# SCIENTIST-TEACHER PARTNERSHIPS AS PROFESSIONAL DEVELOPMENT:

# AN ACTION RESEARCH STUDY

By

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To the Faculty of Washington State University:

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SCIENTIST-TEACHER PARTNERSHIPS AS PROFESSIONAL DEVELOPMENT:

AN ACTION RESEARCH STUDY

Abstract

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The overall purpose of this action research study was to explore the experiences of ten middle school science teachers involved in a three-year partnership program between scientists and teachers at a Department of Energy national laboratory, including the impact of the program on their professional development, and to improve the partnership program by developing a set of recommendations based on the study's findings. This action research study relied on qualitative data including field notes recorded at the summer academies and data from two focus groups with teachers and scientists. Additionally, the participating teachers submitted written reflections in science notebooks, participated in open-ended telephone interviews that were transcribed verbatim, and wrote journal summaries to the Department of Energy at the end of the summer academy. The analysis of the data, collaboratively examined by the teachers, the scientists, and the science education specialist acting as co-researchers on the project, revealed five elements critical to the success of the professional development of science teachers. First, scientist-teacher partnerships are a unique contribution to the professional development of teachers of science that is not replicated in other forms of teacher training. Second, the role of

the science education specialist as a bridge between the scientists and teachers is a unique and vital one, impacting all aspects of the professional development. Third, there is a paradox for classroom teachers as they view the professional development experience from two different lenses – that of *learner* and that of *teacher*. Fourth, learning for science teachers must be designed to be constructivist in nature. Fifth, the principles of the nature of science must be explicitly showcased to be seen and understood by the classroom teacher.

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# Dedication

This report is dedicated to my amazing colleagues in the Science and Engineering Education Department of Pacific Northwest National Laboratory who continuously believe, as I do, in the power of bringing scientists and teachers together for the betterment of both. You allowed me to share my research as it continued to evolve and helped me look at the findings with a clearer lens. You have taught me how important relationships are to any process and most importantly how incredible it can be for someone with my passion to be allowed the joy of following this passion for a living.

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# Chapter 1

# INTRODUCTION

This is a report of an action research study conducted at the Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL) in Richland, Washington, during 2007-2008. PNNL sponsors professional development programs for K-12 teachers that involve partnerships between scientists and teacher participants. The program that is the focus of this study involved middle school teachers in a two-week summer academy for each of three consecutive summers starting in 2007. I am employed by PNNL as a Science Education Specialist and had responsibility for coordinating this scientist-teacher partnership program overseeing all aspects of the program's success for both classroom teachers and scientist-mentors.

The overall purpose of this study was to (a) explore the experiences of middle school science teachers involved in a partnership program between scientists and teachers at PNNL, including the impact of the program on their professional development, and (b) to improve the partnership program by developing a set of recommendations based on the study's findings.

## A Call to Action

In the last several decades, science education and the need for a scientifically literate citizenry have received renewed attention in the United States. Our country is now part of a global community in which other nations increasingly compete for international standing and a share of the global market. This contest is not just for products but also for intellectual property – the ideas that can come from a well educated population of scientists and engineers. However, in recent years, it has been difficult for the United States to keep up with the demand for both well-trained scientists and engineers as well as the teachers who are needed to prepare them (NRC, 2007).

Today, K-12 teachers must be qualified to teach science, technology, engineering and/or mathematics (STEM) in an environment characterized by a highly diverse student population and the highest education standards ever set in the U.S. (Michaels, Shouse, & Schweingruber, 2008). The K-12 education system struggles to "feed the pipeline" with talented, scientifically literate men and women who are qualified to work as scientists and engineers. There is a sense of urgency in regard to encouraging young people to choose the fields of science, technology, engineering or mathematics and to cultivate the teachers needed to prepare them well.

*Science Education Reform*

In examining the history of the United State's science education system, many point to a critical moment that created a heightened interest in science education reform (AAAS, 1993; Dickson, 2007; Michaels et al., 2008; NRC, 2007). On October 4, 1957, a first in a series of satellites collectively known as the Sputnik Program was launched by the Soviet Union. It was the world's first Earth-orbiting artificial satellite, and the announcement of its success took the United States by surprise. The concern that the Soviets had beaten Americans into space sparked a revolution in science education in the U.S. America's scientific community, which had long been pushing for a new direction in science education, seized on the national mood to rejuvenate the curriculum being taught in schools. Washington journalist Paul Dickson, in his book *Sputnik: The Shock of the Century* (2007), tells of the pivotal moment when the federal government infused more than a billion dollars in science education through the National Defense Education Act of 1958. The intent of this act, and other initiatives, appeared to be that scientists and teachers would begin to work together to improve science education. Because scientists knew little of the realities of teaching, and teachers knew relatively little about the content and practice of science itself, each could learn from the other in partnership while working together on National Science Foundation funded curricular projects (Bybee, 1997).

The science education reform projects that emerged from the 1950s to the early 1970s focused on developing new science teaching materials and methods that were not textbook-based. The National Science Foundation funded curriculum-writing projects at universities as well as pilot testing new approaches in the field. First to be published were secondary science programs, and soon to follow were the programs for elementary and middle school levels. Among the most widely used programs were the Science Curriculum Improvement Study (SCIS), Elementary Science Study (ESS), Conceptually Oriented Program in Elementary Science (COPES), and Science: A Process Approach (SAPA), often referred to as the "alphabet soup programs" (Bybee, 1997). These programs provided teachers with science activities that focused on important science content and engaged students with hands-on learning. The supporting teachers' guides included the activities themselves and the science content background the teachers needed to teach the activities.

While there was widespread opportunity for the science community and science educator community to support the reform-based programs, they were never widely adopted by U.S. schools. In fact, only a quarter of schools ever used any of them (Weiss, 1987). Activity oriented science seemed to be all the rage nationally, and in some communities, traditional textbooks were set aside. But the majority of schools across the country were not impacted by these reforms for several reasons.

One of the reasons for the lack of implementation was teacher preparation. To implement these new programs, teachers needed mastery of both science content and appropriate pedagogy to conduct an activity-based, discovery-oriented program. While federal funding provided opportunities for professional development for K-12 teachers, this new way of teaching represented a paradigm shift that few teachers were willing to make. Although some school districts did adopt the new programs, they retreated back to their former practices by the early 1980s, when the back-to-the-basics movement put science education once more on the back burner. The traditional science textbook was again the dominate guide in the science classroom at all levels of K-12 schooling.

However, with the publication by the National Commission of Excellence in Education of *A Nation at Risk*, in 1983, which called for more rigorous and measurable standards, the tide changed. In 1989, the American Academy for the Advancement of Science responded to the report by releasing *Science for All Americans* (AAAS), which created a vision of the knowledge a scientifically literate person should possess. In 1993, AAAS produced a companion report, *Benchmarks*, which specified how students should progress toward that science literacy. The latter publication recommended what students should know and be able to do at three year intervals (K-2, 3-5, 6-8, and 9-12). Together, the two AAAS publications helped bring K-12 STEM education back towards the front burner.

Following on the AAAS work, the National Research Council (1996) promulgated *the National Science Education Standards* connecting the two AAAS publications into a document that paints a picture of effective science instruction from elementary school through high school. It is from these standards that states across the United States have built their own state standards and assessment systems in the wake of the federal government mandate in 2001 of the *No Child Left Behind* act.

In looking back at this relatively recent flurry of activity in science education, one would think that the educational system would be producing an adequate number of scientists and science teachers. But, according to F. James Rutherford (1998), instrumental in the writing of the AAAS publications, school districts all across the United States continually struggle to find qualified teachers to teach in STEM classrooms. Rutherford talks of four lessons often forgotten in preparing teachers of science. The first is the lack of focus on the attainment of long-term educational goals caused by reacting only to immediate crises. For example, in the 1950s, the United States feared lagging behind in an international space race while today this country should be motivated by international trade competition. Second, according to Rutherford, a period of inaction occurred after the initial reaction to the launch of Sputnik. Instead of a continual movement forward, the country turned to a quick fix with science curricula and standards forgetting that true reform takes decades of continuous effort. Third, the federal government can play a definitive role in reform but needs to continue funding reform efforts. Many localized school districts were unable to pick up the tab for the professional development, teaching materials, and hiring needs that accompany a reform effort such as this. Finally, the fourth lesson is that the education of all students is important to consider. In the 1950s, the nation focused efforts on preparing teachers to teach those students seen as potential first-rate scientists and engineers. Today's school system is made up of programs designed to be more inclusive than in the past. All students in the K-12 system should have equal access to science education, but needed are teachers who understand science, how students think about and learn science and what a teacher needs to know to be able to teach science proficiently. Michaels, Shouse and Schweingruber (2008) note:

> If teachers are to create rich science learning experiences for their students, they themselves need to be supported to become learners and investigators of the science they teach, of their students' thinking, and of the best ways to orchestrate their students' learning of complex concepts, tools, and practices. (p.163)

*Professional Development*

Well designed professional development plays a key role in helping to produce the teachers who understand the scientific content and technological pedagogy required to transform teaching practice in the K-12 science classroom. But the current state of professional development for science teachers is less than ideal. Susan Loucks-Horsley et al. (2003) characterize professional development in four ways:

> (a) significant numbers of teachers have few or no professional development opportunities; (b) a large percentage of the opportunities come in the form of workshops, courses, and institutes that may not be appropriate to the learning goals nor provide sufficient support over time for teachers to apply what is learned in classrooms; (c) a focus on individual development, one teacher at a time, places no attention to organizational development; and (d) some pockets of innovation occur, but with minimal means for greater impact, both within their own system or beyond. (p.xviii)

There is little dispute in the research community that improving teaching and learning depends on sustained, high-quality professional development (Darling-Hammond, 1997; Loucks-Horsley et al., 2003; NSDC, 2001; U.S. Department of Education, 2002), but to accomplish this, effective professional development must involve teachers both as learners and as teachers (Darling-Hammond, 1997). Teachers should be engaged in a program designed to improve science literacy that includes a clear image of classroom learning and teaching (Loucks-Horsley et al., 2003), an attention to the content of science and the pedagogical content knowledge of the science classroom (Shulman, 1987), and a level of dissonance that disturbs the teachers' existing beliefs, knowledge, and experiences (Thompson & Zeuli, 1999) causing them to leave behind their prior ways of teaching and move to a new pedagogy of science teaching.

What types of professional development meet this new way of thinking? Loucks-Horsley, et al. (2003) describe a shift from "providing teachers with opportunities to learn generic instructional strategies to designing professional development around the essential scientific literacy teachers need to teach the science embodied in the standards" (p.xv). The work envisioned by Loucks-Horsley and her colleagues was to create a planning tool for professional development providers so that they might engage in intentional planning focused on the needs of a set of classroom teachers of science and mathematics. This framework takes into account the knowledge and beliefs of those in the science and mathematics teaching profession, the critical issues and context surrounding the teacher's practice, and a variety of strategies allowing planners to create a rich, ongoing professional development experience embedded in the daily work of teachers. Loucks-Horsley et al. identified 18 different strategies for professional learning that planners of professional development can select when designing programs. These strategies are grouped around six categories: aligning and implementing curriculum, collaborative structures, examining teaching and learning, immersion experiences, practicing teaching, and vehicles and mechanisms. Each strategy is an example of professional development in science and mathematics that is intended to be matched to the context and purpose of a professional development program.

One of the categories listed above, “collaborative structures,” engages teachers in doing science by inviting them into the world of scientists through a shared partnership between the teachers and the scientists in business, industry, museums, science centers, and universities. This approach is grounded in adult learning research which indicates that learning is enhanced through direct experience of science content and the process of inquiry and problem solving (NSDC, 2001). Joyce and Showers (1995) found that using scientists as role models and “coaches” for teachers dramatically increased the transfer of knowledge, skill and application to the classroom. As a form of professional development that allows the teacher to develop scientific literacy skills in an authentic venue, the impact of the scientist-teacher partnership in an immersion experience has been the focus of numerous studies over the years (Barab, 2001; Kranshy, 1999, Loucks-Horsley et.al, 2003), but the emphasis has most often been on partnerships with scientists in higher education, not with scientists from traditional scientific laboratory settings. Partnerships between teachers and scientists in general are powerful learning experiences for all involved; however, the partnerships with traditional laboratory scientists are not without challenges and are under-researched.

## Action Research

Reason and Bradbury (2006) state that action research has three important purposes: (a) to “bring an action dimension” into the tradition of research; (b) to expand the realm in which research is conducted – away from the university and into other arenas; and (c) to “add impetus to the movement away from a modernist worldview based on a positivist philosophy” toward a more participatory worldview (p. xxiii).

It is commonly agreed that action research involves a collaborative relationship between stakeholders who share a common issue and a need to uncover a potential solution to a problem they confront in their everyday lives leading to some improvement in practice (Greenwood & Levin, 1998; Miller & Pine, 1990; Reason & Bradbury, 2006; Stringer, 2007).

Action research overlaps with qualitative research in that it examines an issue through the collection of data such as interviews, focus groups, and field notes, yet it involves two key differences.  Researchers and their study participants are seen as co-researchers in concert with one another and there is a significant value placed on the importance of "taking action" (Stringer, 2007).

Stringer calls action research "a methodical process of inquiry" that is iterative in nature, wherein co-researchers engage in a basic research cycle of "look, think, act" (p. 54) around a problem of practice.  First, during the "look" phase, co-researchers decide together what information is needed to understand a problem and how to gather their data.  They then engage in observations, interviews, focus groups, examining artifacts, and reviewing the literature, all with the purpose of shedding light on the problem being investigated.  Next, in the "think" phase, co-researchers engage in data analysis that allows them to understand "how people experience and respond to the events and activities that comprise the focus of the research itself" (p.88).  The data analysis includes identifying key experiences that impact participants and a process to deconstruct those experiences to uncover the elements that comprise them.  The co-researchers look for codes or units of meaning that can be grouped into themes to provide greater understanding of the problem, ultimately revealing a theme or set of themes around which solutions can be generated.  Finally, the "act" phase of the cycle is comprised of two parts: communicating and taking action.  To communicate, a report is developed from the "think" phase analysis. The report presents the findings of the research and possible implications for future practice. Then, to take action, the co-researchers carry out specific steps to modify practices, and the ongoing action research cycle begins again to examine the impact of the actions taken.

Bogdan and Biklen (1992) define action research as "the systematic collection of information that is designed to bring about social change" (p.234). They go on to compare action research to qualitative research by saying "action research builds on what is fundamental in the qualitative approach. It relies on people's own words, both to understand a social problem and to convince others to help remedy it" (p. 242).

Reason and Bradbury (2006) approach the definition of action research through a series of three research pathways called the first person, second person, and third person research pathway. The first person action research pathway is done by a researcher inquiring into his or her own life. The second person action research pathway involves others who face a mutual concern agreeing to participate in a community of inquiry. The third person research pathway aims to create a wider community of inquiry involving people who may not be known to one another. They argue that the most "compelling and enduring kind of action research will engage all three action research pathways" (p. xxvi).

It is in the spirit of the action research pathways and the "look, think, act" research cycle that I share the action research study that grew out of personal interest in understanding the impact of partnerships between scientists and teachers in professional development at the Pacific Northwest National Laboratory (PNNL), in Richland, Washington (first person action research pathway). Emerging next was a desire to include the scientist-mentors and the participating teachers in a collaborative approach to think more deeply about improving the professional development experience for our own knowledge base (second person action research pathway) and to inform the literature around partnerships such as this between classroom teachers and scientists in a traditional laboratory (third person action research pathway).

## The Study

This report details an action research study that examined the professional development of ten middle school science teachers involved in a partnership program that began in 2007 at a research laboratory as opposed to a university setting. The overall purpose of this study was to (a) explore the experiences of middle school science teachers involved in a partnership program between scientists and teachers at the Pacific Northwest National Laboratory, including the impact of the program on their professional development, and (b) to improve the partnership program by developing a set of recommendations based on the study's findings. The research questions we asked were: (a) What are the perceptions of the middle school science teachers of the value of the partnership model in regard to their own science literacy development? (b) What are the strategies of professional development the teachers found most valuable when working with scientist-teacher partnerships to develop their science literacy? and (c) What other elements of the summer academy assisted the teachers in developing their own pedagogical content knowledge in order to deliver science as a classroom teacher more effectively?

This action research study focuses on a problem that was revealed while conducting an earlier qualitative case study. The previous study examined the impact of partnerships between middle school science teachers and research scientists at PNNL. The purpose of that study was to uncover the teachers' perceptions of the professional development experience and its impact after the first summer of the program and to see if the partnership fostered change in the middle school science teacher's science literacy, teaching, or both. The qualitative case study revealed frustrations on the part of the middle school teachers around the model for professional development that had been designed for them.

Based on the findings from the earlier study, it became apparent that an action research study would be a valuable way to redesign the partnership program and capture the voices of both the middle school teachers as well as the scientist-mentors. We worked collaboratively to propose changes to the program and to create a set of recommendations for future programs at PNNL. Together we set about creating a partnership program that would be seen by the teachers as powerful professional development to deepen their science content knowledge and to enhance their abilities to teach science and by the scientists as a viable way to have impact on the education of young people.

The Pacific Northwest National Laboratory (PNNL) in Richland, Washington was the site for this action research study. The Laboratory is a part of the United States Department of Energy's National Laboratory complex offering a range of opportunities for teachers, students, and visiting scientists and has developed a reputation both regionally and nationally for its summer programs. From simple week-long workshops, to full eight week research appointments, participants have varying levels of opportunity to work with mentoring scientists at the Laboratory.

This report covers the "look" and "think" phases of the action research cycle (Stringer, 2007) with the understanding that the recommendations generated from the research would serve as the basis for the "act" phase of the cycle. This action research study relied on qualitative data including field notes recorded at the summer academies and data from two focus groups with teachers and scientists. Additionally, the participating teachers submitted written reflections in their science notebooks, participated in open-ended telephone interviews that were transcribed verbatim, and wrote journal summaries to the Department of Energy at the end of the summer academy.

*Research Ethics*

Action research is "inquiry that is done by or with insiders to an organization or community, but never to or on them" (Herr & Anderson, 2005, p3). Because of the participatory nature of an action research study, ethical considerations work in a somewhat different way. All stakeholders have the same rights to care, safety and informed consent as would apply in other forms of research. But in action research, the processes are transparent to the participants allowing all to know what is going on as data are collected, analyzed, and interpreted. The teachers in this study were asked to sign a letter of consent with the option to refuse to participate or to withdraw from the study at any time but each agreed to take part in the study. Together they decided to use pseudonyms to protect their own privacy in case comments reported in the data are at all embarrassing. These accommodations have given the participants a higher level of control than in a qualitative or quantitative research study and created a feeling of mutual agreement about the conduct of the study.

The study was designed to allow all participants multiple opportunities for reflection and dialogue about the partnership, the conduct of the research and the set of recommendations to be made based on the study. These accommodations gave voice and a sense of ownership to the participants.

*Positionality*

My role as the science education specialist who coordinates the summer academies puts me into the action research category of "insider to an organization" (Herr & Anderson, 2005). It is a complex role as I sit between the classroom teacher participating in the summer academy and the scientist-mentors, in a sense, translating one world into the other – a sort of bridge to the classroom. I work throughout the school year prior to the summer institute to help the scientist(s) create a two week adult learning experience that is both meaningful and intellectually accessible to the classroom teachers. I work with the classroom teachers, while at the lab in the summer, to translate how the adult learning experience might look in the middle school classroom and to connect the experience to their existing set of instructional materials. It is through my lens as a former K-8 science specialist that I feel I can understand the classroom from which these teachers come and can help them weave their learning into practice.

Because of my proximity to the research, a bias may potentially exist. Quite honestly, my interpretations are seen through a lens of believing in this model of professional development due to my years of working with PNNL on similar projects with elementary teachers. I must guard against the inferences I might make based on my observations due to the passion I bring to the belief in the power of these partnerships.

This action research study could also be considered "a collaborative form of action research that achieves equitable power relations between insiders and outsiders" to the organization (Herr & Anderson, 2005, p. 31). Many eyes other than mine will see the data. Giving access to the participating middle school teachers and the scientist-mentors allows a sort of "tempering" of my thinking with the thinking of others. In the end, this will allow me to engage in critical reflection on both the process and the experience of doing this research from my position on a team of researchers. The contribution to the knowledge base for improved practice in partnership programs should result in the development of a set of recommendations crafted from multiple perspectives.

## Organization of the Report

This report consists of four chapters. Chapter 1 provides an overview of the study. In Chapter 2, I present a review of the literature in five major areas: (a) the need for science literacy, (b) the learning of science, (c) the teaching of science, (d) professional development of science teachers, and (e) scientist-teacher partnerships. A detailed report describing the setting and the methods used in this action research study follows in Chapter 3, presented via the fully articulated action research phases (Stringer, 2007) of "look, think and act." In Chapter 4, I discuss the conclusions of the study and recommendations for partnership programs at a National Laboratory such as PNNL, along with my aspirations for further inquiry into the power of the partnership model for professional development of science teachers.

# Chapter 2

# REVIEW OF THE LITERATURE

In this review of the literature, I will discuss the importance of science literacy for all, the challenges an education system faces in understanding how students learn science, and the training high quality teachers of science need to teach science. Then, I will examine a framework for the design of teacher professional development for the acquisition of content knowledge and the pedagogy of teaching science through methods such as inquiry. Finally, I will share what is known about promising models of professional development such as partnerships with scientists and teachers as possible avenues for making the changes necessary in professional development for science education reform.

## The Need for Science Literacy

Science and technology are the foundations of a modern civilization in a world that has become a global marketplace. New discoveries are being made and integrated into our lives at an exponential rate (NRC, 1996). This age of scientific discovery brings daily debates of complex issues of science and technology in the press, on television, and on the internet. All around us the standards for technical and scientific literacy are becoming more stringent, not less. As science and technology permeate our lives, they create a strong need for a scientifically literate citizenry.

### *Science Literacy for All*

Robert Hazen, in the book *Science Matters* (1991), describes science literacy for the general population as the “knowledge needed to understand public issues.” There is a clear distinction, according to Hazen, between “using science” and “doing science.” Scientists engage in the “doing science,” whereas the general public needs a basic understanding of science to “use it” on a daily basis (p. xii). The average citizen should possess the foundations of science to understand the national debates around science and technology and to be critical consumers of that information. Therefore, Hazen reasons, scientific literacy is a mix of facts, vocabulary, concepts, history, and philosophy.

The American Association for the Advancement of Science (AAAS) published *Science for All Americans* in 1991. This seminal document addressed what constitutes adult science literacy and recommended what it is that a person should know and be able to do in science, mathematics, and technology by the time they exit a K-12 school system. AAAS explains that literacy in science, mathematics, and technology helps people live interesting, responsible, and productive lives:

> In a culture increasingly pervaded by science, mathematics, and technology, science literacy includes understandings and habits of mind that enable citizens to grasp what those enterprises are up to, to make some sense of how the natural and designed worlds work, to think critically and independently, to recognize and weigh alternative explanations of events and design trade-offs, and to deal sensibly with problems that involve evidence, numbers, patterns, logical arguments, and uncertainties. (p. 171)

Science literacy today can be seen as a union between science, technology, engineering, and mathematics, (STEM) which comprises the scientific endeavor (NRC, 1996). Given that STEM education has become a current topic of concern, the goal to sustain the scientific enterprise with new scientists and engineers is coupled with the goal to improve the mathematics and science education needed to develop a populace generally considered to be scientifically literate.

*Student Science Literacy*

In 1993, AAAS published a second influential document, *Benchmarks for Science Literacy*. The intent of this publication is to "create a powerful tool to use in fashioning curriculum" that "concentrates on the common core of learning contributing to the science literacy of all students" (p. xiii). The publication outlines what students generally should know and be able to do at grade bands of K-4, 5-8 and 9-12 to adequately progress toward science literacy. For example, each grade band offers reasonable checkpoints for student progress toward science literacy, but does not suggest a rigid formula for teaching. *Benchmarks* is not a proposed curriculum, but should be seen as a tool educators can use as they design curricula that fit their students' needs and meet the goals outlined in *Benchmarks*.

Similarly, Yore (2007) developed a set of six important characteristics a student should possess to be scientifically literate. First is the ability to build knowledge claims and make sense of the world. Second is the need to critically analyze claims, procedures, measurement errors, and data to uncover the truth. Third, justifying data as evidence for or against a claim should be based on theory, not inference. Fourth is the possession of analytical reasoning abilities, problem-solving skills and troubleshooting capabilities. The possession of the ability to perform general processes of science is fifth on the list, with observing and measuring being two of those processes. Finally, being able to plan and evaluate investigations completes the list.

Given that acquiring science literacy is so important, it is also important to understand how children develop theories about the world and how it works (AAAS, 1993). In the next section, I will share examples of the research that has begun to uncover the ways in which a learner acquires new science knowledge.

## The Learning of Science

For more than 60 years, cognitive scientists have been observing how children approach and solve problems. Their work has resulted in a body of research about the learning process. Building on and modifying the foundation laid by Jean Piaget in the 1920s through the 1960s, cognitive researchers have uncovered much about how students gain understanding. Michaels, Shouse, and Schweingruber (2008) state that both children and adults, when faced with an unknown situation, try to determine what is happening and predict what will happen next. We reflect on the world around us by observing, gathering, assembling, and synthesizing information. We develop and use tools to measure and observe as well as to analyze information and create models. We check and recheck what we think will happen and compare results to what we already know. Then, we change our ideas based on what it is we learn. These processes can form the underpinnings of scientific thinking and can be used as a foundation to build understanding, even in the early grades.

Other studies have shown that even young children have surprisingly sophisticated ways of thinking about the world based on their direct experiences with the environment, as they have made observations and tried to sort those observations into a conceptual framework for storage into memory (Bransford, Brown, & Cocking, 1999). Ryder, Leach, and Driver (1999) and Driver, Guesne, and Tiberghien (2000) have contributed significantly to the research around the memories or understandings children possess. As children progress through their lives collecting up bits of information and placing them in a conceptual framework, they gain misconceptions that are often tenaciously held. These beliefs, or interpretations of the world, are difficult to change and take concerted effort on the part of the classroom teacher to do so (Driver et al., 2000).

A ground breaking report, *How People Learn: Brain, Mind, Experience, and School* (Bransford et al., 1999), significantly contributes to our understanding of how students learn science. Three key principles emerged from this report. The first principle points out that students arrive to any classroom with a set of preconceptions about how the world works. If a student's initial understanding "is not engaged," the student may fail to grasp new concepts and information presented in the classroom, or they may learn those concepts purely "for purposes of taking a test and then revert to their strongly held preconceptions" (p. 14). The second principle outlines that "to develop competence" in an area of scientific inquiry, students must build a "deep foundation of factual knowledge, understand facts and ideas in the context of a conceptual framework, and organize knowledge in ways that facilitate retrieval and application" (p.16). The third principle is focused on the term *metacognition*, coined by John Flavel, a Stanford University psychologist, in the late 1970s, to name the process of thinking about one's own thinking and learning (Keeley, 2008). This third principle tells of a "metacognitive approach to instruction" that can help students learn to take control of their own learning "by defining learning goals and monitoring their progress in achieving them" (p. 18). Evidence from this research indicates that when these three principles are incorporated into instruction in the science classroom, student achievement improves.

Research has consistently shown that K-12 students do not necessarily develop scientific literacy through merely participating in a K-12 program of science (Lederman, 1992; Meichtry, 1992, NCISE, 1989). The National Center for Improving Science Education (NCISE) argues that "the heart of the problem is not children's inability" to understand science, "but that most children are not taught science at all, and when they are, they are taught in a way that progressively diminishes their interest in the subject and their confidence in their capacity to learn it" (p. 2). The NCISE document goes on to say "by the time the child reaches junior and senior high school, they are expected to memorize science from a textbook" which is "seen as boring, pointless and not to mention, too hard" (p. 3). Driver, Squires, Rushworth, and Wood-Robinson (2005) also share this view. They state that school classrooms often present students with images of scientific knowledge and thinking as "fundamentally different from common-sense reasoning, and it may therefore be perceived by many pupils as inaccessible" (p. 7).

These views have implications for what is taught in science, how science is taught, how to promote deeper understanding in science and the acceptance that science literacy is for all not just an intellectual few (AAAS, 1993).

## Teaching Science

If learning science requires conceptual change to occur in students who hold misconceptions, teachers need to address students' existing beliefs and knowledge and directly confront those misconceptions (Bransford et al., 1999). To challenge these misconceptions, Driver et al. (2005) contend that "learners need to be given access not only to physical experiences but also to the concepts and models of conventional science" (p. 6). If teaching is to "lead pupils towards conventional science ideas, then the teacher's intervention is essential, both through providing appropriate experiential evidence and making the theoretical ideas and conventions of the science community available to pupils" (p. 6). The knowledgeable teacher can guide students through an investigation in which they confront their misconceptions through testing and discussion. Students work toward resolving conflict by accommodating the new concept thus enhancing their understanding (Posner, Strike, Hewson, & Gertzog, 1982).

The National Research Council (NRC), in partnership with the Merck Institute, recently released a book, *Ready, Set, Science* (Michaels, Shouse and Schweingruber, 2008) based on the report, *Taking Science to School* (NRC, 2007). The book summarizes studies of science education practitioners who work with and support K-8 classroom teachers and speaks of a new vision of science education accomplished through change in the way science is taught and learned. In order to teach science well, teachers need to understand science differently from how scientists understand science. A scientist understands scientific theory and its historical origins, the questions being investigated and the ways in which questions are investigated in his or her field. “But a scientist does not necessarily know how to convey scientific knowledge to children or other non-experts, nor how to create appropriately structured opportunities for practicing science” (p. 158).

Research has begun to uncover strategies educators can use to assist children in building a more stable and well constructed conceptual framework for understanding the complexities of science (NSRC, 1997). Research on the transfer of learning has shown that students’ understanding is greatly enhanced when they are asked to apply their knowledge to new and different situations (Donovan et al., 2000). If the experiences they have engaged in have helped them grasp the underlying principles, then they are more likely to be able to apply what they know to new situations and remember what has been learned. Learners need time to wrestle with new information, to explore underlying principles, and to make the connections between new knowledge and their existing frameworks. Students need explicit messages about what it is they are engaged in and why, while being taught by a knowledgeable teacher who is also scientifically literate. These key elements of a learner’s development of understanding of the nature of science encompass an understanding of the purposes of doing scientific work, an understanding of the nature and position of scientific knowledge, and an understanding of the science as it exists in the political and social enterprise (Akerson & Hanuscin, 2005; Lederman, 1992; Schwartz, Lederman, & Crawford, 2004).

Bransford et al. (1999) found that teachers can help their students become increasingly self directed in their learning by asking them to ask questions about their new learning and how they went about learning this new information. Being metacognitive about their own learning enhances their ability to monitor their own processes and aids them in learning how to recognize when they do not understand and should seek more information.

*Teaching Science through Inquiry*

For students to build deep knowledge of science, their teachers must do more than merely cover the topics (Donovan, Bransford & Pellegrino, 2000). With a general consensus about how people learn and develop an understanding of any concept, research from child development, cognitive psychology, and educational practice strongly supports science inquiry and hands-on science as effective teaching pedagogy (Bybee, 1997; Driver et al., 2005; Hurd, 1998; NRC, 2000; Weiss 1987). Conversely, direct instruction dominated by lectures or demonstrations done in the front of the classroom may not build a deep or enduring set of conceptual understandings (Ruby, 1999).

The National Research Council (2000), with the release of standards for teaching inquiry, set about defining inquiry as:

> a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using

tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. (p. 14)

The *National Science Education Standards* (NRC, 1996) state that teachers should build on a student's curiosity about the natural forces of the world to stimulate scientific inquiry. The science standards about teaching encourage teachers to provide their students with inquiry-based science that emphasizes not only the knowledge and skills of scientific inquiry but also its attitudes, and values especially intellectual curiosity. Not all students will choose to become scientists, but the science standards ask teachers to simply "foster in all students, the awareness of science as a dynamic, creative intersection of questions, observations, and evidence, data and ideas, predictions and explanations based on evidence" (p. 12).

Scientific inquiry and hands-on science are not synonymous; many teachers do hands-on science, but not inquiry (NRC, 2000). Many approaches to science teaching have used hands-on activities but not student directed inquiry (Ruby, 1999). Bybee (1997), a staunch proponent of a continuum of inquiry, believes that inquiry moves from being strongly guided, in which the classroom teacher takes the locus of control, to an open ended form of inquiry wherein the student decides on the investigation and is in full control of its outcomes. Whatever the form of inquiry, the teacher should keep the focus squarely on student understanding.

*The Pedagogy of Teaching Science*

Effective teaching of science requires a deep knowledge of the content to be taught interwoven with an adequate knowledge of pedagogy on how to teach science and scientific inquiry. Teachers should comprehend how the ideas within their discipline are interrelated and connected and what is to be taught to students (Abel, 2007). How to teach science effectively is explained by Hewson (2007) as the pedagogy or the art of teaching.

Two dimensions of any knowledge base in any discipline are the content knowledge and the pedagogical content knowledge, as explained by Shulman (1987). The content knowledge consists of the facts, concepts, and principles within the area of science and the relationship these elements have to one another. On the other hand, pedagogical content knowledge is the blending of the content into an understanding of how topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of the students. Michaels et al. (2008) believe that "effectively changing science teaching and learning will require dramatic changes on the part of those involved in the education system" (p. 26). They further state that the educators who shape K-8 science learning should "reexamine their work in light of current thinking about teaching and learning science. In order to be effective, science learning must be supported by a broad, complex education system that supports and guides good teaching" (p. 26).

Teachers need to know science in light of the instruction of science. In other words, they need to know both the subject matter and how to teach it to all students. They need understanding of how science concepts are developed in the minds of students and what those minds are capable of at various stages in brain development. They need to understand how the correct approach to teaching science can create science learning opportunities that change what students know and are able to do in science. A good grounding in science for any learner comes from a foundation laid through early experiences leading to a perspective on the world and nature as reasonable and understandable (NCISE, 1989). To accomplish this, a well prepared teaching staff needs support through a rich program of ongoing professional development informed by current research on how to teach science.

## Professional Development for Science Teachers

Professional development serves as the bridge between where prospective and experienced educators are now and where they will need to be to meet the challenges of guiding all students in achieving higher standards of science learning (U.S. Department of Education, 1995).

Because the world is changing so rapidly, learning science and teaching science are challenging tasks for both teachers and learners. Many elementary and secondary teachers find themselves in the role of science teacher without having received the preparation and support they need to meet the demands of the job they have been hired to do. Sometimes that is because they lack the familiarity with the content they are expected to teach due to limited exposure to science in their own K-12 education, resulting in a partial development of scientific literacy.

Abd-El-Khalick and BouJaoude (1997) conducted research on professional development for teachers to improve their understanding of the nature of science. They found that the teachers' knowledge base was both lacking in all areas of science and that the teachers themselves held very naïve views about the nature of science. The researchers further found that the years of teaching experience and the class level(s) they teach along with their education was not a predictor of their level of understanding. Thus, it was reasoned that teacher preparation programs are not helping prepare teachers with the content knowledge base needed for teaching science and that professional development should be intentionally designed with the nature of science as a strong element of the programming.

Professional development is seen as a key factor in encouraging and supporting types of instructional practices such as inquiry, but it must be understood that this type of teaching science requires a high degree of skill and knowledge on the part of the science teacher (Loucks-

Horsley et al, 2003). Teachers don't just need to know the subject matter of science but also how to teach the subject matter itself.

Zemelman, Daniels, and Hyde (2005) explain that we have more "resources and tools for helping teachers implement new teaching methods than in the past. But professional development takes time and should be considered more like cultural change than mere technical training" (p.156). Professional development should focus teachers on developing the ability to adapt their curriculum to build understanding for all students while promoting inquiry.

Research points to the need to know the essential ingredients of effective professional development in science (Wenglinsky & Silverstein, 2000). An analysis of the performance of more than 7,700 8th grade students on the 1996 National Assessment for Educational Progress (NAEP) science exam, along with their teachers' responses to a NAEP survey of teaching practices, found that student scores tended to be higher when the teachers' professional development experience included significant training in four areas: (a) laboratory skills, (b) hands-on learning, (c) instructional technology, and, (d) frequent formative assessment. Overall, students whose teachers had received ongoing professional development in these areas scored nearly one-half a grade level above students whose teachers lacked such training. Teachers were more likely to avoid cookbook laboratory exercises and encourage more student directed inquiry. Their students were asked to make connections between experiences and underlying scientific concepts. Students who engaged in hands-on science inquiry once a week as opposed to once a month or less were 40 percent of a grade level further ahead in science and students whose teachers attended professional development that encouraged frequent formative assessments were nearly a full grade level ahead of students exposed to less frequent formative assessments.

Thompson and Zeuli (1999) list five features that characterize professional development seen as transformative for teachers: (a) a sufficiently high level of cognitive dissonance is created for the teacher to disturb, in some significant way, the equilibrium between their existing belief structure and their practices on the one hand and their experience with the subject matter, their learning and teaching on the other; (b) provision of time, context, and support for teachers to think – to work on resolving their dissonance through collaborative discussion, independent reading, writing, and other activities that essentially amount to the crystallization and ultimately the revision of their thinking; (c) ensuring that the dissonance-creating and dissonance-resolving activities are connected to the teachers' own students and context, or something very similar; (d) providing a way for teachers to develop a repertoire for practice that is consistent with the new understanding that teachers are building; and, (e) providing continuing help in the cycle of surfacing the new issues and problems what will inevitably arise from actual classroom performance and allowing teachers to make new understanding from this while translating these new understandings into their practice.

Michaels et al. (2008) report that "professional development programs must be sustained over the long term and provide clear, consistent linkages to subject matter and the core tasks of teaching must be made available to teachers" (p. 157). They acknowledge that teacher learning is the "by product of thoughtful design and system wide participation. Professional development programs often provide teachers with opportunities to analyze phenomena, think scientifically, represent and interpret data, build models, and engage in claim making and argumentation about data" (p. 158). Further, professional development should share with teachers how to support their students as they learn new concepts, skills, and attitudes.

Teachers talking with colleagues about their learning is another strong component of high quality professional development. According to Akerson and Hanuscin (2005), not all teachers are willing to change their methods of teaching. A key feature of the professional development that enables teachers to shift their science teaching approach to a more inquiry based model seems to be the provision of an ongoing program to develop teachers' conceptual frameworks as well as providing the release time for them to explore, learn, and discuss changes in their teaching together with colleagues.

Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) agree that moving teachers to a new way of teaching is not easy. They indicate that high quality professional development can cause teachers to shed their deeply held beliefs and assumptions to embrace a new set of understandings about science teaching and about how students learn, but the professional development must be done intentionally and with planning tools such as their *Professional Development Design Framework* (see Appendix A). This framework is based on the following set of shared values and beliefs:

1. Professional development experiences need to have all students and their learning at their core;
2. Excellent science and mathematics teachers have a very special and unique kind of knowledge that needs to be developed through their professional learning experience;
3. Principles that guide the reform of student learning should also guide professional learning for educators;
4. The content of professional learning must come from both inside and outside the learning, and from both research and practice; and

5. Professional development must both align with and support system-based changes that promote student learning. (p. xxv–xxvi)

The *framework* is a map of a process that can be used to design both small- and large-scale professional development. It guides design that is “an ideal to strive toward, rather than an accurate depiction of how it always happens” (p. 5). The framework asks professional development providers to commit to a shared vision and standards in the context of the knowledge and beliefs of the learners and teachers for which it is being designed. Next, data and the context surrounding the data such as the student demographics, curriculum in place, national and/or state standards, history of professional development, and parent and community support, should be analyzed to get a broader picture of the system. Goals for the professional development program should reflect the critical issues commonly experienced, such as time available for professional development, equity and diversity of the teaching staff, professional culture, leadership structure, capacity for sustainability and/or scaling up. The professional development is then planned, presented and evaluated so that the cycle can then be repeated.

Unique to the Loucks-Horsley et al. (2003) framework for professional development is the set of 18 strategies to consider when designing experiences for teachers of science and mathematics. These strategies are intended to be thoughtfully chosen after designers are informed by all other inputs into the process of designing professional development. The strategies share “common underlying assumptions about teaching, learning, and professional development” (p. 113). Some strategies focus on developing awareness, so they are used at the beginning phases of professional development when teachers are introduced to new approaches or content. Some strategies focus on building knowledge in both content and pedagogy. Other strategies help teachers translate new knowledge into practice or practice teaching. Finally, some strategies provide opportunities for teachers to reflect deeply on teaching and learning as they examine their practice and assess its impact on their students.

Professional development is thus seen as a set of criteria that emphasizes the purpose, the planning, and the rigor necessary to provide teachers the opportunity to learn the content of science and the pedagogy of delivering science instruction to their students. Effective professional development programs are sustained over a period of time and provide clear and consistent linkage to the subject matter and the core ways in which students learn (Zemelman et al., 2005). At the very center of professional development is the decision about which strategy or approach to use. Every program, initiative, and professional development program should use a variety of strategies in combination with one another to form a unique design (ENC, 1999). The following section describes a particular strategy which shows promise for developing the science literacy of classroom teachers in partnership with scientists as mentors.

## Scientist-Teacher Partnerships

Loucks-Horsley et al. (2003) list partnerships with scientists and teachers as a significant form of professional development for K-12 teachers of science who need to deepen their scientific literacy and their understanding of the nature of science. This strategy is grounded in adult learning research that indicates learning is enhanced through direct experience of the science content and the processes of inquiry and problem solving.

According to Loucks-Horsley et al. (2003), partnerships between teachers and scientists are as diverse as the individuals involved. An important characteristic of a partnership is that both partners bring expertise to the experience with the ultimate goal of improving teaching and learning of science in the classroom. There are several key elements they have identified. First, the partners must be seen as equal with a two-way exchange of resources and knowledge. The scientists and teachers play different roles but must believe that each has expertise to share; each must value the knowledge and expertise of the other. Second, the roles for scientists should be clearly defined as content experts helping teachers become more confident in teaching science. The scientists can model inquiry and provide new insights on the nature of the practice of science in the real world. The third key element states that both partners need to ensure that their involvement is guided by a shared vision that is consistent with the values, goals, and objectives of the professional development program and that neither partner will undermine the process. Partnerships involve significant allotments of time and energy, and both parties need flexibility in their schedules and professional responsibilities. The fourth and fifth elements state that there is a benefit to both teachers and scientists. The teacher benefit is in working closely with scientist role models who can highlight real-world applications of the subject matter. For the scientist, the benefit includes the opportunity to become familiar with the needs and realities of a school system and to become an advocate for quality science education.

In 1990, the National Research Council's Commission on Life Sciences convened a committee to examine over 200 professional development programs nationwide to identify a list of characteristics of effective programs. The findings, reported in the publication *The Role of Scientists in the Professional Development of Science Teachers* (NAP, 1996), state:

> The scientists have an obligation to assist in science teachers' professional development through providing research opportunities for practicing teachers; acting as scientific partners; providing connections to the rest of the scientific community; assisting in writing grant proposal for science-education projects; providing hands-on, inquiry-based

> workshops for teachers; and providing teachers access to equipment, scientific journals, and catalogs not usually available in schools. (p. 3)

Partnerships between teachers and scientists can be powerful learning experiences for all involved; however, there are often challenges to face and obstacles to overcome. There are cultural and communication differences between the two worlds. Each partner lives in a world with its own language unique to their discipline. Sometimes the scientists feel they are present to "fix" the school system, "believing the educational problems can be solved if only the teachers knew more content" (Loucks-Horsley et al., 2003, p.145). Teachers sometimes fear intrusion by outsiders, especially from those they might feel inferior to.

Partnerships can support the long valued view that teachers too need to be active instead of passive learners in doing scientific investigations. According to Barab (2001), apprenticeship or participatory learning occurs when teachers are under the tutelage of a research scientist in the scientist's lab, using the equipment of science that contributes to the scientist's work, and where the teacher-learner has a vested interest in the outcome of the investigation. Barab lists a number of key characteristics of participatory or apprenticeship learning. First is that the learning be carried out in an authentic environment supporting the learner while doing the science with the goal of engaging the learner in authentic science. Second, a teaching/learning cycle is adhered to where the learner is engaged in an authentic dilemma or problem to solve, not just an exercise to complete. This allows the learner to become engaged in the hands-on learning instead of memorizing a set of readymade knowledge. Third, learners must also be engaged in work with others who have more experience and expertise than they do and that work must be done in collaboration not in isolation. Finally, learners in these environments do not just complete a task for some simple reward but are working toward solving a real-world need that they too have identified as important to them.

Tanner (2003), in her research around approaches to teaching and learning and the professional development that occurs when schools partner with universities, uses the term "scientist-teacher partnership" to mean a collaboration among a group of college or university scientists and K-12 classroom teachers, with the goal of improving science education along the kindergarten through postgraduate educational continuum. Tanner writes about outreach partnerships between the university scientists and classroom teachers by describing the largely unidirectional way the partnership has come to be and the challenges and shortcomings of that type of partnership for K-12 science education. She states that there must be a "demand that both partners examine their own science teaching and learning and promote both external and internal reform" (p.35). She believes that three major shifts must occur to take full advantage of the opportunities for positive effects. First, the adoption of a mutual learning model of partnerships must be undertaken. Each partner needs to understand and genuinely commit to a model of mutual learning. It can no longer be the scientist as sole provider and the classroom teacher as the sole recipient. A successful partnership can have providers and recipients residing in both groups. Second, because the partnership can be a win-win for each partner, it is imperative that the scientist engage in a "crash course" in teaching and learning so that the scientist partner understands the ways in which content can be delivered taking into consideration a variety of learning styles. Many scientists teach the way they were taught in highly competitive courses that taught to the top. Third, the development of sustained infrastructures for partnerships should not solely be dependent on grant funding so that this effort of outreach can be moved to a level of sustained partnership.

The analysis of data from a study conducted at the University of Florida (Brisco & Peters, 1997) indicates that the collaboration of elementary teachers with higher education scientists facilitated change in the teachers' teaching practice, because it provided opportunities for the teachers to learn both content from the scientists and pedagogical knowledge from one another. The collaboration also encouraged teachers to be risk takers in implementing new ideas. The analysis of interview statements showed that the partnership supported and sustained the process of individual change in science teaching. The researchers chose to write about three pairs of teachers who were representative of the successful partnerships in the study. After a lengthy description of the three teacher pairs, the researchers summarized three assertions. The first was that collaboration is an important process that assists teachers to learn content and pedagogical knowledge from one another. The second was that knowing that a colleague would be there to try similar activities and discuss successes and failures provided teachers with courage to take risks that they would not otherwise have taken. Finally, weekly meetings provided a valuable opportunity to reflect on what worked and what did not work in the classroom. The experiences rejuvenated teachers and encouraged them to continue to use problem-centered activities. They felt the major areas of change occurred in their integration of science into reading, writing and social studies; the time to collaborate assisted them in picking up content and pedagogy; and the collaboration was essential for them to support the change for the long-term.

## Summary

In summary, the growing importance of science education has focused increased attention on the science literacy of all in a well designed K-12 system of science education. Through the development of a common view of science literacy and the creation of national standards and benchmarks, we have a better view of what students should learn in science classes. Research on learning and teaching allows for deeper understanding about key aspects of the professional development teachers need to prepare them to teach. Professional development frameworks can assist in reminding planners to attend to critical factors necessary to target professional development to the needs of teachers developing their expertise in science teaching. Strategies such as partnerships between scientists and teachers exist and have been shown to be effective ways to build unique and successful professional development opportunities for science teachers. However, the scientist-teacher partnership research to date has primarily focused on partnerships between teachers and university-based scientists. This research needs to be expanded to partnerships that are not university-based. This action research study addresses this need by focusing on scientist-teacher partnerships at a national research laboratory.

## Chapter 3

## REPORT OF THE STUDY

### Introduction

The overall purpose of this study was to (a) explore the experiences of middle school science teachers involved in a partnership program between scientists and teachers at the Pacific Northwest National Laboratory (PNNL), including the impact of the program on their professional development, and (b) to improve the partnership program by developing a set of recommendations based on the study's findings. This action research study began as a qualitative case study examining a professional development strategy of partnerships (Loucks-Horsley, 2003) between teachers and laboratory scientists. The original case study was in response to a class assignment in a qualitative research course offered at Washington State University. The initial case study quickly evolved into an action research study intended to address a problem identified through analysis of the case study data. The problem related to the design of the professional development partnership program.

#### *Setting for the Study*

The Pacific Northwest National Laboratory (PNNL) in Richland, Washington was the setting for the original case study and for this action research study. PNNL is one of the U.S. Department of Energy's (DOE) ten national laboratories, performing research to deliver breakthrough science and technology to meet today's key national needs. The DOE, along with PNNL, has a strong commitment to supporting science, technology, engineering, and mathematics (STEM) education. At PNNL, the Science and Engineering Education Programs link the human, financial and technical resources of the Laboratory with elementary and secondary schools, colleges and universities, and other education-oriented organizations as education partners. To this end, the Science and Engineering Education Department (SEE) of PNNL has as its mission: (a) promoting and facilitating strategic research and education partnerships with post-secondary institutions; (b) enhancing science and technology literacy of students and teachers; (c) contributing to the education of future scientists and engineers; (d) promoting diversity in the science and engineering pipeline; (e) connecting academic learning to the world beyond the classroom; and (f) providing an education forum for discussing science issues.

The Science and Engineering Education Department (SEE) is known for its exemplary summer programming for pre-college, college, graduate school and post graduate school levels. It annually offers a variety of partnership programs during the summer months that serve K-20 students as well as K-12 teachers. From simple one and two week long workshops on science content to full eight week research appointments, teachers and students have the opportunity to be immersed in the authentic work of science with a mentoring scientist from PNNL.

*The Qualitative Case Study*

To understand the timeline of both pieces of research, the original case study and the continuing action research study, I will begin with an overview of the original case study and how it set the stage for the continued action research study. In April of 2007, the PNNL Science and Engineering Education (SEE) Department was successful in requesting funding from the Department of Energy (DOE) to facilitate a cohort of teachers in the DOE's Academies for Creating Teacher Scientist (ACTS) Program. The application for funding requested that teachers come to PNNL in teams of two or three from individual middle schools or school districts. Ten middle school teachers were accepted into the program to begin during the summer of 2007. The program required that they spend two full weeks each summer, for three consecutive summers, engaged in adult learning experiences. The partnership with laboratory scientists had the goal of increasing the teachers' science literacy as adult learners and as science teachers. Incentives for the program consisted of a stipend for their participation in the two-week summer academies and a yearly mini-grant they could use for classroom materials of their choosing.

As a doctoral student employed by the SEE Department as a Senior Science Education Specialist and the lead on this project, I realized that the start of a new project with a new cohort of teachers was a unique research opportunity. I applied to the Institutional Review Board of Washington State University for an approval to conduct a qualitative case study starting in July of 2007. The purpose of the case study was to explore the experiences of the middle school teachers in the summer academy and their perspectives of the impact of the partnership with scientists in professional development. I focused on two research questions: First, I wanted to know the teachers' perceptions of the impact of the partnership on their own science literacy development; second, I wanted to know the impact of the program on them as middle school science teachers.

In mid July of 2007, ten middle school teachers arrived from Anchorage, Alaska, as well as Issaquah, Richland, and Tumwater, Washington. All but the local teachers from Richland were housed near the PNNL campus in an apartment building in which they were paired in one and two bedroom apartments, allowing for relationships to build beyond the academy itself. At the beginning of the two-week summer academy, the qualitative research protocol was discussed with the teachers. They all signed a consent form that clearly stated the option to participate or not. Each teacher readily signed the consent form and chose a pseudonym to protect his or her identity. I began collecting data in the form of field notes taken on a daily basis of the activities the teachers were involved in and my observation of their reactions to the summer academy.

During any scientist-teacher partnership program conducted at PNNL, the teachers are presented a scenario following a teaching-learning cycle that was developed by the National Center for Improving Science Education (1989). This teaching-learning cycle parallels the approach taken by practicing scientists both in research and in applying science to create technologies (see Appendix B). The PNNL staff feels that the original model, with some modifications is very viable for the PNNL summer academies. The model can be described in four stages. The first stage of the teaching-learning cycle is the *invitation*, which often takes the form of a letter similar to an actual job request a scientist or engineer might receive as part of their job at PNNL. A description of a real-world problem (science aspect) or a problem of human adaptation (technology aspect) is shared, and the teachers are asked to solve the problem. The teachers are given time to read the scenario and discuss with one another what they currently know (preconceptions) about the problem. They generate a series of questions and list concepts they need more information about in order to move forward. They categorize the questions and outline the information they must gather in order to begin working on the scenario. At this point, the stage is set for further investigation by the teachers. The challenge is to invite them into a complex world in a manner that engages them but does not overwhelm them.

The second stage of the teaching-learning cycle includes *exploration, discovery, and creativity*. This stage builds upon and expands the science learning initiated by the *invitation.* At this point, it is critical that teachers have access to scientific investigations with ample opportunities to observe and collect data as they organize the information. The teachers are encouraged to think of additional investigations that might provide further information. This stage is characterized by a strong element of constructive play and informal investigation. Teachers begin to explore how new information gained from their investigations relates to previous experiences and their current level of understanding. At PNNL it is my role, along with the scientist-mentors, to stage investigations and in-depth discussions that lead the teachers to new discoveries and the formation of a conceptual framework of understanding. New information is gathered and processed as they observe and ask questions. In this stage, teachers exhibit many responses, such as awe, enthusiasm, curiosity, and the temporary suspension of judgment, that are characteristic of scientists as they work.

The third stage of the teaching-learning cycle is that of *proposing explanations and solutions*. In this stage, the teachers continue to refine their developing understanding of a concept by merging their new views (based on evidence gained through investigations, lectures from guest scientists, use of text resources, searches of the internet, and presentations by teacher colleagues) with their prior understanding. Through analysis of all data, teacher teams are led to consider alternative interpretations and discuss discrepancies. Guided by the team of scientist-mentors and myself, teachers perform additional investigations to resolve conflicts between their ideas and those of others while adding the new information to their developing conceptual framework. The cooperation between teachers, scientist-mentors and me is an opportunity to model qualities that characterize the nature of science: proposing and accepting alternative points of view, listening and questioning, persisting in seeking solutions, and working together cooperatively.

The final stage in the teaching-learning cycle is *taking action*. Once the teachers have constructed a view of a concept, they are usually ready to act on that new level of understanding. They might be asked to apply their new learning by creating a demonstration of a product that incorporates the science concept, defend a point of view to a panel of experts, or write a letter to local authorities. Their new level of understanding may, and frequently does, lead to new questions that provide the foundation for new explorations and subsequent refinement of conceptual understanding. The scientist-mentors' role is to encourage the teachers to take action and to assist them in transferring their new knowledge to their developing conceptual framework through guided inquiry. The teachers' role is to acquire new knowledge as adult learners and then to filter that information through the lens of the classroom teacher. My role is to build a bridge between the scientists who deeply know their science content and the classroom teachers who are grounded in the pedagogy necessary to teach in the middle school classroom but may not have a full grasp of the science content.

To see how this teaching-learning cycle played out during the summer of 2007, the teacher participants were given the *invitation* in the form of a challenge or design scenario (see Appendix C) in which they were told that PNNL was looking for a blueprint of a new "green" laboratory building. The scenario went on to say that they were being hired as teams of consultants to submit proposals for the design of a 200,000 square foot office and laboratory space to house 1000 staff members. The laboratory and office spaces had a number of specific requirements and constraints that the teachers needed to learn about and address in their blueprint of the building. They had two weeks to learn enough to complete a design and present it to a panel of PNNL experts.

At the beginning of the two-week academy, the teachers were engaged in a brainstorming activity designed to surface the content knowledge they lacked to solve the design challenge. They generated the questions that needed answers and listed concepts to learn. In response to this information, they were then provided a content overview of sustainable development and its drivers, such as global climate change, water shortages, energy shortages, bioaccumulative toxins, and biodiversity.

A large part of the two weeks was spent in the *exploration, discovery, and creativity* phase of the learning cycle as teachers worked as teams through the real-life design challenge to collect additional information and create sample drawings of their building ideas. The teachers experienced the process of building design and engineering tradeoffs through discussions and fieldtrips on the PNNL campus and across Washington State. They engaged in a number of hands-on investigations, including a game simulation on sustainability, and utilized mathematics and modeling to evaluate the expected energy and water performance of design alternatives, while learning how to assess the potential environmental impact of their team's building design. The experience incorporated systems thinking as well as detailed science, engineering, and mathematics skills. Because the content information was delivered by a variety of experts in their field, the teachers were exposed to additional guest scientists from PNNL.

Towards the end of the two-week academy, the *proposing explanations and solutions* phase of the learning cycle was implemented. This phase saw the teachers trying out their thinking by drawing the blueprint of their proposed buildings and engaging in discussions as they reconciled their ideas. They accessed the lead scientist-mentor to acquire additional information and she challenged their proposals by asking probing questions about design elements that she knew needed work.

Finally, it was time for the teacher teams to *take action* by presenting their drawings to a panel of PNNL scientists, their colleagues, and me. They shared their final blueprints and used the data they had analyzed to justify the design elements they had included. They concluded their presentations with a discussion of the costs and the environmental impact of their proposals. After presenting, each team was asked questions and given feedback on the overall design.

During the final days of the two week summer academy, the middle school teachers were invited to participate in a focus group in which they were asked questions about the impact of the experience from both a personal and a professional perspective. Field notes were collected during the final focus group debrief. In response to open-ended questions, a fair number of the teachers shared frustrations about the summer experience not meeting their expectations or their needs. Clearly, additional information would need to be gathered to understand the breadth and depth of these frustrations. The teachers were told that I would be phoning them after they returned to their middle school classrooms in the fall to collect some additional information about their feelings and to make recommendations on changes that should be made for the second summer planned for July 2008.

One frustration seemed relatively easy to resolve when two of the teams told of not having any materials from which to teach physical science. In fact, they explained, they had the expectation of coming to the lab to "design a physical science curriculum." The PNNL team decided to purchase, for the teachers' use, research-based instructional materials from a national developer to provide equal access to high quality physical science materials across all four teacher teams.

After the teams left the lab, I initially examined the data (field notes from the summer academy activities and the focus group meeting) and generated three open-ended interview questions (see Appendix D) that could be utilized in the follow-up interviews. Phone interviews were conducted with each of the ten teachers during September, October, and November, 2007. The semi-structured interviews provided the teachers an opportunity to describe the pros and cons of the immersion experience and the impact on their understanding of the nature of science and their developing science literacy. The interviews also allowed teachers to elaborate on their perceptions of the impact of the partnership with the scientists on themselves as adult learners and as classroom teachers. The interviews were recorded and transcribed verbatim.

Using the constant comparison method of analysis (Glaser & Strauss, 1967), I read over the transcripts and the field notes multiple times, looking for key elements or issues that could become themes for focus. The frustrations, on the part of the classroom teachers, began to emerge into five general themes. First, the expectations of some of the teachers were clearly not met. Some believed they would be placed into a laboratory to conduct lab-based research at the elbow of a scientist-mentor. This model is used during PNNL's eight-week immersion appointments but not in the two week professional development programs. Second, the delivery of some of the content by the PNNL guest scientists was not perceived as constructivist in nature and therefore difficult for the teachers to sit through and to make meaning from. The scientists delivered what they believed to be well designed PowerPoint presentations and thought that if the teachers had questions, they would have asked them. Third, the content and concepts of sustainability, presented in the summer program, did not immediately appear to align with the instructional materials or state standards from which the teachers were teaching, making it difficult for them to see true connections to their teaching and their classrooms. Fourth, some teachers had difficulty putting themselves in the role of a learner acquiring new information for their own development of science literacy. Instead of being able to suspend their role as *teacher* and thus participate as *learner* in a new environment, they continually saw any new learning through the lens of a middle school teacher and wondered how to deliver the same information to their students. Finally, their own misconceptions about the type of work done by PNNL scientists and engineers caused a considerable amount of cognitive dissonance (Thompson & Zeuli, 1999), when their first encounter with a scientist-mentor demonstrated that she did not perform experiments in a laboratory but rather collected data from research to use when consulting on projects around sustainability.

As a follow-up to the original case study and its findings, in the spring of 2008, the teachers and scientists were gathered together to collect one last set of data in a focus group meeting. The outcome of the meeting was to be recommendations for how the summer academy, being designed for 2008, should change and what elements were important enough to the teachers to keep in place. Teachers were split into teams and asked to respond to questions placed on each of four wall charts around the room. The charts contained the following prompts: (a) How did your summer academy experience at PNNL deepen your understanding of the relationship between science and technology? (b) Which science skills or habits of mind were most impacted by your summer workshop experiences at PNNL? (c) In what ways did the experience at PNNL encourage you to use a teaching-learning model in your own classroom that reflects how scientists and engineers uncover knowledge and solve problems? and (d) What elements of the past summer should be kept and what elements should change to make the summer academy a more positive experience for you?

The responses were captured on the wall charts to be used both as data to examine later and as commentary to be shared with the planning team for the next summer. The teachers indicated, in conversations after the meeting, that they had greatly appreciated being asked to share their thinking with the hope of making some changes for the following summer. The teachers clearly wanted to keep several aspects of the two week summer academy, such as the real-life scenario, working with scientists as partners, and learning new and challenging material. They wanted to change the location where we spent most of the previous summer academy to a laboratory space in which they could do some lab-based investigations. They were clear about changes they wanted in the way guest scientists made presentations and asked that a culture be established to allow the teachers opportunities to interact with the presenter, to ask questions during lectures or PowerPoint presentations, and to discuss difficult concepts so that they could try to make sense of the new information together with the scientists (Rosebery & Puttick, 1998).

In late March, I brought together a planning team of the two PNNL lead scientist-mentors, Kim Fowler and Eric Nyberg, and Science and Engineering Education staff members to work together for the next several months to create the agenda for the second two week summer academy. We were armed with a summary of the data - the themes that emerged from the previous study and the recommendations the teachers made on what to keep and what to change collected at the focus group meeting in March. While planning the second summer, I worked with the scientists to make sure that the design of the summer academy would be more constructivist in nature. The two lead scientist-mentors, Kim and Eric, for the next summer had been working on partnership programs for many years with the PNNL Science and Engineering staff so they fully understood the elements we needed to incorporate. With their help, we brought on the next guest scientist and assisted him in weaving in elements of hands-on laboratory investigations, multiple opportunities for teachers to play a more active role in constructing their own learning, and a change in the guest scientist's role from that of *lecturer* to one of *consultant* and *coach* to the teacher learners.

*The Action Research Study*

What started out to be a qualitative case study now clearly presented itself as an opportunity for an action research study aimed at examining and perhaps solving the problem of dissatisfaction that had emerged from the first summer's academy. In learning more about action research and a strategy known as cooperative or collaborative inquiry discussed by Reason and

Bradbury (2006), I chose to focus on designing an action research project that was going to be done “with” rather than “on” people with an emphasis on participants being “involved in making research decisions as co-researchers” (p.149). I also turned to Miller and Pine’s (1990) description of action research as “learning through descriptive reporting, intentional conversation, collegial sharing, and critical reflection for the purpose of improving practice” (p. 59).

In looking for a model of the process of action research, I decided to utilize the “look-think-act” phases of research conceptualized by Stringer (2007), specifically what he refers to as a “fully articulated model.” This model incorporates the following three phases: (a) the “look” phase, which consists of the *design* and *data collection processes* and which asks the researchers to carefully refine the issue to be investigated, to plan systematic processes in inquiry, to check the ethics and validity of the work, and to collect data from a variety of sources; (b) the “think” phase, which involves *analyzing the data* to identify key features of the issue or problem; and (c) the “act” phase made up of both *communicating the outcomes* of the analysis to all research collaborators, and *taking action* by using the outcomes to work toward a resolution of the issue or problem being investigated. This model is represented in Figure 1.

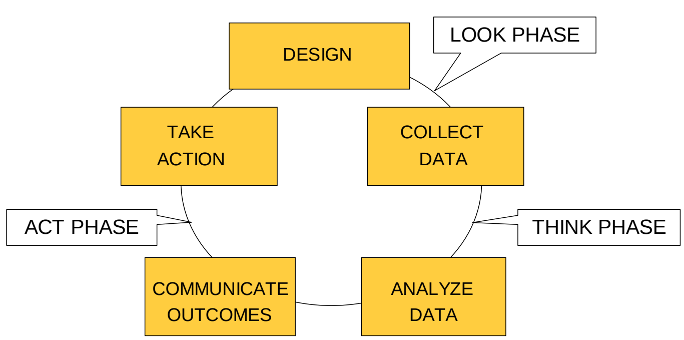



Figure 1: Stringer’s (2007) Fully Articulated Action Research Model

I began to realize that the data collected and analyzed in the first summer (2007) could be thought of as an initial round of the action research cycle itself. I had done the first part of the "look" phase essentially on my own, but soon thereafter, I had included both the teachers and the scientists in discussions about how to "think" about the data and how we might "act" in the upcoming summer.

I embarked on a second round of the action research cycle and brought on board Kim Fowler, one of the lead scientist-mentors on the project, to assist me in reexamining the data and deciding what new data to collect for the summer of 2008. Kim was unfamiliar with action research as a methodology but quickly gained appreciation for the idea as I shared with her examples from the literature (Stringer, 2007; Herr & Anderson, 2005; Reason & Bradbury, 2006). We agreed on the use of Stringer's fully articulated "look-think-act" model, and I shared with her my thinking to date based on my initial analysis of case study data.

*The "Look" Phase.* I applied for a new IRB from WSU stipulating action research as a methodology and readied for the teachers to return to the laboratory for the second two-week academy in July of 2008. The purpose for this phase of the action research study was to further explore teachers' experiences in the program and their perceptions of the impact on their developing understanding of the nature of science and physical science content, and their ability to modify that content for delivery in the middle school classroom. We planned to use this data to develop programmatic revisions and recommendations to PNNL and the field. The research questions we asked in this phase were: (a) What are the perceptions of the middle school science teachers of the value of the partnership model in regard to their own science literacy development? (b) What are the strategies of professional development the teachers found most valuable when working with scientist-teacher partnerships to develop their science literacy? and

(c) What other elements of the summer academy assisted the teachers in developing their own pedagogical content knowledge in order to deliver science as a classroom teacher more effectively?

The teachers arrived on campus for the second summer. We began the academy with a dinner the night before our first work day. The group consisted of the two lead scientist-mentors, Kim Fowler and Eric Nyberg, the ten middle school teachers, and several members of the Science and Engineering Department from PNNL. We met for casual conversation and pizza at the home of a Science and Engineering Education colleague. The teachers seemed very relaxed as they welcomed one another and joked about their past school year working with middle school students.

On the first day of the academy, we met in a classroom at the Tri-Cities campus of Washington State University. I introduced the action research model to the teachers and asked them to join me in conducting research around partnerships between teachers and scientists in the hopes that we could, together, design a professional development partnership experience that was most beneficial in allowing them to grow as science literate adults as well as enhance their abilities to teach science to middle school students. The teachers agreed to participate and signed a new consent form. I overviewed for them the themes found in the findings of the previous study, and we discussed the agenda crafted for the next two weeks with their recommendations in mind. They seemed anxious as to what their role would be in the research process, but were soon engulfed in the work of the summer, forgetting all about the research itself.

The teachers started the two weeks by participating once again in a teaching-learning cycle. This time the cycle was preceded by a number of laboratory investigations, lead by Eric Nyberg, to enhance their understanding of materials science, the sustainability of materials, and the impact of materials used in the transportation world. During the first few days of the two week institute, the teachers investigated the properties of various metals, such as tensile strength, conductivity, malleability, hardness, elasticity, and ductility in a laboratory space also on the WSU's branch campus. They gathered data, compared data with one another, and discussed the application of the concepts they were learning to their middle school classrooms. This change in the way the academy started was in direct response to the feedback from the teachers the previous spring. In hopes they recognized the changes made to the schedule, Kim and I asked the teachers to do a reflection in their science notebooks on how things were going after just four days. It was our intent to collect information from them early enough in the summer so as to have time to discuss with them how to monitor and adjust.

As the two week academy continued, time was spent in lecture format focused on sources of energy in the form of alternative fuels. The teachers heard from guest senior research scientist, Pete Rieke, who works on fuel cell technology at PNNL about the various ways energy is gleaned from the environment, both renewable and non-renewable, and the perceived impact of each. The content was challenging. The technical content centered on the specific topic of fuel-cell technology, which currently is a major research focus at PNNL. These presentations were newly designed to deliver science content with the opportunity for the teachers to develop a conceptual framework of understanding. During lectures, the teachers were engaged with the scientists in wrestling with the difficult content through the ability to ask questions, viewing of video clips, creation of drawings illustrating the connections from one concept to another, and note taking in their science notebooks. At any time that I thought the teachers were losing focus, I would interject a question of my own to stir a reaction from the scientists and/or the teachers to generate additional discussion.

Technical content was a huge area of concern for the teachers during the first summer, but my observations and subsequent field notes did not detect those same frustrations in this new model.  I took advantage of the opportunity to take additional field notes from conversations I had with the teachers in which I asked them why this summer's content was not meeting with the same level of frustration as last summer.

The teachers returned to the laboratory, where they were given a fuel-cell model and led through a number of investigations utilizing that model to understand how the fuel cell functions to produce usable energy.  Explained simply, through the process of hydrolysis of water powered by a photovoltaic cell, hydrogen gas is collected and used as fuel to power a simple motor connected to a propeller, which demonstrates motion as it spins.

Next, a small model fuel-cell car was given to each teacher and they were asked to apply what they had learned from the larger fuel-cell model to this smaller model.  The model used the same hydrolysis of water process to power a motor, but this time the motor was connected to a set of axles and wheels which allowed the vehicle to move in a forward direction.  After problem-solving and troubleshooting the issues inherent in a model system, the teachers felt they were beginning to develop a conceptual framework of fuel-cell technology.

Just before the end of the first week, the teachers were connected back to the summer of 2007 through a presentation of a complicated process of life cycle analysis, reminding them of the central sustainability theme for the three year program.  This was provided by Kim, the scientist-mentor they worked with on this topic during the first summer, allowing the teachers to come full circle in their learning.

At the end of the first week, the teachers were immersed in the teaching-learning cycle once again.  They were given an *invitation* in the form of a new scenario or design challenge (see

Appendix E). They were asked to form design teams and use a creative approach to designing a "machine that could do work" drawing from knowledge they had gained in the laboratory investigations of materials science as well as the technology they had experimented with around the generation of energy in fuel-cells. After collecting up their thoughts about what they still needed to learn, they embarked on the second phase of the teaching-learning cycle in another round of *exploration, discovery and creativity*. They split off into three teams consisting of teachers that had not worked together before, as a way to model scientist teams that gather from around the world to develop a solution to a technological design problem. Each team was told they would have multiple opportunities to ask questions directly of the scientist-mentors on materials science, fuel-cell technology, sustainability, and elements of the design of their emerging "machine."

Early in the second week, the teachers gathered more information through visits to real world examples of materials science and fuel research in the workplace. Fieldtrips included visits to local manufacturing plants and businesses that use a variety of metals and their inherent properties for manufacturing purposes as well as opportunities to observe the production of alternative energy generation through wind mills and solar engines. Several research laboratories at PNNL were visited to showcase what is being done in materials science around vitrification, use of polymers in vehicles, and an examination of alternative fuels such as the production of biofuels through biochemical and thermochemical processes. The fieldtrips embedded in the two weeks were again designed to show the teachers examples of how science and engineering are impacting the world around us.

At the end of the first day of the second week, another reflection prompt was given to the teachers to explore the science literacy they believed they had gained so far and to reveal the processes for learning the content the teachers valued most. This time we asked teachers what they had learned (science content) and how they believed they had learned it (science process). Because there had been a lot of very technical information imparted to the teachers, much like the first summer, we had tried to include elements of discussion, visual images through videotapes and models, as well as opportunities to question the scientist-mentors in an informal setting. To address the prior frustration involved in making connections between the summer content and the instructional materials and state standards from which the teachers were teaching, we spent time talking about this and encouraged the teachers to continue conversations after hours.

The teacher teams now returned back to their laboratory investigations with continuous access to the scientist-mentors. Using the information they had gained from all available sources, they entered the *propose solutions* stage of the teaching-learning cycle with the final research and development being done on their "machines." After much trial and error and eventual success, the teachers were ready to *take action* and move into the final stage of the teaching-learning cycle as they made presentations to the scientist-mentors and PNNL staff who were gathered to judge and celebrate the teams' successes.

Finally, at the end of the two week academy, we brought the two lead scientist-mentors and middle school teachers together for a focus group in which we collected two important sets of data. The first set of data involved thinking about the value of the partnership for a variety of stakeholder groups, not just teachers or scientists. We asked all participants to number off into new teams to do a "gallery walk" around a set of wall charts that displayed the name of representative stakeholder groups. These groups were middle school students, the middle school teachers attending the academy, the school districts the teachers represent, the scientists in partnership with the teachers, and the Laboratory or the Department of Energy or the society at large. At each poster they were to ask themselves this question: “What is the value of the partnership for the group represented on this piece of chart paper?”

The second set of data consisted of final reflections on the strengths, weaknesses, opportunities, and threats to the success of the summer academy. This debrief used a protocol often employed at PNNL that asks participants to respond to those four elements. This is called a SWOT analysis which goes beyond the typical pro and con examination. The SWOT analysis is intended to elicit subjective opinions from participants but is organized into logical categories that serve as prompts. We asked the whole group of teachers and scientist-mentors to comment openly as we recorded information on a white board. We asked everyone to watch as we captured what they said so as to make sure we were recording it truthfully and accurately. The SWOT analysis enabled us to do summary thinking about the summer and it gave us a chance to deviate from a more typical protocol of what worked and what didn’t work. We chose to adjust the SWOT analysis to include a final “S” meaning “solutions” so that we could put those thoughts to work in the “act” phase of the action research cycle, in other words, as we planned for the final two week summer to occur in 2009. This was done in a whole group setting so that we could collaborate together through intentional conversations, collegial sharing, and critical reflection to improve practice (Miller & Pine, 1990).

*The “Think” Phase.* In the fall of 2008, Kim and I began to read through all the data we had gathered throughout the summer to try to identify elements that either agreed with my previous case study analysis or might cause us to create new themes to capture thoughts and ideas. Table 1 provides an overview of all data sources for both the original qualitative case study and the action research study. We decided that my original themes continued to be a viable way to categorize and examine the new data collected in order to see whether we had made inroads on the previous summer's frustrations.

**Table 1**
***Data Sources***

| | DATA SOURCE | WHEN COLLECTED | DATA TYPE |
| --- | --- | --- | --- |
| QUALITATIVE CASE STUDY | Observations of summer institute | Summer 2007 | Field notes taken in researcher's journal |
| | Interviews of teachers | Fall of 2007 | Audiotapes with transcription done by the researcher |
| | Focus Group | Winter 2008 | Field notes in researcher's journal and the artifact of charts |
| ACTION RESEARCH STUDY | Observations of summer institute | Summer 2008 | Field notes taken in researcher's journal |
| | Reflection Prompts | Summer 2008 | Scans of Journals used by teachers |
| | Focus Group | Summer 2008 | Field notes in researcher's journal and the artifact of charts |
| | DOE Journal Reflections | End of Summer 2008 | Writing submitted to the DOE website in evaluation of the summer experience |

The first reflection prompt from early in the second summer asked teachers to write about what they were struggling with, and why, along with what they were feeling successful at, and why. Responses to *struggles* varied from comments on being unfamiliar with some of the tools being used in the lab and the units of measurement as well as the conversion of those units to the basic mathematics needed to utilize them. It wasn't that the teachers didn't possess the skills; they just had not used those skills "in a very long time." One team member wrote of the frustration of feeling rushed by her teammates to move more quickly than she was ready to and that she was fascinated to realize that this was similar to frustrations often witnessed by her in her own students. Another teacher said, “The inquiry activity has helped me to experience what my students might feel when not having a strong background in this particular content area.”

Teacher reflections included comments on feeling successful when given “the opportunity to do hands-on investigations in a laboratory with small steps along the way to build understanding.” This also seemed to meet the need for diverse learning styles of many of the teachers. Another teacher wrote, “We were all engaged and excited to be trying out the creative tests Eric had designed for us.” One teacher clearly appreciated the opportunity to be in a laboratory space when he said, “this is something that I enjoy greatly and what I think this experience should be all about. The idea that we learn the same way that our students do, with hands-on activities, is very true.”

The teachers also appreciated the opportunity to compare data after their investigations and to take the time to “wrestle with the discrepancies or experimental error.” They felt that having to do continual “trial and error made it more real and less like a cookbook lab.” The teachers suggested that new tools be introduced early in the summer experience with time to practice using the tools before being asked to use them in investigations. Two of the teachers requested that new science concepts be identified before the summer session so as to allow the teachers time to read introductory materials ahead of needing to apply the content. This was noted as a recommendation for the third summer academy.

In examining my field notes regarding the scientist’s delivery of the technical content, the first teacher I talked with about the change to a more supportive type of presentation commented that the presentations were “very interactive using a combination of direct instruction and visuals to teach about tough concepts.” The second person I spoke with felt the scientists “did a great job of thinking about how to bring the difficult concepts down to an inexperienced level.”

Clearly these comments are in direct opposition to the comment of "death by PowerPoint" received at the end of the first summer.

In my field notes regarding the fieldtrips the teachers participated in during the summer, the feelings of two of the participants I spoke with were that the fieldtrips were indeed a valuable aspect of this professional development experience. One teacher remarked, "The fieldtrips deepened my understanding of how science and technology are intertwined." Another teacher said, "I learned many facts and have images of experiences that will be shared with my own students to enrich their learning during our units in physical science."

In the second reflection prompt that asked teachers what complex content they had learned and how, teachers made statements such as "the great graphics on the board kept my interest and my mind growing as the explorations continued to grow." Another teacher wrote, "We have such enthusiastic scientists to work with; they seem to really want us to understand." The teachers certainly appreciated both the minds-on aspects of the discussions as well as the visual aspects of the lectures and the opportunities to ask questions as they were constructing their new understanding. One teacher wrote:

> The interactive discussions while lecturing allowed us to wrestle with ideas and ask more questions to get clarity. It was fun to engage in the pro and con discussions with the scientists as they continuously asked us more questions to push our thinking. Finally, I guess when they thought we really knew the stuff, they would give us their opinion or finally answer our direct questions!

The teachers also commented on the value of the hands-on aspects of the labs that demonstrated what the lecture had been driving home. A teacher wrote, "The lab activities done in small steps, allowed us to begin to put it all together." Then, when all the data had been collected and shared, one teacher said it well when writing, “I learned something about these lab activities that I want to share with my students - scientists learn a lot more when the results are unexpected!”

In the first final focus group debrief that collected participants’ comments on the value of the partnership to each of the different stakeholder groups, teachers wrote down many statements that pointed to the value of the partnership model of professional development. In regards to relationships that develop between the teachers in the group as well as with the scientists, comments such as “engaged dialogue with scientists and peers in collaboration is of tremendous value” and “it is good to be involved in current research to get a glimpse of what the scientists are thinking.” Responses also spoke about the content of science (science literacy development) and the processes of teaching (pedagogy) in general. Comments such as “igniting curiosity and passion in students due to teachers getting recharged through challenging discussions about the application of learning to the classroom” and “learning about the different perspectives and passions around science” were common on charts. We saw comments about acquiring a new understanding of the nature of science and how to solve scientific problems, as well as an increased awareness of each others’ work place. These statements seemed to capture positive perspectives on the scientist-teacher partnerships.

In the second final debrief, the collection of information from the SWOT analysis, teachers began with saying things about the *strength* of the involvement with scientists. They felt a valuable take-away was the current thinking from the scientists’ perspective on issues surrounding sustainability. The teachers appreciated a genuine look at the nature of science at work through both the partnership itself and the field trips where they could see actual examples. Comments about working together with other teachers showed that they appreciated the chance to engage in “adult learning was a nice change” and hearing about “how things work in other schools and districts” as well as the chance to “engage in dialogue with peers and to collaborate with others.”  They also appreciated the “adult learning activities to push their thinking” and the “mix of classroom and laboratory work” allowing them “time to make meaning with the application of learning into design scenarios.”

The *weaknesses* highlighted were few and comprised mostly personal things such as “it is hard to be away from home for two weeks” and “my background knowledge is lacking.”   They also commented about wanting to all be located in the same housing complex to continue to develop their working and social relationships.  In connection to what was a huge issue during summer one, one teacher reminded the group that when they came to PNNL at the beginning of summer one, “expectations didn’t match reality at first.”

When it came to sharing what they thought were the *opportunities* of partnership programs, they said positive things about appreciating the financial rewards inherent in the DOE programs. They said they valued things like, “funding for our classroom materials in the form of mini-grants from DOE” and “the gift of instructional materials gives us the tools to deliver high quality science to our students.”   They also spoke of the opportunities for adult learning by stating that the science content “challenged our way of thinking about sustainability in an in-depth way so that we could learn some pretty difficult stuff.”  When it comes to thinking of themselves as classroom teachers, they said things like “layering of knowledge helps with curriculum design and instructional strategies” and “we will teach with higher expectations for our students.”  They also said, “This will strengthen what it is we teach our students.”

The comments offered in regards to the *threats* to the scientist-teacher partnership program revolved primarily around going back to their classrooms with new learnings and new sets of strategies. They wrote about being “worried about finding time in the day to teach differently or to add new things,” and “fellow teachers at home don’t have the same passions as we are going home with.” One teacher also wrote, “Our district or our teaching peers can punish us for innovation.”

We next talked about *solutions* we could implement so as to turn the *threats* just discussed into *solutions*. The responses centered on spreading the word about science education and the need to move the entire system of schools into a new era of thinking. The group said things like, “instill excitement in others,” and “model inquiry teaching and learning.” The teachers felt the need to develop “advocacy statements for the resisters back home” and that we all needed a good dose of “patience, persistence, and pacing!”

As Kim and I examined all the data captured during the summer, we generally believed the teachers felt they had learned, at least at a basic level, some difficult content around energy use, fuel cell types, properties of materials and the associated tests, as well as the differences between the generation of energy from a fuel cell versus that of a battery. They also reported learning about the limitations of each as well as the controversies surrounding this form of energy research and the complex nature of doing life cycle analyses to get at the real truth about the impact of one form of energy over another. It appeared that the laboratory activities supported this learning as did the partnership that was developing between the teachers and the scientist-mentors.

At the end of the two weeks, the teachers bid farewell and returned home for the rest of the summer. They had one last deliverable to complete for the Department of Energy before the start of their school year in the fall: the journal summary. The journal summary is done on the DOE website and is intended to allow the managers of the DOE/ACTS program at the national level to tap into the teachers' thinking about the two week summer experience. As the local manager of the PNNL program, I too have access to these submissions. We had gotten verbal permission from the teachers to use the summaries as data, so Kim and I turned to analyzing them as well. We found evidence of a change in the level of frustration around the teachers' expectations of being in a laboratory at the elbow of a scientist. The impression across all teachers was that the summer was "a tremendous success!" One of the teachers, who had been so disgruntled after the first summer, began his journal entry with "Overall this was a very enjoyable summer. There was clearly lots of thought given to the audience, the tours that we went on and the labs that we did. I am excited to get back to school and apply some of the ideas and pass on some of the information from this summer." Another formerly dissatisfied teacher said, "The time in a hands-on lab, the lectures from the scientists, and the tours gave us an incredible experience I will not forget." Another teacher, who had not been associated with the first summer's frustration and in fact was angered by his colleagues speaking negatively of the first summer, summed it up when he said:

> Overall, I think this has been the best professional development experience of my life, and if everyone could go through something like this, we'd have such a different level of science education going on. On the whole, I believe that sometimes people just don't know how to operate in ways that are always looking forward, rather than focusing on the negative or bringing up problems that in the eyes of others are not expectations we came with in the first place.

The delivery of the content, done by the PNNL guest scientists, garnered a reaction very different from the first summer. "The senior research scientist on fuel cells was our presenter this summer. It was a fabulous and interesting set of presentations. He used a combination of direct instruction and visuals to teach us about very complicated topics," wrote one teacher. Another said, "The scientists filled my mind. They are extremely smart yet did a great job of bringing the difficult concepts down to our inexperienced level." Certainly the teachers had noticed a change in the delivery of content. As mentioned earlier, we had decided to be very explicit with the guest scientists as to how a more constructivist model of teaching and learning could take place to support the teachers' development of conceptual understanding.

During the second summer, as opposed to the first, teachers were able to make stronger connections to the standards around the nature of science and their classroom teaching. In my role as science education specialist, I tried to be intentional about connecting the nature of science the teachers experienced at the Lab to the standards found in their state science standards. The teachers and I discussed how difficult it is to meet the nature of science standards using traditional science curriculum. They had experienced a rich model of authentic science at work in such a way as to give them vivid examples of the nature of science principles. We spent time trying to identify examples of each principle at work at the lab. I created a giant wall chart of the principles and referred to them quite often as we attached narratives of real examples we had identified. I also engaged them in hands-on investigations of examples of the nature of science to share with their students to further cement the connections to the classroom. An observant teacher wrote, "The nature of science in practice – it is authentic and chaotic! I think the student examples will work with my students." Another teacher said, "I can see that this summer gave us a glimpse of what the scientists are thinking not just what the media tells you to believe."

Also connected to the teachers' state standards were elements of communicating findings to others in a variety of ways. I chose to showcase the science notebook as a way to access that aspect of a scientists' work. I had actual scans of scientists' notebooks to share with the teachers. These powerful examples were taken from the notebooks of a materials scientist, a computational chemist and an ecologist. I also spent time at the beginning of the academy as well as at the end talking about student science notebooks and the ways they can be used to uncover student thinking and learning. I implemented the use of reflection prompts to gather data for the action research study but was also intentional about making their use transparent to the teachers. I discussed how the prompts were being used to monitor and adjust the academy and how they could use similar prompts in their students' science notebooks to reveal thinking and/or misconceptions. I talked about how I modified the academy in response to the data gathered by the prompts and how they could use the information to modify their teaching. Numerous teachers commented on this in their final journal summaries. One teacher wrote, "I will make a concerted effort to try the skills and techniques with science notebooks taught to us this year to see what my students are thinking and learning." Another teacher described the information on using reflections in science notebooks by saying, "We were given some great prompting strategies that I am excited to put into use with my middle school students. It will change the way I check the notebooks." Finally, one teacher said, "For me this summer combined the opportunity to analyze and learn more about science notebooks, assessment strategies, the nature of science and more time in relationships with active scientists and engineers."

Based on their journal summaries, some of the teachers still had difficulty understanding or separating the two roles we hoped they could play as participants in the partnership program. The first is the role of *adult learner* engaging in experiences designed to develop their own science content understanding. The second role is that of *classroom science teacher* in which we expect that they will filter the adult learning experiences through the lens of how it might be adapted to the middle school student. For some teachers, their journal summaries did indicate their ability to engage as *learner* and for them, the adult learning opportunities were very powerful. Responses such as "this is challenging my way of thinking" and "these are real-life applications of science" did not include the classroom science teacher filtering so often done by others. One teacher wrote, "Adult learning is a nice change," and another teacher said that the summer "deepened my understanding of how science and technology are intertwined and are major underpinning in our world."

Of the teachers who had a more difficult time separating the two roles, some saw value in the two week summer academy only if it seemed readily applicable to their own classrooms. Those teachers wrote things like, "I might be able to bring in fuel cells to the students and give them a deeper understanding of where the technology is taking us but I am not sure about where it meets the standards" and "almost all of the laboratory tests could be easily replicated in our classroom with our students, which is a very big plus." They objected when the concepts were too complicated or challenging for them, usually because they did not see how they could scale it down to their own students. One teacher said, "This might work with my students but I would have to do some serious modifications." Another teacher wrote, "How in the world could I get middle schoolers to get this heady stuff? It is hard enough for me."

Another element emerged in many of the journal summaries. The value of the scenario approach seemed to provide deep learning and a connection to a possible technique for the classroom. "Scenarios are a good way to get depth out of the learning process," wrote one teacher. Another said, "We were impressed at how much we were learning about fuel cell technology and engineering by having to do this project." Finally, another teacher commented:

> A few of us on the team weren't sure about the challenge because we felt that the fuel cell itself wasn't essential in energy generation. But this scenario idea was actually quite an enjoyable activity coming up with ways to make a model that works and then figure out what it would take to scale that up to a real production model. As a challenge, it was both fun and educational. We were impressed at how much we were learning about fuel cell technology and engineering with this project. We got to see, on a smaller scale, some of the advantages and disadvantages of the fuel cell technology including working out the approximate cost for our design.

*Anticipating the "Act" Phase.* To prepare for the "act" phase, we will gather the teachers together in Richland, in the early spring of 2009, for another focus group meeting where we will craft a set of recommendations for partnership programs in general. Those recommendations will initially impact the final summer (2009) for the teachers, but more importantly, they will be used to both inform the literature on professional development for science classroom teachers as well as give future direction for these types of programs at PNNL.

## Summary

From reflections in science notebooks to field notes of side conversations, from whole group analysis of strengths and weaknesses to journal summaries of experiences, the second summer academy was replete with many data points. We felt we had provided multiple opportunities for reflection and dialogue to enhance our collective understanding of the value of the partnership. The problems that emerged in the qualitative case study that first summer were turning into opportunities to think about the partnership in a comprehensive way. We were also beginning to give shape to emerging recommendations for partnerships, which was the intended outcome of the action research cycle.

# Chapter 4

# CONCLUSIONS, RECOMMENDATIONS AND REFLECTIONS

The overall purpose of this study was to (a) explore the experiences of middle school science teachers involved in a partnership program between scientists and teachers at the Pacific Northwest National Laboratory, including the impact of the program on their professional development, and (b) to improve the partnership program by developing a set of recommendations based on the study's findings. The research questions that guided this study were: (a) What are the perceptions of the middle school science teachers of the value of the partnership model in regard to their own science literacy development? (b) What are the strategies of professional development the teachers found most valuable when working with scientist-teacher partnerships to develop their science literacy? and (c) What other elements of the summer academy assisted the teachers in developing their own pedagogical content knowledge in order to deliver science as a classroom teacher more effectively?

In the following section, the conclusions reached by me and my co-researchers are presented in juxtaposition to the recommendations we are making for future partnership programs. I have chosen to represent the information in this manner to tightly link together these final elements of the study. It is these recommendations that will shape the "act" phase of the action research cycle as we move forward with the third and final summer (2009) of the three year academy.

## Conclusions and Recommendations

Through engagement in this action research study, we have reached five main conclusions that center on the critical components of the scientist-teacher partnership for professional development. First, scientist-teacher partnerships form a unique contribution to the professional development of teachers of science that is not replicated in other forms of teacher training. Second, the role of the science education specialist within the scientist-teacher partnership model is a unique and vital one, impacting all aspects of the professional development of the teachers. Third, there is a paradox for classroom teachers as they view the professional development experience from two different lenses – that of *learner* and that of *teacher*. Fourth, learning for the teachers must be designed to be constructivist in nature. Fifth, the principles of the nature of science must be explicitly showcased to be seen and understood by the classroom teachers. These conclusions are further explained in the paragraphs below and are explicitly linked to recommendations for partnership programs in general and for future PNNL partnership programs specifically.

The first conclusion we reached was in regard to the strategy of partnerships between teachers and scientists in an industry such as a national laboratory. We believe the partnership model to be a powerful strategy of professional development that benefits both the scientist who chooses to engage and the classroom teacher who chooses to enroll. But for partnerships to be an effective way to impact a teacher's thinking, teaching, or both, the partnership must be a collegial exchange in which both partners trust they have something to gain. For the classroom teacher, the gain is in a deeper understanding of the core content embedded in science as well as an enriched idea of how science is done in the real world. It opens the teacher's mind to a more complex conceptual framework for understanding science itself – a real world application of what a scientist does and how and why he or she does it. For the scientist, it is an opportunity to become familiar with the realities of a school system and the need to become an advocate for quality science education. It allows the scientist to perform a role different from his or her traditional roles in education as science fair judge or expert speaker; the partnership promotes a more collaborative and authentic role of sharing one's life as a scientist and deep knowledge of science with classroom teachers.

This first conclusion of the study leads to a recommendation that scientist-teacher partnerships be based on shared beliefs that guide the work, including that each member of the partnership has a valuable role to play in educating the other about their differing worlds and that each of those roles is important in the overall educational purpose of building the next generation of young scientists and engineers.

The second conclusion, and perhaps the most significant one for me, was in regard to the critical and complex role the science education specialist plays in partnership programs. Often, the role is defined merely as establishing a relationship between the teacher and the scientist-mentor, but we found the role to be much greater than that. The science education specialist, as the significant third player, must intuitively monitor and adjust the professional development program from initial conception to final closing. This role involves balancing the world of the teacher with that of the scientist while being knowledgeable of the elements inherent in each world. For the middle school teacher, the science education specialist weaves together knowledge of the classroom and the pedagogy of teaching with an understanding of how adult learners learn while helping the teachers link the science they are learning to their own classroom teaching. The science education specialist needs to know the knowledge and beliefs of the teachers, the context and critical issues linked to their teaching environments as well as the design elements that are involved in creating high quality professional development planned for the acquisition of science content. For the laboratory scientist, the specialist needs to know the uniqueness of the laboratory setting in which the scientists practice, along with a strong understanding of the principles of the nature of science that exist at PNNL, and the needs of the scientist-mentors who are taking time away from their busy schedules and demanding research to partner with classroom teachers.   Thus, the science education specialist's role can be seen as the builder of a bridge (see Figure 2) between the scientists who deeply know their science content and the classroom teachers who are grounded in the pedagogy necessary to teach in the middle school classroom but may not have a full grasp of the science content.

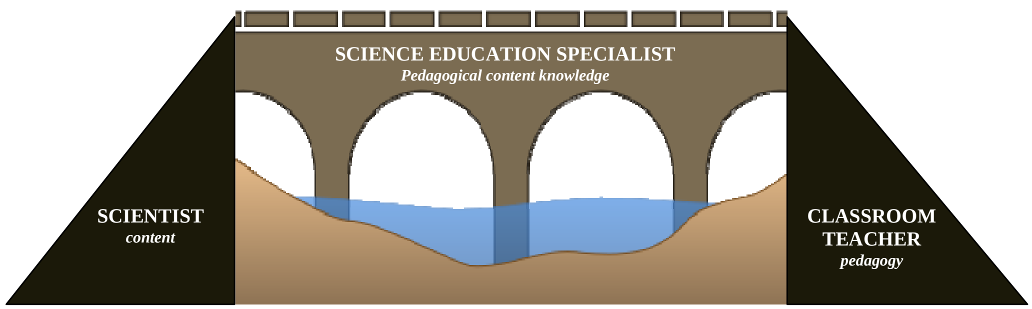



Figure 2:  Role of the Science Education Specialist

The recommendation, related to this second conclusion, is to engage a science education specialist who can bridge the two worlds of teacher and scientist, early on in the conceptual stage of a partnership.  The specialist should have a background in teaching as well as a developed relationship with the various scientists who have expertise to share.  The specialist should have a strong background in professional development with teachers of science as well as former teaching experience in the K-12 science classroom.  Drawing on each of these skills to enhance the pedagogical presentations given to the science teachers will bring a high level of credibility to the role of specialist and to the partnership.

The third conclusion of the study centers on a paradox for classroom teachers as they struggle with two roles they must play when engaged in the scientist-teacher partnership model of professional development – the role of *teacher-as-learner* and the role of *teacher-as-teacher*.

We found that some teachers were readily able to use a *learner lens* when engaging in adult learning of science concepts, but other teachers were not able to settle into adult learning activities without constantly filtering all new learning experiences through their *teacher lens.* This filtering often caused them to reject a learning experience that was intended to develop their own science literacy, because they could not imagine how to scale down the science content to the level of their middle school students. All teachers were more willing to suspend judgment on the applicability of a learning experience to their classrooms, when asked specifically to wear their *learner lens* to wrestle with new conceptual understandings. They were willing to do this if they knew time would be set aside later to wear their *teacher lens* and work collaboratively with their teaching colleagues to make connections between the science concepts and the science curriculum and state standards used in their classrooms.

The recommendation linked to this third conclusion is that the science education specialist and scientist-mentors be very intentional about when each lens – the *learner lens* or the *teacher lens* - should be used to filter the science content. First, when the teachers are engaged as adult learners with a *learner lens* securely in place, the content should be sufficiently challenging as to create a level of cognitive dissonance (Thompson & Zeuli, 1999) or challenge their beliefs, making the learning transformative for them. These learner lens experiences should include time for the teachers to discuss with one another and with the scientists and to challenge each others' thinking to make sense of what they have learned. Then, interwoven into the academy, should be time to allow the teachers to wear their *teacher lens* as they work together to situate their learning in the context of their classrooms (Loughran, 2007). They need time to think together about what content is appropriate to their middle school students and how they might approach the delivery of that information as a part of their teaching pedagogy.

The fourth conclusion is closely related to the third conclusion. In order to accomplish, through a scientist-teacher partnership, professional development that is meaningful both for *teacher as learner* and *teacher as teacher*, a constructivist approach should frame the learning experience. However, the scientists involved in these partnerships typically do not have the intuitive or professional knowledge to teach in a constructivist fashion. The scientists bring the critical asset of content knowledge to the partnership, and many have experience as didactic lecturers. But to engage in a constructivist approach, the scientist must assume the role of facilitator of knowledge acquisition, not deliverer of content, which, for most scientists, is a shift in thinking about their role. The scientists involved in these partnerships typically need some level of development to engage in constructivist teaching.

Thus, we recommend that the science education specialist play the role of "coach" to the scientist-mentors in regard to delivering the content in a way that will be accessible to the classroom teachers. The scientist needs to create a learning environment that is orchestrated with opportunities for hands-on learning activities and discourse as each new learning is constructed for the teachers. Since this entails reorganizing prior knowledge to accommodate for the new learning (Schmansky et al., 1997), the scientist, with the help of the science education specialist, creates a collaborative and collegial community of learners doing, thinking, talking, writing, and reading about science.

Finally, the fifth conclusion of the study is that teachers involved in the scientist-teacher partnership do not automatically acquire a sense of the principles of science at play in the work of the scientists. Rather, beyond providing opportunities for teachers to observe the scientists at work in the laboratory, the scientists' work must be intentionally showcased and linked to the nature of science principles found in the science education standards (NRC, 1996; Abd-El-Khalick & BouJaoude, 1997; Lederman, 1999).

The recommendation linked to this conclusion again involves some work on the part of the science education specialist who must be explicit and diligent in capturing examples of those principles in real life vignettes for the teachers to witness in action at the laboratory. Since the partnership offers potential for impacting the way teachers learn and subsequently teach about the nature of science to their students, it is further recommended that the teachers have time to search the internet and then discuss and adapt examples of activities that best model the nature of science principles to their middle school students.

## Reflections

If we are serious about the science education of children in our schools, we should be equally serious about supporting the professional development of the classroom teachers who are charged with the task of teaching science. If we are to meet the nation's needs for a scientifically literate citizenry, not to mention skilled workers, we should look to professional development programs that give teachers the opportunity to expand their knowledge while developing their pedagogical skills and laboratory expertise. It is my contention that partnerships between scientists and classroom teachers are a valuable professional development model that shows great promise.

One of the criticisms of partnership programs sponsored by national laboratories around the country is that the impact sits solely with the teacher who participated and does not impact the system as a whole (NRC, 1996). Perhaps this is true, but further research needs to be done on the long term impact of programs such as the PNNL program in this study. We, at PNNL, see

K-12 teachers who have "graduated" from our partnership programs emerge as school district leaders of professional development, as members or leads of curricular adoption committees, or as participants on leadership teams working on science education reform. In addition, many go on to identify themselves as building-level science specialists, or to move into science education specialist jobs with laboratories to work on developing partnership programs.

My future research aspirations find me wanting to know more about the impact of the partnership program in professional development at the student level. I want to examine what happens in classrooms after the teachers leave the academy. What does the teacher do with the new knowledge when teaching in their classrooms? What impact might this have on the students they teach? Is it possible to see evidence of the partnership in student outcomes such as an enhanced understanding of science?

I am also curious about the impact a summer academy experience might have on the success of a professional learning community in a school building. What elements of the academy could the science specialist design to create a learning community among the participating teachers? How could the partnership play a more direct role during the school year in developing professional learning communities where the teachers work? What role might the scientist play in that learning community? How could the scientist be engaged in delivery of additional content as the teachers work with their colleagues on the pedagogy of teaching science?

In addition, I am interested in understanding how partnership programs impact teachers at different grade levels such as elementary and high school. The content understanding of each of these levels of teachers is significantly different. How does the constructivist nature of the partnership change to accommodate elementary teachers who have little to no understanding of the content of science?  How do we create powerful learning in those high school teachers who have a high degree of understanding of their content?

Finally, I wonder about the difference in the impact of the eight-week immersion model in which high school teachers are paired with a single scientist to conduct research versus the two-week partnership program studied here, wherein a group of teachers and scientist-mentors engage in a teaching-learning cycle embedded in a scenario.  What is the role the science education specialist plays in each of these venues?  Can the science education specialist impact the eight-week immersion experience as significantly as the partnership program?  Which of these programs, the immersion or the partnership, is the most valuable for elementary teachers, middle school teachers or high school teachers?

I now see myself and my work in a different light.  It is through this action research experience that I truly have begun to more fully understand the critical role I play as the science education specialist in partnerships at the lab.  Certainly, I learned a great deal about collaborating with others in action research and the sense of empowerment it brought to the teachers in this study.  I also know how important action research can be in learning how to create a professional development design that is more powerful for teachers. I also learned about my resiliency in the face of difficulty.  After the first summer academy, when some of the teachers railed against the professional development program we had crafted for them, it was difficult, at best, to accept their frustrations without passing judgment on those teachers.  I saw, in myself, a willingness to focus on a serendipitous research opportunity, not a reason to give up, and it is that aspect in my quiet tenacity that I believe has impacted me more than anything through this research.  I have such passion for science education and the professional development necessary to achieve science education for all.  It is that passion at my back that will propel me forward in my journey to uncover new understanding of professional development design using partnerships as a venue and action research as a methodology.

## References

Abd-El-Khalick, F., & BouJaoude, S. (1997). An exploratory study of the knowledge base for science teaching. *Journal of Research in Science Teaching, 34,* 673.

Abell, S, (2007). Research on science teacher knowledge. In S. Abel & N. Lederman (Eds.), *Handbook of research on science education* (pp. 1105-1149). Mahwah, NJ: Lawrence Erlbaum Associates.

Akerson, V.L., & Hanuscin, D.L. (2005). A collaborative endeavor to teach the nature of scientific inquiry. In R. Yager (Ed.), *Exemplary science: Best practices in professional development*, (p. 1-12). Arlington, VA: NSTA Press.

American Association for the Advancement of Science (1991). *Science for all Americans.* New York, NY: Oxford University Press.

American Association for the Advancement of Science (1993). *Benchmarks for science literacy: A project 2061 report*. New York, NY: Oxford University Press.

Barab, S.A., & Hay, K.E., (2001). Doing science at the elbows of experts: Issues related to the science apprenticeship camp. *Journal of Research in Science Teaching, 38,* 70-102.

Bogdan, R., & Biklen, S. (1992). *Qualitative research for education.* Boston: Allyn & Bacon.

Bransford, J., Brown, A., & Cocking, R.R. (1999). *How people learn: Brain, mind, experience and school.* Washington , D.C.: National Academy Press.

Briscoe, C., & Peters, J. (1997). Teacher collaboration across and within schools: Supporting individual change in elementary science teaching. *Science Education, 81*, 51-65.

Bybee, R. (1997). *Achieving science literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Darling-Hammond, L. (1997). *Doing what matters most: Investing in quality teaching.* New York, NY: National Commission on Teaching and America's Future.

Dickson, P. (2007). *Sputnik: The shock of the century*. New York, NY: Walker & Company.

Donovan, M.S., Bransford, J.D., & Pellegrino, J.W., (2000). *How people learn: Bridging research and practice.* Washington, DC: National Academies Press.

Driver, R., Guesne, E., & Tiberghien, A. (2000). *Children's ideas in science.* Philadelphia, PA: Open University Press.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2005). *Making sense of secondary science: Research into children's ideas.* New York, NY: Routledge.

Eisenhower National Clearinghouse. (1999). *Ideas that work: Science professional development.* Columbus, OH: Author.

Glaser, B. & Strauss, A. (1967). *Discovery of grounded theory: staged for qualitative research.* Chicago, IL: Aldine.

Greenwood, D., & Levin, M. (1998). *Introduction to action research: Social research for social change.* Thousand Oaks, CA: Sage Publications.

Hazen, R.M., & Trefil, J. (1991). *Science matters: Achieving scientific literacy.* New York, NY: Random House Books.

Herr, K, & Anderson, G. (2005). *The action research dissertation.* Thousand, Oaks, CA: Sage Publications.

Hewson P. (2007). Teacher professional development in science. In S. Abel & N. Lederman (Eds.), *Handbook of research on science education* (pp. 1179-1203). Mahwah, NJ: Lawrence Erlbaum Associates.

Hurd, P.D. (1998). Scientific literacy: New minds for a changing world. *Science Education, 82,* 407-416.

Joyce, B., & Showers, B. (1995). *Student achievement through staff development.* White Plains, NY: Longman.

Keeley, P. (2008). *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning.* Thousand Oaks, CA: Corwin Press.

Kranshy, M.E. (1999). Reflections on nine years of conducting high school research programs. *Journal of Natural Resources and Life Science Education, 28,* 17-23.

Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29,* 331-359.

Lederman, N.G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36,* 916-929.

Loucks-Horsley, S.L., Love, N., Stiles, K.E., Mundry, S., & Hewson, P.W. (2003). *Designing professional development for teachers of science and mathematics* (2nd ed.). Thousand Oaks, CA: Corwin.

Loughran, J. (2007). Science teacher as learner. In S. Abel & N. Lederman (Eds.) *Handbook of research on science education* (pp.1043-1065). Mahwah, NJ: Lawrence Erlbaum Associates.

Meichtry, Y.J. (1992). Influencing student understanding of the nature of science: Data from a case of curriculum development. *Journal of Research in Science Teaching, 29,* 389-407.

Michaels, S., Shouse, A., & Schweingruber, H. (2008). *Ready, set, science: Putting research to work in K-8 science classrooms.* Washington, D.C.: National Academies Press.

Miller, D., & Pine, G. (1990). Advancing professional inquiry for educational improvement through action research. *Journal of Staff Development, 11*, 56-61.

National Center for Improving Science Education. (1989). *Getting started in science: A blueprint for elementary school science education.* Washington, DC: The Network, Inc.

National Commission for Excellence in Education. (1983). *A nation at risk: The imperative for educational reform.* Retrieved July 12, 2008 from http://www.ed.gov/pubs/NatAtRisk/index.html.

National Commission on Mathematics and Science Teaching for the 21st Century. (2000). *Before it's too late: A report to the nation.* Washington, DC: U.S. Department of Education.

National Research Council.(1996). *National science education standards*. Washington, DC: National Academies Press.

National Research Council. (1996). *The role of scientists in the professional development of science teachers.* Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: Author.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, DC: The National Academies Press.

National Science Resources Center. (1997). *Science for all children: A guide to improving elementary science education in your school district.* Washington, DC: National Academy Press.

National Staff Development Council. (2001). *Standards for staff development.* Oxford, OH: Author.

Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual plan. *Science Education,* 211-227.

Reason, P., & Bradbury, H. (2006). *Handbook of action research.* Thousand Oaks, CA: Sage Publications.

Rosebery, A., & Puttick, G. (1998). Teacher professional development as situated sense-making: A case study in science education. *Science Education*, *82*, 649-677.

Ruby, A. (1999). *Hands-on science and student achievement.* Santa Monica, CA: Rand Corporation.

Rutherford, J. (1998, January 12). *Sputnik and science education*. Paper presented at the meeting of the Center for Science, Mathematics, and Engineering Education. Retrieved October 28, 2007 from http://www.nas.edu/sputnik/ruther1.htm

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching, 36,* 201-219.

Schmansky, J., Yore, L., Treagust, D., Thiele, R. Harrison, A., Waldrip, B., Stocklmayer, S., and Venville, G. (1997). Examining the construction process: A study of changes in level 10 students' understanding of classical mechanics. *Journal of Research in Science Teaching, 34,* 571-593.

Schwartz, R., Lederman, N., & Crawford, B. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Teacher Education, 88,* 610-645.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review,* 57, 1-22.

Stringer, E. (2007). *Action research* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Stringer, E. (2007). *Action research in education.* Upper Saddle River, NJ: Pearson Education, Inc.

Tanner, K., Chatman, L., & Allen, D. (2003). Approaches to biology teaching and learning: Science teaching and learning across the school-university divide-cultivating conversations through scientist-teacher partnerships. *Cell Biology Education, 2,* 195-201.

Thompson, D., & Zeuli, J. (1999). The frame and the tapestry. In L. Darling Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 341-375). San Francisco: Jossey-Bass Publishers.

Trautmann, N., & MaKinster, J. (2005). Teacher/scientist partnerships as professional development: Understanding how collaboration can lead to inquiry. *Journal of Research in Science Teaching, 23*, 20-38.

U.S. Department of Education. (1995). *Mission and principles of professional development.* Washington, DC: Author.

U.S. Department of Education. (2002). *Does professional development change teaching practice? Results from a three-year study.* Washington, DC: Author.

Weiss, I. (1987). *Report of the 1985 -1986 national survey of science and mathematics education*. Research Triangle Park, NC: Research Triangle Institute.

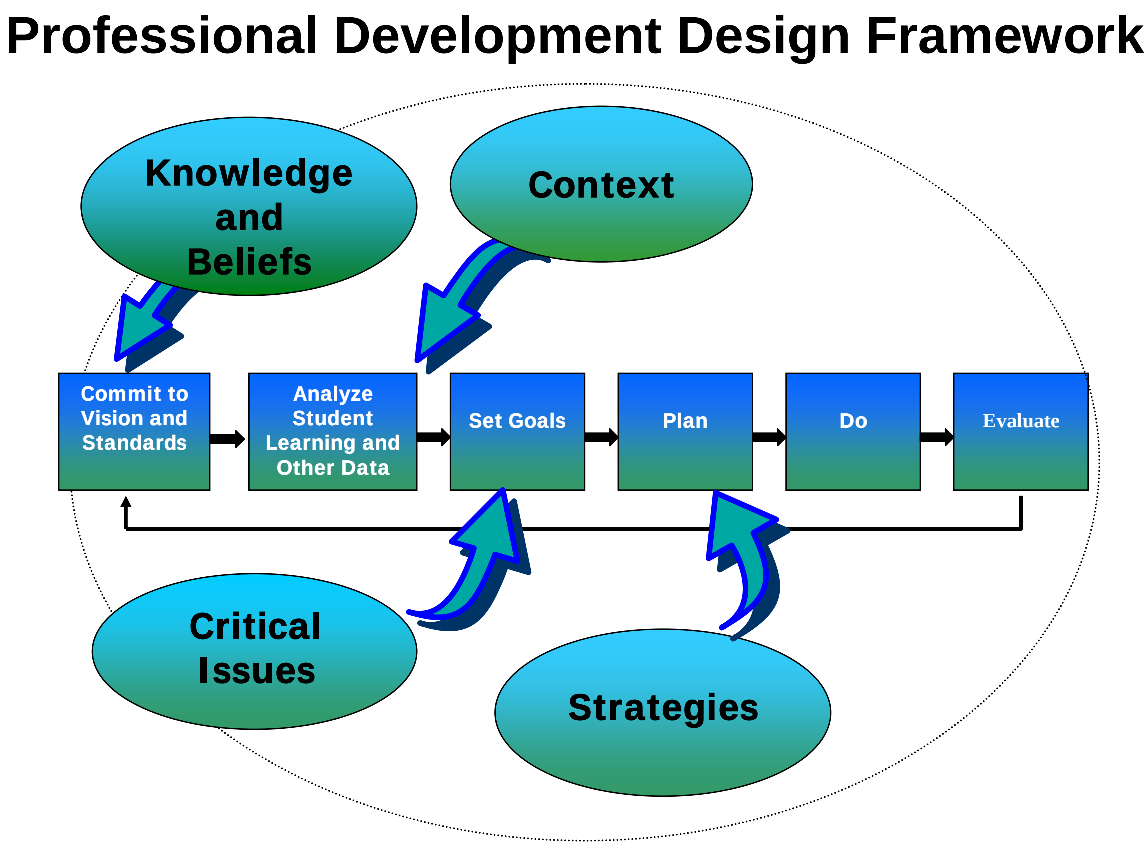
Wenglinsky, H., & Silverstein, S. (2000). The science training teachers need. *Educational Leadership, 64,* 24-29.

Yore, L., Pimm, D., & Tuan, H. (2007). The literacy and component of mathematical and scientific literacy. *International Journal of Science and Mathematics Education, 5,* 559-589.

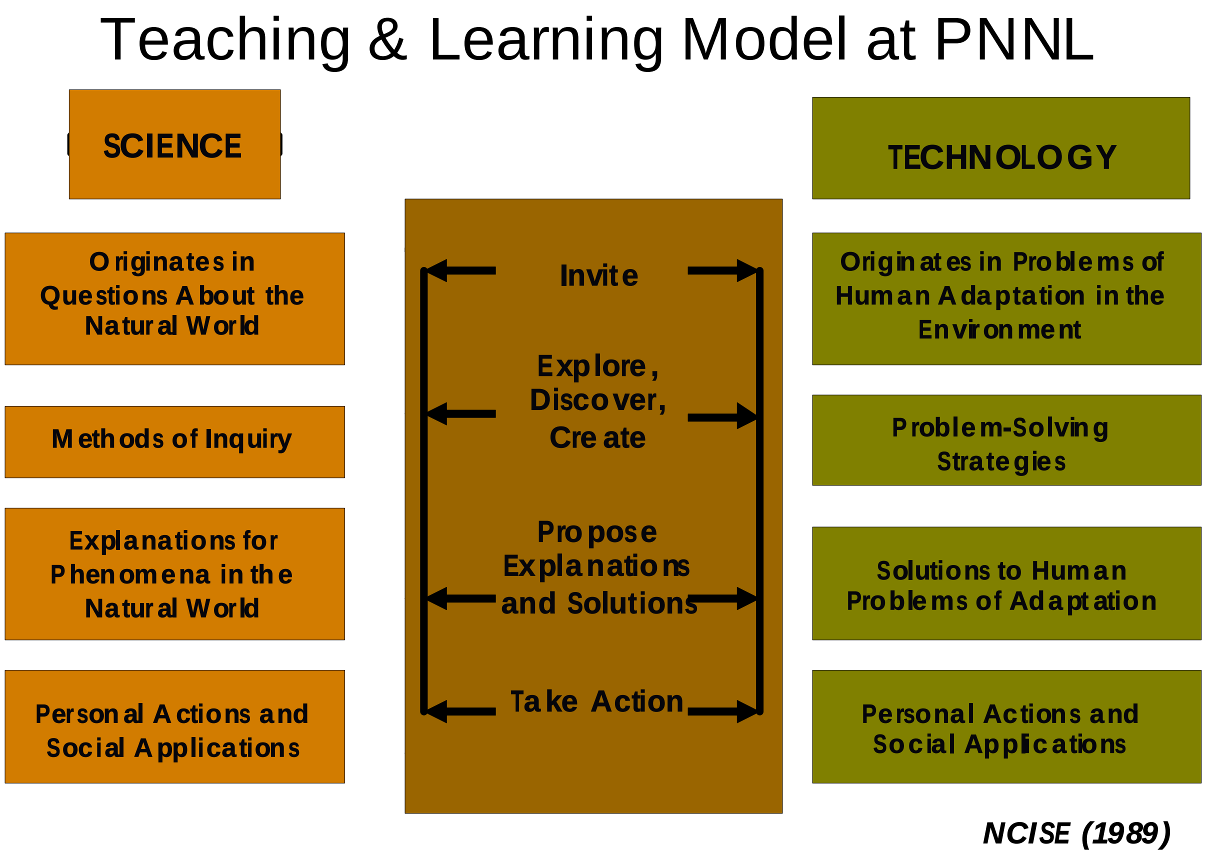
Zemelman, S., Daniels, H., & Hyde, A. (2005). *Best practice: Today's standards for teaching and learning in America's schools. (3rd ed.).* Portsmouth, NH: Heinemann.

Appendix A

Professional Development Design Framework (Loucks-Horsley et al., 2003)



Appendix B


Teaching & Learning Model at PNNL
SCIENCE
TECHNOLOGY
Originates in Questions About the Natural World
Methods of Inquiry
Explanations for Phenomena in the Natural World
Personal Actions and Social Applications
Invite
Explore, Discover, Create
Propose Explanations and Solutions
Take Action
Originates in Problems of Human Adaptation in the Environment
Problem-Solving Strategies
Solutions to Human Problems of Adaptation
Personal Actions and Social Applications
NCISE (1989)

Appendix C
Scenario/Design Challenge from Summer 2007

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TO: DOE/ACTS Consulting Group

FROM: Management of Battelle – Office of Building and Management

SUBJECT: Laboratory Space Blueprint

DATE: July 23, 2007

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Battelle is in the process of examining proposals of design blueprints for a new laboratory building, the Physical Sciences Facility, to be located on the Horn Rapids Triangle just north of the Pacific Northwest National Laboratory (PNNL) campus in Richland, Washington.

It will be part of PNNL's strategy for replacing nearly 500,000 square feet of office and laboratory space, due to the demolition of many of the Hanford Site's 300 Area facilities in Eastern Washington.

Battelle is requesting the DOE/ACTS Consulting Group to submit a proposal to:

*Design a 200,000 square foot office and laboratory space to house 1000 staff members. The laboratory space must include radiological laboratories and physics/engineering laboratories.*

- The Lab space will have:
  - *no windows;*
  - *once through air;*
  - *approximately 200 cubicles of 500 sq ft each; and*
  - *if radiological in nature, separated from office space and able to be closed off in case of contamination.*

- The Office space needs to be:
  - *as near as possible to the laboratory space;*
  - *as near as possible to like groups (assume each group has 40 people in it);*
  - *considerate of "quality" of workspace; and*
  - *as energy efficient as possible.*

## Appendix D
## Open-Ended Interview Questions – Fall 2007

The following open-ended interview questions formed the basis of the semi-structured interviews conducted in the Fall of 2007 for the qualitative case study:

1. Tell me about your experience in the program at the lab this past summer? What was particularly good/useful? Why?

2. What science content did you learn? How did you learn it?

3. Has this experience impacted you as a teacher? How? Why? Why not?

Appendix E
Scenario/Design Challenge from Summer 2008

## 2008 X-Prize Fuel Cell Design Challenge

TO: DOE/ACTS Consulting Group

FROM: Robert K. Weiss, Vice-Chairman X-Prize Foundation

SUBJECT: X-Prize for Fuel Cell Machine Adaptations

DATE: July 25, 2008

The X-Prize Foundation of Santa Monica, California, in association with Pacific Northwest National Laboratory (PNNL), is requesting your team to participate in a design challenge to create a socially beneficial machine or piece of equipment using a hydrogen powered fuel-cell(s).

Your design must be based off of the fuel cell(s) provided to you at the DOE/ACTS Institute during the summer of 2008.

In addition to a working model, your presentaion / submission must include the following:

1. Technical drawing and/or photograph of your prototype;
2. Written description of materials required;
3. The estimated cost of full-scale;
4. An energy flow diagram.

On Wednesday, July 30th, your team will be presenting your model and the associated documents to a panel of scientists gathered to assist you.