualitative, of the natural sciences and the social sciences may not be appropriate for developmental teacher research.

The methods require resources that many teachers do not have, they may not satisfy the teachers' need to know, and they often do not match the rhythm of teaching (Feldman & Atkin, 1995). And, unless teachers are provided with time and other resources, the methods of action research need to be embedded in what teachers already do. In addition, ways should be found to allow teachers to maintain sustained conversations about their action research.

- In order for teachers to engage in research, or any noninstructional professional activities, ways need to be found to provide them with release time.

How can these lessons be applied to the use of action research in funded projects? The items in the list suggest that if action research is to be an integral part of funded research or development projects, it must be well structured and highly organized by the starting date of the action research component. Teachers need to be clear about what they are committing to, they must be provided with adequate resources including release time, and there must be ongoing support by trained facilitators. Teachers should be aware that not only are they committing to being a part of a project that provides them with colleagues and status, but also that they have a specific job to do. While the specific job may evolve as the overall project progresses, they need to be clear about what the agenda of the project is and who has set it. It is important to realize that the project directors have a responsibility to have thought this out carefully before asking teachers to make their commitment and to have enlisted the aid of individuals who have expertise in action research.

It also is important for the project directors to recognize that teachers' professional lives differ significantly from those of university researchers. Teachers have very little unscheduled time during the school day, are responsible for large numbers of students, are often involved in extracurricular and other professional activities, and have personal lives, too. If the teachers are being asked to do more than what Feldman has described as enhanced normal practice, they must be provided with real release time; for secondary school teachers, this means a reduction in the number of classes taught each day. Obviously, that would result in action research not being as cost-effective as some assume.

The project directors also should be clear that there are multiple conceptions of action research and that the type that they promote as a part of their project should be consonant with the goals of the project. From Feldman's experience with the CA SS&C Project and with PTARG, he has come to realize that a self-developmental form of action research can be at odds with the goals of a funded project.

Finally, it is important to build into the project methods for the maintenance of sustained conversations among the action researchers. This may mean having regular meetings about once every three or four weeks throughout the academic year and someone who can convene and facilitate those meetings. Without these gatherings and conversations, the action research may get put into that "next thing to do" pile and

emerge only when the teachers feel the professional obligation to deliver what they had agreed to.

As we come to the end of this chapter, there remains one more lesson that we must articulate. It is clear from Minstrell's narrative that, under the right conditions, a teacher who has the proper resources can engage in classroom-based action research that meets all of the validity demands of university-based research and adds significantly to the knowledge base on teaching and learning science. This suggests to us that, in addition to thinking about how teachers can be utilized as researchers in others' funded research and development projects, the possibility should be considered that they can be researchers in their own right. Clearly they would need to learn how to be researchers and most likely go through some sort of apprentice experience. In effect, what Minstrell did when he completed his doctorate at the University of Washington. But, more importantly, ways would need to be found to support them in their roles as teachers and researchers through significant funding opportunities.

Conclusion

The purpose of this chapter has been to help readers develop their understanding of what action research is and can be, and how it can be used for the professional development of teachers, the formative and summative evaluation of programs, and the generation of new knowledge about teaching and learning.

There are four main points that we want to reiterate and relate to the use of action research as a part of funded projects:

- Action research has a history. As with any human endeavor, that history can be told in many ways, and how one reads it affects the understanding of what action research is.

- Learning how to do action research is a part of the process of becoming an action researcher. In other words, it is a developmental process that occurs over time. We saw that in Minstrell's action research autobiography and in the projects that Feldman facilitated. Teachers begin with a curiosity about teaching and learning, which may be tied to a moral imperative that they feel to help students learn. This leads them to try out different ways to teach and then to their feeling a need to know that their new methods are having the desired effects. By grappling with ways to satisfy that need, teachers begin to realize that systematic inquiry can be used to understand the educational situations in which they practice and to help them change those situations so that learning can take place.

- Doing action research can result in teachers feeling a tension between teaching and researching. This tension arises from the uncertainty about their role in the classroom as well as questions about the validity and reliability of their research. While Minstrell has been able to construct his practice so that he is a

teacher, a researcher, and an action researcher, others have felt the dilemma that results from that tension (Feldman, 1994a; Wong, 1995).

- We have produced a list of suggestions and concerns about the use of action research. It should be clear that while this list may provide useful guidelines for engaging teachers in action research to improve their practice, they can be at odds with the use of action research for the furthering of the goals of funded research and development projects.

How, then, do these points relate to the use of action research as a part of funded research and development projects? The first suggests to us that it is important to make explicit what one means by the term whenever action research is considered as a method for these projects. The second raises the issue of time. While becoming an action researcher can stretch over a teacher's career, funded projects have definite timetables by which they are constrained. The third point reminds us that the demands on teachers and their teaching goals may be in conflict with the agendas of the projects or the methods that help to ensure reliability and validity. And the list of lessons highlights the differences between action research for the professional development of individual teachers and action research that is institutionalized to meet the needs of a funded project. All of this suggests that if teachers' action research is to be used successfully in funded projects, the principal investigators of those projects need to give careful consideration to what the purposes of that action research are, how it fits into the overall goals of the project, and how teachers will be supported so that they can become action researchers.

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