Fidelity of Implementation of

Research Experience for Teachers in the Classroom

by

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ABSTRACT

In this study, the Arizona State University Mathematics and Science Teaching Fellows 2010 program was analyzed qualitatively from start to finish to determine the impact of the research experience on teachers in the classroom. The sample for the study was the 2010 cohort of eight high school science teachers. Erickson's (1986) interpretive, participant observational fieldwork method was used to report data by means of detailed descriptions of the research experience and classroom implementation. Data was collected from teacher documents, interviews, and observations. The findings revealed various factors that were responsible for an ineffective implementation of the research experience in the classroom such as research experience, curriculum support, availability of resources, and school curriculum. Implications and recommendations for future programs are discussed in the study.

DEDICATION

To my parents who encouraged me to dream big and reach my goals

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Introduction

There are a number of studies on the success of programs related to research experience for teachers that are based on reports given by teachers. However, not enough data has been found on the nature of implementation of the research experience in the classroom. The idea behind funding such programs is that the teachers will take back the research experience to their classrooms and in turn influence their students to pursue a career in science. The assumption is that teachers gaining such experience will in turn influence their students.

Teachers are funded to spend time during summer in research laboratories and complete a course in curriculum development so they can go back to their science classrooms with enriched teaching skills. In addition, teachers receive funds for classroom materials. Therefore, it is imperative to learn how much of the research experience and the curriculum planning acquired by the teachers during the program is actually implemented in the classroom.

In this study, data has been collected before, during, and after the Arizona State University Mathematics and Science Teaching Fellows 2010 program using multiple means. Data has been analyzed qualitatively to obtain an understanding of the kind of professional development that was provided to the teachers during the program and the extent to which the research experience was implemented in the classroom. The results found have provided insights into developing more effective research experience programs in the future.

Literature Review

Professional development for teachers

All professional development programs are designed with the main goal of improving student learning. There are several kinds of professional development programs that have been designed for teachers in the past and a substantial number of these programs have faced criticism. Corey (1957) stressed that while there was strong evidence of a growing need for continuing professional development among school persons, it was also apparent that "much of what goes for inservice education is uninspiring and ineffective". There have been equally dismal reports by others (Flanders, 1980; Harris, Bessent, and McIntyre, 1969; Howey and Joyce, 1978; Lawrence, 1974; McLaughlin and Marsh, 1978; Rubin,1978; Wagstoff and McCullough, 1973; Wood and Thompson, 1980 cited in Guskey, 1986). Having said all that, there have been continuing efforts to design better professional development programs and teachers have shown continued interest in participating in these programs in order to enhance their teaching practices. Fullan (1982) believes that generally the most promising and readily available way of growth in jobs is through staff development.

In order to understand the fidelity of implementation of teacher professional development, it is worthwhile to look at some of the models of professional development that have been developed by researchers and have been used to design many professional development programs for teachers. I will be looking at some of those models and some studies that have been conducted using those models. I will then look at models of fidelity of implementation put forward by some researchers and studies done based on those models. Finally, I will look at studies on research experience for teachers.

Guskey (1986) presents a model that describes the change in teachers' classroom practices, attitudes and beliefs, and outcomes of student learning through professional development programs. He says that the staff development programs that emphasize the initial commitment of teachers' are based on the assumption that teachers change their beliefs and attitudes first (refer to Figure 1). Such programs, however, seldom result in noticeable change in attitude or commitment of the teachers (Jones & Haynes, 1980 cited in Guskey, 1986). The model proposed by Guskey suggests that significant change in teachers' beliefs and attitudes is likely to take place only after teachers find evidence of change in student learning outcomes. He realizes that the model does not account for all the variables that might be associated with the teacher change process. Studies done by Crandall, 1983 and Huberman, 1981 support this model.

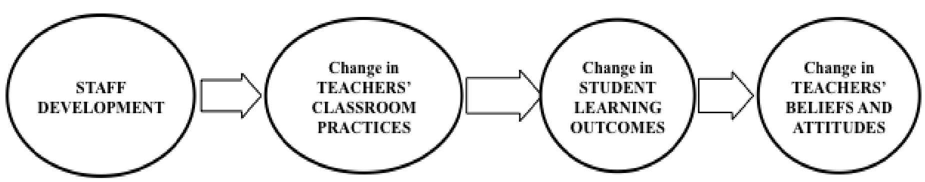

Figure 1. A model of the process of teacher change (Guskey, 1986)

The implications for staff development as listed by Guskey are as follows:

1. Understand that learning to be proficient at something new and finding a new way of doing something meaningful requires time and effort.

2. Make sure that teachers receive regular feedback on effects of these changes on student learning.
3. Provide continued support and follow-up after the initial training because most teachers need some time and experimentation to incorporate new practices into their own classroom conditions (Berman & McLaughlin, 1976; Joyce & Showers, 1980, 1982; Smith & Keith, 1971) This support can be provided by administrators, curriculum supervisors, college professors, or fellow teachers.

Guskey's proposed model suggests that the process of staff development may be complex but has some order to it and paying attention to that order can facilitate and endure change resulting in effective and powerful professional development programs (Guskey, 2002).

Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) proposed a revised framework of professional development in Science and Mathematics (refer to Figure 2). This framework emerged as a result of collaborative reflection from outstanding mathematics and science educators on their programs who combined different models to design complex programs through series of changes over time. During the design of professional development programs, they considered previous research and their own beliefs about the nature of mathematics and science; student and adult learning.

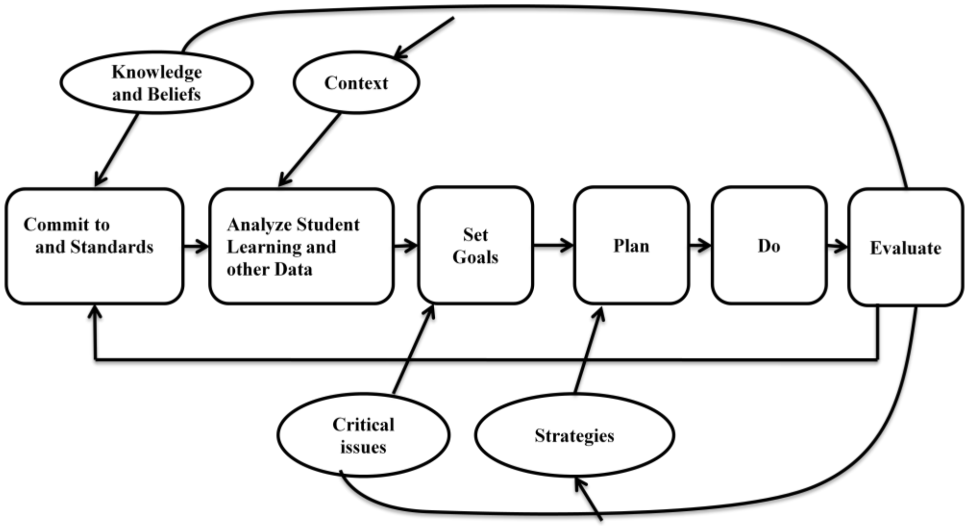

Figure 2. Design framework for professional development in science and mathematics (Loucks-Horsley et al., 2003)

They chose from a repertoire of strategies, struggled with challenging critical issues that were related to the field of mathematics and science education reform. They studied their own context and analyzed student learning to set goals to improve teacher and student learning and classroom practice. The various approaches that would be best for a particular place and time were taken into consideration. The goals and plans were based on all the above elements. The design kept evolving after implementation as they learned from their mistakes, as teachers' developed, and as new contexts emerged. The final step was evaluating the programs, which was done on the basis of teacher satisfaction as well as the extent to which teacher and student learning goals were met. Many educators have used this thoughtful and consciously designed framework at various stages of their professional development programs to help them reflect on their outcomes and think of ways to redesign their programs.

Supovitz and Turner (2000) compiled a set of six critical components that reflect a national consensus of the researchers and educators about what may constitute effective science professional development. They use the term “high quality professional development” to refer to teacher training experiences that incorporate these six elements in their program.

1. Should model inquiry forms of teaching by immersing participants in inquiry, questioning, and experimentation (Arons, 1989; McDermott, 1990; Bybee, 1993).
2. Intensive and sustained training (Smylie, Bilcer, Greenberg, & Harris, 1998; Hawley & Valli, 1999).
3. Should be based on teachers' experiences with students and engage teachers in concrete teaching tasks (Darling-Hammond & McLaughlin, 1995).
4. Enhance teachers' content skills by focusing on subject-matter knowledge (Cohen & Hill, 1998).
5. Should show teachers how to connect their work to specific standards for student performance (National Research Council (NRC), 1996; Hawley & Valli, 1999).
6. Other aspects of school change such as school development should be taken into consideration in the reform strategies (Fullan, 1991; O' Day & Smith, 1993; Corcoran & Goertz, 1995).

Based on these components, they designed an implicit logic of focusing on professional development as a means of improving student achievement (refer to

Figure 3). According to the logic, high quality professional development will lead to superior teaching practices, which will in turn result in improved student achievement. This whole sequence is mediated by the school environment and state and district policies.

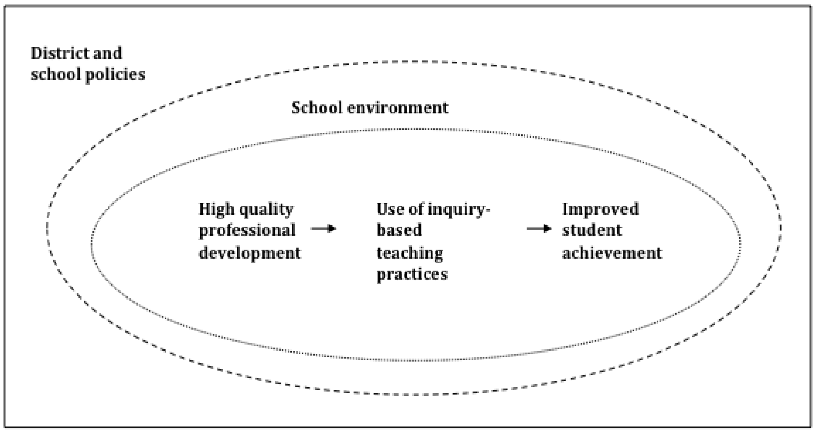

Figure 3. Model depicting theoretical relationship between professional development and student achievement (Supovitz & Turner, 2000)

Professional Development for Science Teachers

Supovitz and Turner (2000) studied the relationship between teacher background characteristics, teacher professional development experiences, school environment characteristics, teacher practices, and classroom culture. They used data from a National Science Foundation Teacher Enhancement program called the Local Systemic Change initiative and employed hierarchical linear modeling to examine the relationship between professional development and the reformed teaching practices. They found that the number of professional development in which teachers participate is strongly related to both inquiry-based teaching practice and investigative classroom culture. At the individual level, teaching practice and classroom culture was strongly influenced by the teachers' content preparation. At the school level, teaching practice was substantially more influenced by socioeconomic status rather than principal's support or resources available.

Desimone, Porter, Garet, Yoon, and Birman (2002) designed a series of quantitative studies that examined the relationships between alternative features of professional development and its effects on teachers' instruction in mathematics and science in a cross-sectional, national probability sample of teachers and a smaller, longitudinal study. Some of the key features under investigation were structural features: form and organization of the activity, duration of the activity, and the degree to which the activity emphasizes the collective participation of groups of teachers. The others were core features: the extent to which the activity offers opportunities for active learning, the degree to which the activity promotes coherence in teachers' professional development, the degree to which the activity has a content focus, use of technology, use of higher order instructional methods, and use of alternative assessment methods. All of the studies were conducted in the context of an evaluation of the Eisenhower Professional Development Program, which at that time was the federal government's largest investment solely focused on developing the knowledge and skills of classroom teachers. Since the data was collected at two levels (strategy-level and teacher-activity-level), they estimated the effects of professional development by using a hierarchical linear model. Their findings from the cross-sectional, national research show that, in addition to content focus, five key features of professional development are effective in improving teaching practice:

three structural features–reform type, duration, and collective participation; and two core features–active learning and coherence (Birman, Desimone, Garet, & Porter, 2000; Cohen & Hill, 2001; Garet, Birman, Porter, Desimone, & Herman, 1999; Garet, Porter, Desimone, Birman, & Yoon, 2001; Kennedy, 1998 in Desimone et al., 2002). The findings from the longitudinal study provided partial support for the importance of four of the additional five features of professional development identified in the national study. It indicated that professional development is more effective in changing teachers' classroom practice when it has collective participation of teachers from the same school, department, or grade; and active learning opportunities, such as reviewing student work or obtaining feedback on teaching; and coherence, for example, linking to other activities or building on teachers' previous knowledge. Reform type professional development also had a positive effect. They did not find any effects for duration of activities.

This study, however, was not designed to directly examine the effects of the Eisenhower program because the practices supported by the program varied. Therefore, they attempted to determine more or less effective practices within the context of the program and its practices. The distribution of the effective and ineffective practices on a representative sample of districts and teachers was then determined.

Radford (1998) conducted quantitative and qualitative research to study the effect of Project LIFE, a state systematic initiative professional development program for middle grades life science teachers on the teachers and their students.

He was specifically interested in the effect of the professional development on the science content knowledge, science process skills, and attitudes towards science teaching of the teacher participants and the effects of teaching on the process skills and attitude toward science of the students. He compared the students of project-trained teachers with students of teachers who did not participate in the program. Results of statistical analysis conducted on pre-post survey data showed that professional development project had a significant impact on science instruction in the classrooms of the participants. Qualitative analysis of teacher interviews, classroom observations and student interviews found that the teachers were using ideas, materials, and activities from Project LIFE and the most frequently mentioned differences by students were that they were conducting more experiments, science was more fun, and they were learning more science. (McGee-Brown, 1995 in Radford, 1998)

Luft and Pizzini (1998) studied a program designed to teach a model of problem solving in science, which was called the Search-Solve-Create-Share (SSCS) model. Thirteen elementary school teachers in the United States volunteered to participate in a four-day workshop and information on the model, be a student in the model cycle; and plan and implement the model in their classroom. Seven teachers completed the cycle that had three phases: implementation of the model, observation of an experienced teacher implementing the model up to four times, and repetition of the implementation. A researcher observed all the implementations. A specially designed instrument, the SSCS implementation assessment instrument was used to assess the use of problem solving model by teachers. Some key categories that the assessment instrument focused on were learning group performance, student participation, and the teacher's role in supporting a student-centered classroom. The level of use of each category before and after the teachers observed the demonstration lessons was compared. The findings show that there were significant increases in three categories (time in groups, group cohesiveness, and active participation) at the .05 level and two categories (teacher role and students generating problem and action plans) at the .01 level.

Fishman, Marx, Best, and Tal (2003) reported on a study that was based on an iterative model for evaluation of professional development that specifies that the design of professional development should be based on evidence of students' performance with respect to particular content standards. The developed professional development should be evaluated by the teachers and ideas explored enacted. The enactment should be observed and student performance evaluated which should lead to redesign of the professional development by following the same cycle over again. Eight middle school science teachers in a large urban school district in United States were participants of the study. The redesigned professional development was conducted in four Saturday workshops of six hours' duration held once a month. The activities during these workshops used strategies of curriculum review, peer information exchange, and examination of student work. It included an overview of the unit, modeling activity from unit, and practice with software tool used for building student understanding of watersheds. The results of teacher observations show that the teachers used several strategies developed in the workshops. Evaluation of student learning showed that there was a statistically significant improvement in responses to water quality test items from the previous year.

Kahle, Meece, and Scantelbury (2000) conducted a study on a statewide NSF-funded systemic initiative (SSI) in the United States. SSI in Ohio focused on reforming middle school science and mathematics in urban districts through intensive teacher professional development. Teachers attended a six-week summer institute with six follow-up seminars throughout the following year. The institutes focused on teachers' lack of content knowledge and modeled inquiry teaching with emphasis on standards-based teaching practices such as cooperative groups, open-ended questioning, extended inquiry, and problem solving. This study was based on a subset of data gathered from students. The data included student achievement tests (prepared by SSI from National Assessment of Educational Progress public-release items) and student questionnaires (included subscales on student attitudes, standards-based teaching strategies used by teachers, parents' involvement in science homework, and peers participation in science activities). Eight middle school teachers who had participated in the program were matched with one or more teachers teaching similar classes who had not. The results of eight SSI and 10 non-SSI teachers showed that there was a positive relationship between the SSI's standards based professional development and students' science achievement and attitudes, especially for boys.

Huffman, Thomas, and Laurenz (2003) conducted an external evaluation of a large-scale statewide professional development project in science and mathematics in the southern United States. Extensive and diverse professional development was provided by the state, which consisted of coordinated workshops in summer and extended follow-up through the school year. The five general professional development categories proposed by Loucks-Horsley et al. (1998) were used. There was variation in type and duration of professional development because the teachers were free to decide on the opportunities that they would engage in. The authors surveyed 94 eighth-grade science teachers on the type and duration of professional development and the type and frequency of use of standards-based instructional methods they used. Existing state achievement test (included multiple-choice, short-answer, and comprehensive scientific inquiry task) was used to measure student achievement. Regression analysis was conducted with the independent variable as type and duration of professional development and dependent variable as reported frequency of use of standards-based instructional methods and class means on the state-achievement tests. Results showed that only the professional development strategies of curriculum development and examining practice were predictive of the use of standards-based instructional methods. Relationship between any of the professional development strategies and student achievement was not found to be significant.

Van Driel, Beijaard, and Verloop (2001) examined research on professional development in the context of the current reforms in science education from the perspective of developing teachers' practical knowledge and believe that teachers’ practical knowledge is conceptualized as action oriented and person-bound. According to Van Driel et al. practical knowledge integrates experiential knowledge, formal knowledge, and personal beliefs because teachers in the context of their work construct it. They strongly believe that multi method designs are necessary in order to capture this type of complex knowledge. They recommend that teachers' practical knowledge be investigated at the start of the project and the changes in the practical knowledge be monitored throughout the project, which would ensure the reform project to benefit from the teachers expertise and be tuned to improve the chances of a successful implementation.

There are some important points about teachers' practical knowledge that van Driel et al. mention in their article, which would prove beneficial while looking at fidelity of implementation of professional development. They believe that there are various reasons why teachers find it difficult to apply innovative ideas in their teaching practice. One reason is that teachers do not want to change their own practice that is rooted in practical knowledge, which has proved to work satisfactorily over the course of their careers. According to Thompson and Zeuli (1999) teachers tend to change their practice by picking up new materials and techniques from here and there, and incorporating them in their existing practice. Another reason is that although there is an increase in the practical knowledge of the teachers with experience, there is a decrease in the variety within that knowledge. This results in teachers feeling more and more comfortable within their area of expertise making it more difficult for them to move into an area of experience that they are not familiar with (Berieter & Scardamalia, 1993 as cited in Van Driel et al., 2001).

As a summary to the results of research on science teachers' practical knowledge, Van Driel et al. conclude that experienced science teachers, contrary to the beginning teachers, develop an integrated set of knowledge and beliefs that is influenced by the mandated (national) curriculum, and the school culture, which in turn may lead to various problems in the context of curricular reform. First, teachers may not possess adequate knowledge of the new content or pedagogy to be implemented. Second, the intentions of the innovation may differ from teachers' beliefs with respect to the new content or pedagogy. Van Driel et al. believe that an innovation is not merely adding new information to the existing knowledge frameworks, but instead, teachers need to reframe their knowledge and beliefs, and integrate the new information based on their teaching experiences. They support the view that teachers should be involved in all phases of a reform effort and it is necessary to build partnerships between teachers, educators, researchers, and administrators.

On the basis of their literature review they conclude that long-term professional development programs are needed to achieve lasting changes in teachers' practical knowledge. They believe the following strategies can prove to be powerful: (a) learning in networks, (b) peer coaching, (c) collaborative action research, and (d) the use of cases. They recommend that teachers' practical knowledge be investigated at the start of a reform project and changes to this knowledge be monitored throughout the project, which would ensure that the reform projects benefit from teachers' expertise and adjustments made for a successful implementation of the reform.

Knapp (1997) assembled a review of studies and analyses of large-scale systemic reform initiatives aimed at mathematics and science education, especially those undertaken by state governments and the National Science Foundation. Knapp concluded from his review that many science and mathematics teachers have been affected by the reforms in a variety of ways. There is little evidence that teachers fully grasp and internalize the reform vision, though there are signs of attempt to realize some aspects of the reform. Implementation of reforms in the classroom is often seen to be fragmented and may involve segments of instruction related to different sciences but not a coherent whole such as a fully integrated science curriculum across the year. Teachers seem to rely on what they already know best and are frequently unaware of how much or how fundamentally their practice is changing in the direction of the advocated reform.

Hewson (2007) conducted a review on professional development programs with science teachers. He included two groups of studies: the first group considered the influence of the programs on teachers and the second group considered student outcomes from classes taught by teachers who participated in professional development programs. From the viewpoint of fidelity of implementation, some important conclusions were derived from this review. One of the conclusions is that without continuing support during the critical phases of planning, implementing, and reflecting on instruction, teachers are unlikely to make major changes in their teaching, specifically if the changes require the teachers to reconsider their core beliefs about science, teaching, learning, instructions and/ or instruction. Hewson used the pathway metaphor to explain what future research in teacher professional development should be considered. He suggests that it is necessary to consider both the outcomes that the programs seek to achieve as well as the means, the processes, and the pathways by which those outcomes will be achieved. The latter is the one that is most seldom ignored, and only considered when the desired outcomes are not achieved.

Literature on professional development shows that programs that are long, sustained and designed to engage teachers in concrete teaching tasks that they can directly transfer to their classroom, encourage networking between teachers, and focus on content, have been successful to some extent in bringing changes in teaching practices. However, there are not many studies that report gains in student outcomes as a result of the professional development program.

Fidelity of Implementation

The research studies on professional development programs that were discussed above were focused on examining the impact of professional development on classroom practice. The studies have examined some key features of the program. None of these studies have examined in detail the objectives of the professional development programs and the extent of program objectives that are actually implemented in the classrooms. Studies of this nature are known as "fidelity of implementation" (FOI) studies. Fidelity of implementation has been defined in different ways by different researchers. O'Donnel (2008) compiled a list of definitions of fidelity of implementation of K–12 core curriculum interventions in his review:

1. “The extent to which the project was implemented as proposed (or laid out)” (Loucks, 1983, p. 5).
2. “A measure of the basic extent of use of the curricular materials. It does not address issues of instructional quality. In some studies, implementation fidelity is synonymous with ‘opportunity to learn’” (NRC, 2004, p. 114).
3. “To implement it [an already developed innovation] faithfully in practice—that is, to use it as it is ‘supposed to be used,’ as intended by the developer” (Fullan, 2001, p. 40).
4. “The extent to which the project was implemented as originally planned” (Berman & McLaughlin, 1976, p. 350).
5. The extent to which the program components were implemented (Scheirer & Rezmovic, 1983).
6. The extent to which teachers enact innovations in ways that either follow designers’ intentions or replicate practices developed elsewhere, or the “extent to which the user’s current practice matched the developer’s ‘ideal’”(Loucks, 1983, p. 4).

There are not many research studies done in the education field on fidelity of implementation (FOI). Researchers in the field of health were the first ones to develop refined approaches to assessing and characterizing fidelity of implementation (FOI) that point out the complexity and multidimensional nature of FOI.

Dane and Schneider (1998) reviewed studies on prevention programs and found that most studies did not measure “program integrity” and the ones that did measured characteristics such as adherence, exposure, quality of delivery, responsiveness, and program differentiation. They suggested that all of these characteristics should be measured in order to have a good understanding of program integrity. Dane and Schneider help to bring consensus on some aspects for measuring FOI. Based on definitions found on diverse evaluation studies, these authors presented five aspects of FOI that have been measured across studies: (a) adherence – extent to which specified program components are delivered as the program prescribes; (b) exposure – amount of program content received by participants (i.e., number or length of sessions or frequency with which program techniques are implemented); (c) quality of program delivery – extent to which providers approach a theoretical ideal in terms of delivering program content and processes; (d) participant responsiveness – extent to which participants are engaged; and (e) program differentiation – uniqueness of the features of the program or treatment components that can be reliably distinguished from others. In a later review, Dusenbury, Brannigan, Falco, and Hansen (2003) revised these definitions, but their essential meaning did not change. Dane and Schneider (1998) recommend measuring all five aspects in order to provide a comprehensive picture of the fidelity of the program. The model of FOI by Dane and Schneider has been widely used in fidelity studies in the field of education.

Century, Freeman, & Rudnick (2008) developed a conceptual framework to measure fidelity of implementation of instructional materials based on features pointed out by Dane and Schneider (1998), Mowbary, Holter, Teague, and Bybee (2003). They defined fidelity of implementation as: "The extent to which an enacted program is consistent with the intended program model" and identified a working set of critical components of the reform-based mathematics and science instructional materials that would help in measuring FOI (Figure 4).

FOI OF INSTRUCTIONAL MATERIALS			
CATEGORIES OF CRITICAL COMPONENTS			
Structural Critical Components		Instructional Critical Components	
Procedural	Educative	Pedagogical	Student Engagement

Figure 4. Critical components for measuring FOI (Century et al. 2008)

The categories in the framework are defined as under:

Structural critical components portray the developers' decisions about the design and organization of the printed materials. This is further subdivided into procedural and educative components. Procedural components involve procedures of the instruction and physical organization of the program. Educative components involve expectations about how to structure and organize the information for the teachers or their expectations of what the teachers need to know in order to use the program as intended. Instructional critical component reflects expectations about teacher and student interactions during classroom instruction. This is further subdivided into pedagogical and student engagement components. Pedagogical component reflects the expectations about the instructional strategies that the teacher uses in the classroom. Student engagement component reflects expectations about the students' participation in the instructional process.

Hall and Loucks (1977) used the model of "Level of Use" in their study on determining whether the treatment is actually implemented in their evaluation study of Individually Guided Education (IGE) in collaboration with the Austin Independent School District evaluation staff. They identified and operationally defined, eight Levels of Use of the Innovation in their model. The behavior of innovation users and nonusers defined the content of the Levels of Use (LoU) dimension. The focus was on what they did in relation to the innovation and not on how they felt about it. Since the school district's evaluation plan was focused on pupil achievement in reading and mathematics, the Level of Use assessments were made for each teacher for the two innovations: individualized instruction in reading and individualized instruction in mathematics. Level of Use data were collected by interviewing teachers from second and fourth grade from eleven IGE schools and 11 non-IGE schools. Comparison of achievement between the IGE and non-IGE schools using one-way analysis of variance resulted in no significant differences between groups for both subject areas at both grade levels. The results for the overall use and nonuse groups showed a sizable number of IGE school teachers not in fact individualizing, and many of the teachers in the non-IGE schools were individualizing their instruction. The study had assumed the presence of innovation or treatment without firsthand knowledge of its presence.

This could have greatly increased the danger of spurious findings. The inability to detect real differences could be because of the unaccounted variance in users and non-users. This may be attributed to why many studies find that the treatment has no significant effects or that the comparison group does better.

Songer and Gotwal (2005) used the term fidelity as defined by Mowbary, Holter, Teague, & Bybee (2003) as “the extent to which delivery of an intervention adheres to the protocol or program model originally developed.” They examined three main categories of fidelity of implementation in their study based on the model by Lynch (2007): Structure (adherence to the unit, exposure, and program differentiation), process (quality of delivery), and self-perceived effects by participants. The purpose of their study was to examine how fidelity of implementation influences student learning. Twenty-three teachers with a range of experience and expertise taught the students. Students took both a pretest and posttest for each curricula made up of questions ranging in complexity of content as well as inquiry. In addition, graduate student researchers kept track of how much of the curriculum teachers completed. The authors believed that worksheet implementation is a good measure of fidelity of the curricular units that they were working on. The findings clearly showed how much and in what way teachers implement curricular units plays a large role in the learning that takes place. Using the measure of fidelity as the amount of student worksheets implemented, it was clear that students in high fidelity classrooms make larger gains from pre to post test than their peers in low fidelity classrooms.

Fullan and Pomfret (1977) analyzed several studies in terms of the conceptual criteria and methods of assessing implementation that involved a range of curriculum and organizational innovations. They suggested that a curriculum change consists primarily of five dimensions: changes in subject matter or materials, organizational structure, role/behavior, knowledge and understanding, and value internalization, in relation to a particular innovation. They characterized the following dimensions:

1. Subject matter components refer to the content of the curriculum that the teacher is expected to communicate to the student or that students are expected to acquire on their own or in cooperation with their peers, to the order of content to be communicated or acquired, and to the medium of communication.
2. Structural components involve changes in formal arrangements and physical conditions, different ways of grouping students, alternative arrangements, and presence of personnel to perform new roles, and an adequate supply of new materials.
3. Role/ behavior components refer to the extent to which teachers are able to recognize the range of behavioral alternatives open to them, ascertain which ones are applicable in a given setting, and change accordingly.
4. Knowledge and understanding refer to the understanding that users have about the innovation's various components, such as its philosophy, values, assumptions, objectives, subject matter, implementation strategy, and other organizational components, particularly role relationships.

5. The fifth dimension, value internalization, concerns the valuing and commitment to implementing various components of the innovation.

Fullan and Pomfret emphasize that for an implementation to occur, it is not sufficient in itself to value an innovation. They believe that the reverse is also true, that sometimes people do not value an innovation because the process of implementation was frustrating and not because it was undesirable as a goal. **I**n strongly concurring with House (1975) they believe that new approaches to educational change should have more small-scale intensive projects, more resources, time, and mechanisms for contact among implementers at both the initiation or adoption stages and especially during implementation for an effective implementation to occur. They realize that in many situations, providing these resources may not be politically and financially feasible.

O'Donnell (2008) building on Fullan and Pomfret's review conducted a literature review to identify studies that have used quantitative research methods to determine the relationship between fidelity of implementation to K-12 core curriculum interventions and outcomes. The purpose of their literature review was to examine how fidelity of implementation is defined, conceptualized, measured, and applied. They conceptualized the fidelity of implementation studies to fall under two stages of research: Efficacy studies and effectiveness studies. The rationale that he presents for studying these two stages is to help the researchers in testing their assumptions that the failure of an evaluated program is either the result of poor program design or that the implementation failed even though the program design worked. While conducting his literature review, O'Donnell found that there was a lot of conflict and overlap between the term *fidelity of implementation* and other educational constructs such as curriculum potential, curriculum-in-use, curriculum use, perceived curriculum, and adaptation.

Ruiz-Primo (2006) suggested a multi-method and multi-source approach for studying fidelity of implementation. The study proposes a conceptual approach for studying fidelity of implementation in the context of inquiry-based science curricula. The approach involves three elements: types of curriculum, curriculum dimensions, and the aspects of fidelity. They propose the types of curriculum as described by Schmidt, Jorde, Cogan, Barrier, Gonzalo, Schimizu, Sawasa, Valverde, McKnight, Prawat, Wiley, Raizen, Britton, and Wolfe (1996) previously: (a) The intended curriculum, that refers to the content, pedagogy, and structure expressed in the instructional materials that reflect the developers' theory of knowledge and skill acquisition; (b) the enacted curriculum that refers to the way teachers deliver the instructional materials; and (c) the achieved curriculum, what students experience and integrate in their existing knowledge and skill structure. Keeping in mind the purpose of fidelity of implementation, they propose four major dimensions of curriculum as described by Leithwood and Montgomey (1980), Madaus and Kellaghan (1992), Mortimer and Scott (2000) previously: (a) theoretical stand – system of implicit and explicit beliefs and assumptions used as the basis for deciding the characteristics that the curriculum have (b) curriculum materials– content and activities that have been put together in a specific sequence and that can take different forms of documentation; (c) instructional transactions between the teacher and the students that involve the teacher interventions enacting the curriculum and directing it towards making scientific knowledge available to students, and (d) outcomes–the intended goals for students. Finally, the approach considers the five aspects involved in measuring FOI described previously by Dane & Schneider (1998) and Dusenbury et al. (2003): (a) adherence–extent to which specified curriculum components are delivered as prescribed (b) exposure–coverage of the curriculum (c) quality of curriculum enactment (d) student responsiveness (e) curriculum differentiation. The approach is described with curriculum dimensions, as a guide. The curriculum dimensions are first described from the intended perspective. Then some critical components to be considered in FOI studies as well as some criteria to consider for determining the level of fidelity are described from the enacted perspective. Finally, the component and criteria are linked to aspects of FOI.

This conceptual approach was used in fidelity of implementation study that was part of a larger project focused on the effects of formal embedded assessments on students' learning (Shavelson & Young, 2000). The study was based on a small randomized experiment over one school year with six "experimental" and six "control" teachers. The study was conducted within the context of the "Foundational Approaches in Science Teaching" (FAST) middle-school science curriculum (Pottenger & Young, 1992). The preliminary results of linking assessment practices with students' performance reveal that teachers who have practices more aligned with FAST critical components show the highest student performance on different achievement assessments. The author summarizes some lessons learned from preliminary results of a series of studies conducted by the research group. First, determining the critical components of the curriculum is crucial for developing FOI instruments. Second, in determining configurations of critical components, the degree of variation must be clearly specified. Third, planning FOI studies for a program during the time in which the program is actually being written appears to be the first step for a successful FOI study. Fourth, direct observations or videotapes are a necessary means of determining fidelity of implementation. Finally, they think that in order to address all aspects of FOI, one should most probably use multiple methods and multiple sources.

Penuel and Means (2004) examines variations in patterns in the enactment of a large-scale kindergarten through Grade 12 science inquiry program. Data on program activities involving a web-based data archive and teacher reports help to examine implementation from the perspective of implementation fidelity and program adaptation. Student data reports in the GLOBE program provide a useful measure of implementation because key design elements in the program are student collection and reporting of local environmental data. They examined associations among teachers' responses to survey items on patterns in GLOBE data reporting to develop hypotheses about important contextual factors related to program implementation. The GLOBE inquiry program model has a number of important assumptions. Analyzing how well some of these assumptions stand up to data on GLOBE program implementation was the main aim of the evaluation research. The assumptions that were analyzed are as follows:

1. Classrooms can carry out globe data-reporting activities with fidelity, following the protocols and reporting data consistently.
2. Teachers' choices about globe enactment will not undercut the scientific aims of the program.
3. Local partners can provide follow-up support to increase the likelihood that schools will report data.
4. Demonstrating alignment of existing materials with locally defined learning objectives increases the chances that globe schools will report data.

The GLOBE student data archive shows that consistency and persistence in data reporting are closely related. GLOBE-trained teachers who report deciding to engage their students in GLOBE data collection and reporting activities have schools reporting GLOBE environmental data at higher levels than those who say they do not engage in these activities. There were no significant associations between consistency in data reporting and teachers' decisions to engage students in extended investigations with GLOBE data or in collaborative projects with other GLOBE schools. Of the supports provided, mentoring, materials, and incentives appear to have a significant effect on data reporting. Communications activities, the support most commonly offered by GLOBE partners, did not appear to have a significant relationship to steady reporting. The GLOBE teacher survey reveals a number of barriers teachers face in reporting data to the GLOBE website. The greatest difference in the reported effect of barriers to data reporting is the difficulty teachers' face in integrating GLOBE with the curriculum. Another commonly experienced barrier to reporting data is the difficulty teachers' face in finding time to report data. Some teachers believe that the value for their students lies in taking GLOBE measurement, not in reporting them. A final barrier is problems with Internet connectivity. All of these barriers to reporting data affected non-reporters more than steady reporters.

They suggest using the four elements of infrastructure important for improving implementation fidelity as recommended by Feldman, Konold, and Coulter (2000): providing training in which desired activities and approaches to teaching and learning are modeled, providing ongoing face-to-face support, ensuring access to a sound technology infrastructure, and ensuring that teachers have local support to take the time they need to become comfortable with the new program. The authors also suggest that modeling of teaching and learning processes must focus on the most challenging content and procedures that are integral to the program, especially with programs following scientific protocols unfamiliar to many teachers.

Schneider, Krajcik, and Blumenfeld (2005) conducted a research to describe teachers' enactments in comparison to reform as instantiated in the reform-based science materials. Four middle school teachers' initial enactment of an inquiry-based science unit on force and motion were analyzed. Findings indicate that enactments of two teachers were consistent with intentions whereas two teachers' enactments were not. However, enactment ratings for the first two were less reflective of curriculum intent when challenges were greatest, such as when teachers attempted to present challenging science ideas, respond to students' ideas, structure investigations, guide small-group discussions, or make adaptations. Based on the findings the authors suggest that purposefully using materials with detailed lesson descriptions and specific, consistent supports for teacher thinking can help teachers with enactment. However, they believe that in addition to materials reform efforts must include professional development and efforts to create systemic change in context and policy to support teacher learning and classroom enactment.

The literature on FOI studies show that teachers who have practices that are more aligned with the program objectives are the ones that show highest student gains. Also, it looks like FOI studies that identify critical components at the time of program design are the ones that are successful in affecting a change in teaching practice. Such programs are better able to focus on the objectives of the program. Teachers often face difficulty in integrating the program experience with the curriculum. In such cases it helps to provide support to the teachers for learning desired activities.

Research Experience for Teachers Programs

Let us examine how fidelity of implementation has been addressed in research experience programs for teachers. There are not enough studies that use a model of fidelity of implementation as described in FOI studies that we examined earlier. One aspect that makes these professional development programs different from other similar programs is that most of the learning that takes place during these programs is implicit. Program objectives are not always explicitly laid out. In most cases, leeway is given to teachers for making adaptations in classroom implementation making it difficult to measure the fidelity of implementation for these programs.

Dresner and Worley (2006) examined some long-term impacts of a professional development program called “Teachers in the Woods” (TIW) that provided ecology research experiences for science educators at a variety of national forests and national parks. The program was delivered through a 5-week summer institute with additional academic-year workshops to ensure transfer of new skills to the classroom. During the summer institute, teachers received training in forest ecology and field techniques, as well as worked with scientists on one or more research projects at a site that was relatively close to their school. Fifteen out of a total of 70 program participants were interviewed and pre-test data of 70 participants were used for analysis. The pre-test contained information on teachers background knowledge and skills in research, how ecology and science inquiry had been integrated into their teaching, and the degree to which their students had participated in research and science inquiry prior to involvement in the TIW program. Some outcomes of the program that the participants acknowledged as having been valuable were: developing a network of like-minded teachers, developing a network of scientists and teachers, and an increase in teachers’ ecological knowledge and field skills.

The following observations were made with regard to professional development: a) an effective way for teachers to gain ecological knowledge and skills is by engaging them in real-world field science research b) developing collegiality among teachers and scientists during the period of fieldwork can enhance science learning c) opportunities to discuss pedagogy-related issues are provided by enhancing collegiality among teachers.

Brown and Melear (2007) conducted research on an apprenticeship course that was designed to give opportunity to pre-service secondary science teachers to engage in an authentic, extended, open-ended inquiry. Their study described apprenticeship experiences of three teachers with research scientists. Their model included placing pre-service teachers with scientists in expert/novice roles where each teacher is actively engaged in constructing knowledge. The purpose of the study was to investigate how teachers characterize their apprenticeship experience, how the apprenticeship experience affect their actions within the secondary school classroom, and what elements of the apprenticeship experience does the teacher value and why. Erickson's (1986) interpretive approach to qualitative research was used to analyze data collected from interviews, laboratory notebooks, and reflective summaries to identify common themes from re-occurring statements. They found that participants acquired scientific skills and content knowledge. However, the teachers expressed limited use of these in their classrooms. Constraints such as time limitation, content coverage, and end-of-course testing prohibited their use of long-term or short-term investigative approaches.

Raphael, Tobias, and Greenberg (1999) conducted a study to learn how the participants of the Future Teachers Research Program (FTRP) felt the program affected them. The three research questions that were explored were whether and how their undergraduate research experiences enhanced their undergraduate or post-baccalaureate education in a valuable way, contributed to the content and pedagogy of their current teaching assignment, and influenced participating science and mathematics faculty. To assess the three research questions, a series of one and a half hour focus groups with nine former participants and data collected since the program began were analyzed using Erickson's (1986) interpretative method. Findings revealed that participants stressed the value to education and to the understanding of science. Participants were particularly advantaged by choosing to expand their knowledge in an area of research unfamiliar to them. They valued the benefit of learning to operate instruments. They stressed the increased understanding of method in which science was done in the laboratory. Teachers had the opportunity to grow in new ways by combining research and education. The teachers believed that the experience would enable them convey to the students about the methods in which science is actually done by the scientists. Gaining insights about science from the program affected their pedagogical practices. The relationship that developed between participants and researchers or other participants affected their teaching. The close link with the professional community enabled the teachers to seek support to enhance teaching. The conclusions in this study were reached based on the participants' perspectives and represented their beliefs and desires rather than objective evidence. The researchers claim that this kind of research experience will enhance the abilities of teachers to implement the objectives of science education reform.

Westerlund, Garcia, Koke, Taylor, and Mason (2002) conducted a qualitative study to determine the nature of a summer research experience for practicing teachers, identify the features that indicate that teachers are having authentic research experiences, and the effect of summer research experience on the teachers and their students. The context of the study was the Science/Math/Technology Education Institute (SMTEI) program for secondary school teachers. Qualitative methods (Lincoln and Guba, 1985; Patton, 1990) were used to collect and analyze data and triangulation was used to validate the data. Data was collected by means of teacher journals, teacher logs, interviews, focus groups, teacher presentations of project, plans of transfer activities in classroom, pre- and post-tests of scientific knowledge, documents of communication between teachers and scientists, classroom observations, and end of year survey on effect of SMTEI program on teaching. The results of the analysis indicated that most of the teachers engaged in background reading of their research areas and were primarily focused on their research project. Teachers discovered that besides learning new scientific techniques and instrumentation, they had to learn to manipulate equipment, and realize that scientific research can sometimes be slow and need alterations of experimental and descriptive designs. Most of the teachers were satisfied with the professional relationships established with their research scientists and graduate students during summer. Teachers reported an increase in their knowledge of the science content of their particular research area which helped in framing questions and answers to student questions, an increase in enthusiasm for teaching science, and an increase in student research and laboratory activities.

Silverstein, Dubner, Miller, Glied, and Loike (2009) measured the impact of New York City public high-school science teachers' participation in Columbia University's Summer Research Program (CUSRP) on their students' academic performance in science. They compared pass rates on Regents biology, chemistry, and earth science exams of 7209 students of CUSRP teachers with those of 36,101 students who studied the same subjects at the same time and in the same schools in classes of non-CUSRP teachers. In the year before program entry, students of participating and nonparticipating teachers passed a New York State Regents science examination at the same rate. In years three and four after program entry, participating teachers' students passed Regents science exams at a rate that was 10.1% higher ($p = 0.049$) than that of nonparticipating teachers' students. An average of 15.5 more participating teachers' students passed a regents science exam than nonparticipating teachers' students in the 4 years after each teacher's entry into CUSRP. This stepwise improvement in Regents exam pass rate was expected because of teachers' adoption of new teaching methods and materials. This gain in student pass rate was attributed to the change in teaching practice of the teachers as a result of participation in the program. Teacher responses to CUSRP's Spring Implementation Survey indicated increased hands-on classroom activities and/or introduced new laboratory exercises, developed new or revised content for lessons and/or laboratories, introduced new technologies in their class and laboratory exercises (e.g., chromatography, micropipettes, PowerPoint), increased requirements for formal written and/or oral reports, read scientific journals (e.g., Science, Nature) more frequently, discussed science careers and related jobs with their students, and assumed new leadership roles/responsibilities in their schools or districts.

Sadler, Burgin, McKinney, and Ponjuan (2009) reviewed and synthesized empirical studies that have explored learning outcomes associated with research apprenticeships for science learners. The outcome themes that emerged from their analysis were career aspirations, ideas about the nature of science (NOS), understandings of scientific content, confidence for doing science, intellectual development, attitudes, discourse practices, skills and understanding, collaboration and changes in teacher practices. Most of the data in the literature they reviewed were self-reports of the participants through interviews and surveys. They found that the main goal of these programs was to prepare the teachers so they understand and are capable of conducting science research and transfer that to their science classrooms. Sadler et al. reported that in Yen and Huang's (1998) study teachers participating in a summer apprenticeship program initially viewed scientific research as just following established procedures of experimental repetition and modification, but exhibited much more sophisticated views about the time and persistence necessary for collecting high quality data and the complex and messy procedures involved in scientific research towards the end of the program. Sadler et al. found reports of teachers' perception of their own knowledge gains as a result of apprenticeship experiences and studies that argued that increases in field skills and confidence levels among teachers results in a transfer of science research methods from the apprenticeship program to the classes they teach. They found studies (Buck, 2003; Dresner & Worley, 2006) in which teachers reported modifying lessons and lab activities to include more authentic research, but these were not based on direct observations. Only one study (Westurland, Garcia, Koke, Taylor, & Mason, 2002) conducted classroom observation to study teacher implementation of inquiry-based teaching following an apprenticeship. They found other studies that documented difficulties in transferring research experiences to classrooms (Boser et al., 1988; Brown & Melear, 2007). Lack of time, equipment, and financial resources were reported to be responsible for limiting the effects of apprenticeship courses on classroom practice.

Boser and Others (1988) reported on studies of Science Teachers Research Involvement for Vital Education (STRIVE) program developed to help teachers facilitate learning and transfer of scientific knowledge, experiences, and attitudes to their students. The purpose of the study was to determine the impact of the program on participants who were secondary school science and mathematics teachers. Data was collected by means of pre-test in the beginning of the summer program and post-test (evaluation questionnaire) at the end of the summer program and at the end of school year following participation in the STRIVE program. The items on the questionnaire were based on program objectives. The results of qualitative analysis revealed that the participants had increased their knowledge about the research and application of science and mathematics outside the classroom, awareness of the relationship of subject matter to industry and career, and interest in research and applied sciences. Although teachers exhibited an increase in knowledge, understanding and awareness, interest and confidence in science by participating in the program, there seems to be no significant change in their practice except for an increased amount of time devoted to laboratory activities.

Several reports and editorials are available that report success stories of teachers who have undergone research experience for teachers (RET) programs at various science and engineering laboratories all over the country. Fraser-Abder and Leonhardt (1996) reported success of a RET program that was a collaborative effort between Brookhaven National Laboratory (BNL) and New York University (NYU). The teachers reported feeling confident, were willing to take risks, and understood what involved in being a scientist and a student after their experience at BNL. NYU faculty reported that the students taught by these teachers had shown increased interest, participation and achievement in science. The article, “Bridging the gap between classroom and research laboratories” is about the RET experience of one teacher who participated in a mycology workshop at Clark University and plans of transferring that to his classroom (Dempsey, Hibbett, & Binder, 2007). An editorial on RET emphasizes the value of such programs to help teachers see the practical aspect of the importance of science and math education and as a consequence attract students to the field of science (Ononye, Husting, Jackson, Srinivasan, Sorial, & Kukreti, 2007). The teachers who participated in an RET program at Auburn University reported being more knowledgeable about real world applications for skills that the students develop in their math and science classes. They said they could better communicate the need for a solid understanding of those skills (Averett, Smith, & Giachetti, 2003).

The literature on research experience for teachers reveal that most studies done are based on self-reports of teachers by means of teacher interviews and surveys or questionnaires. There are very few studies that have collected classroom observations data. None of the studies have collected observation data during the program to ascertain what the research program was actually offering to the teachers. Unless appropriate data on what was provided to the teachers is available, fidelity of implementation of the research program cannot be appropriately determined. Most of the studies we see above report successes of teacher implementation, but none have reported on the specifics of the lessons delivered and how they matched the program objectives or the intent of the program. Some studies look at student outcomes, but most of them are based on self-reports of teachers and students. It looks like the programs that have been successful are the ones that had sustained professional development for the teachers and provided support to the teachers throughout the school year. However, in order to understand the impact of a program, it is clearly necessary to understand the efficacy and the effectiveness of the program. In order to do that, research needs to be conducted on examining the structure of program by determining its components and needs to be followed by examining the process of implementation. The student outcome based on program objectives should depend on the way the program is structured and the process of its implementation in the classroom.

Keeping in mind the above points, I was interested in designing a research study that would answer the following questions:

1. What were the teachers' science practices before the research program?
2. What were the components of the research program and what did the teachers gain from the program?
3. How did the teachers implement the research program in the classroom?

Methods

The literature on professional development of teachers in the classrooms shows that researchers have used various methods to assess impact of professional development. Some methods employed are quantitative and others are qualitative. Let us examine the methods of data collection and analysis used to conducted studies on the impact of professional development in science, and others that are specifically on research experience programs for teachers.

The study conducted by Supovitz and Turner (2000) was based on survey data collected from teachers and principals as part of the core evaluation of the LSC initiative. The surveys asked teachers questions about their attitudes, beliefs, and teaching practices, as well as for personal demographic information. Principals of the schools in which these teachers worked were asked to answer questions about their support for the reform, as well as demographic data on the school and community. Flora and Panter (1999) conducted both exploratory and confirmatory factor analyses on the LSC teacher and principal survey data. They developed a series of distinct scales of inquiry-based teaching practice–investigative classroom culture, teacher attitude toward reform, teacher content preparedness, principal support; classroom and school resource availability. Based on this, individual scale values were created for each teacher or school. They used a series of hierarchical linear models (HLM) to investigate the relationship between professional development and the reform indicators of inquiry-based teaching practices and investigative classroom culture. HLM was an appropriate statistical technique to more precisely model these nested relationships since teachers are naturally grouped within schools and they were interested in both the effects of individuals' characteristics as well as their school environments (Bryk & Raudenbush, 1992). However, there is a lot of debate among educational researchers over the reliability and validity of self-reported teacher survey data. On one hand, there is no doubt that surveys are more cost-effective than observations, interviews, artifacts, or teacher logs as a way to collect data on teaching practices. On the other hand, it is doubtful whether curricular practice can be accurately measured on a survey without observing the interactions between teachers and students and whether teachers can validly report on the schooling process (Burstein, McDonnell, Van Winkle, Ormseth, Mirocha, & Guitton, 1995).

Schneider, Krajcik, & Blumenfeld (2005) conducted a qualitative research to study initial enactment of four middle school teachers' in an inquiry-based science unit in comparison to the science reform materials. Classroom enactments of these teachers were recorded on videotapes and used as the primary data source for this study. One class period for each teacher was selected and videotaped during enactment of this unit. Two teachers were videotaped daily during the first year. The following year two additional teachers were videotaped two or three times per week. Sections were chosen for observation based on compatibility with the number of occasions when staff could be in the school to collect data and provide support. Detailed descriptions of classroom events were written from the videotape for each target lesson sequence and teacher. Miles and Huberman's

(1994) recommendations for rigorous and meaningful qualitative data analysis were followed for developing the coding schemes used to analyze the data.

Boser and Others (1988) used a quantitative method to determine the impact of active research involvement on secondary school science and mathematics teachers. All participants completed a four-page pretest in the opening session of the beginning of the summer program. The items on the pretest were developed on the basis of project objectives. At the conclusion of the summer, participants completed a four-page post-test, which had nine items pertaining to program effectiveness (increased knowledge, understanding, awareness, and interest) and asked the participants whether or not participation in the program had affected them in each of the ways listed. They also rated their perceived knowledge, understanding, awareness, and interest on the seven items identical to those on the pre-test and two additional ones related to their specific research topic. Towards the end of school year following participation in the program, participants completed and returned follow-up questionnaires.

Frequency distributions were tabulated for items pertaining to participants' perceptions of their knowledge, understanding, awareness, and interest on the post-test and of their confidence on the follow-up post-test. Paired t-tests were used to compare pre-test and post-test ratings of knowledge, understanding, awareness, and interest. Paired t-test were also used to compare pretest and follow-up test ratings of participants' confidence, the number of students completing independent research projects and science fair projects under participants supervision, and the percentage of time devoted to demonstration activities and laboratory activities by the participants. Sign tests were used to compare the frequency of classroom teaching activities on the pre-test and follow-up. The main drawback of this study was that all the data was based on self-perceptions of teachers and not on observed behaviors. Reliability and validity of the instruments was not clearly reported.

Ruiz-Primo (2006) in their study on the effects of formal embedded assessments on students' learning used a multi-method multi-source strategy of data collection. Six matched pairs of FAST teachers were randomly assigned to experimental and control groups in a pre and post-test design. All teachers responded to a questionnaire and a set of vignettes before and after the implementation study. The teachers were asked to complete a web-based teacher log and to videotape themselves in every session they taught FAST. Teachers were asked to send weekly videotapes and classroom artifacts used during that week (stamped envelopes were provided). Each classroom was visited once during the course of the implementation over a two- or three-day period. At the end of the school year, all the teachers provided their students' science notebooks. The study used three sources of information, the curriculum providers (teachers), independent observers (the researchers), and the participants (students). They believe that the diverse sources of information allow triangulation and provide a good source of validation across instruments.

The main methods utilized in the studies that Fullan and Pomfret (1977) reviewed were observation techniques, focused interviews, questionnaires, and content analysis (of key documents and specific curriculum plans). Some of those studies that used observation methods were problematic because they were based on an overall judgment not identifying specific dimensions or criteria. They believe that overall if the innovation is considerably well specified, the use of observation probably represents the most rigorous measurement of behavioral fidelity or degree of implementation. In conclusion to the studies they reviewed and identified some problems that might come up with observations. First, some dimensions of implementation could be more difficult to assess than others. Second, the impact of observers may affect the quality of performance of the implementation, particularly if the raters are perceived as evaluators. Third, observation methods do not adequately assess the philosophy and general strategies of the innovation; instead focuses mainly on mechanical aspects. They believe that unstructured observation methods may have the advantage of identifying more specific aspects of innovations, particularly those requiring considerable adaptation. Fourth, observation methods are expensive and often unfeasible when large samples are involved. Questionnaires can be used for assessing knowledge and understanding of the philosophy and basic strategies of an innovation program, considering that both specific and open-ended questions are used to assess various aspects of the users' thinking and approaches to the innovation. More thorough assessments can be done with the help of focused interviews and document analysis than questionnaires and do not have the drawbacks of consuming time and expensive observation. An important point that they make is that it is desirable to use different methods in any given situation because it takes into account the fact that every method has its own advantage and disadvantage as well as gives the opportunity for cross validation.

The purpose of my research is to study the fidelity of implementation of the ASU MSTF summer research program in the classroom. The working definition of fidelity of implementation (FOI) that I will be using for my study is adapted from Louck's (1983) definition of FOI that is the extent to which the teachers enact the research curriculum in ways that follow the designers' intention. The research studies on fidelity of implementation of professional development imply that the ideal way to collect information is by using a multi method system and to gather data from multiple sources for the purpose of triangulation.

Researcher Interest

My interest in this study began while I was involved as an intern during the second year (Summer 2008) of the Mathematics and Science Teaching Fellows (MSTF) program at Arizona State University. I contacted the program instructor in spring 2008 for an internship in Chemistry as part of my PhD requirements. She told me about the MSTF program and invited me to come to the afternoon sessions during the summer program. This was a great opportunity for me to get an idea about a program that I had heard about in the past and wondered what it was all about. I had the opportunity of visiting some of the classrooms when the teachers implemented the curriculum unit that they had planned during the program. I was not happy with some of the lessons that I observed. That is when I decided to study the program and find out why such a heavily funded program had so little impact in the classroom. I worked as a teaching assistant for the following two years of the program (2009 and 2010).

I decided to collect most of my data as a participant observer so I could study the meaning behind the little impact that I had observed in the classrooms of the participating teachers of ASU MSTF 2008. I wanted to collect data while being involved in activities with the teachers. As a teaching assistant, my job during the summer sessions was to assist the instructors in planning the afternoon sessions by making copies, collecting assignments, and troubleshooting technical problems. I assisted teachers with the new computer technology in the highly modernized facility, with registering for the summer course, with ordering classroom materials through the program budget, and with questions regarding curriculum planning. I visited the teachers at the laboratories to find out how things were going with the research experience and visited the classrooms when the teachers implemented their curriculum unit in their respective schools. During the summer program, I participated as a learner when there were sessions on a new software program, a new scientific tool, or during site visits. I made a conscious effort to socialize with teachers during breaks because I wanted them to feel comfortable with my presence in the classrooms and laboratories. During my classroom visits at the high schools, I walked around the room instead of standing or sitting in one corner. I observed the students closely and showed interest in their activities. This was done intentionally to make the students feel comfortable with my presence and also to get a better sense of the activities in the lesson.

Overall Description of the ASU MSTF Summer Program.

The Arizona State University Math and Science teaching Fellows Program initially received a grant for three years to provide research experience to 105 high school science and math teachers. The program was supposed to be a collaboration between 14 ASU research science laboratories and CRESMET-ASU's Center for Research on Education in Science, Mathematics, Engineering and Technology. The goal of the program was to provide teachers with a deepened understanding of the nature of science, a stronger grasp of the content they teach, and improved pedagogical knowledge and skills based on data emerging from STEM education research (ASU-CRESMET, 2007).

According to the project proposal CRESMET was going to take the responsibility of providing the teachers with assistance in converting their laboratory experiences into modules that include lesson plans and instructional approaches based on national mathematics and science education standards. They had planned to coach the teachers in inquiry teaching methods and assessing student's reasoning abilities and scientific inquiry skills.

CRESMET was also supposed to provide services such as accounting, operational and administrative as well as contribute approximately 40,000 dollars to provide salary support for PIs, participating lab scientists, and graduate assistants. However, CRESMET was no longer involved with the actual program due to administrative changes. As a result, there was no salary support provided to the directors or graduate researchers in the laboratories.

The Math and Science Teaching Fellows (MSTF) project at ASU was designed to improve the understanding of the nature of science, and pedagogical content knowledge of middle school and high school science and mathematics teachers with the help of STEM (*Science*, *Technology*, *Engineering and Math*) education faculty (ASU-CRESMET, 2007). The teachers spent five weeks in the summer in assigned laboratories at ASU. The laboratories were assigned according to each participant's area of expertise. The teachers worked in groups at the research science laboratories during the first half of the day. In the laboratories, the teachers were assigned to research assistants or postdoctoral students who guided them through research projects. The teachers met as a group working with science educators during the second half of the day to discuss pedagogical issues in teaching and implementing science curricula. They were introduced to new technological skills that they could use in their classrooms, helped with creating wiki spaces (to give teachers a chance to share their research work and post comments on each others' research work), and preparing posters on their research projects. At the end of the program each group of teachers presented posters describing what they found interesting during their research experience, and briefly described their plans to incorporate the research experience in their science curriculum during the coming year. Some returning teachers that were in the program for the second year were assigned the role of mentors and were expected to help the new teachers in the program with their experienced knowledge. The following school year the teachers were required to implement their research curriculum in their respective classrooms.

The teachers received a stipend for participating in the program, one laptop each to keep for themselves and funds to buy materials for their classroom. The teachers who were selected from the rural areas were provided on-campus housing by the program. The teachers returning for the second year did not get a laptop, but they could use that money to buy materials for their classrooms. The teachers also got three hours of university credit in the fall of that year, which they could apply towards a master's of natural science degree.

The goals for the program as given in the program website were as follows (http://mstf.physics.asu.edu/):

1. Bring cutting-edge science and pedagogy research into Arizona classrooms.
2. Immerse fellows in a variety of research groups in biochemistry, biophysics, nanophotonics, materials, fuels, robotics, aquaponics, and biological applications of mathematics.
3. Initiate discussions with mentors in the research group and MSTF peers.
4. Develop and implement a 4-5 day set of novel activities—non-literal translation of the research into developmentally appropriate work for their students. The activities would follow the spirit of the Arizona state curriculum standards.

The research projects chosen for the program was in three areas: Advanced Computing and Information Systems, Bioscience, and Sustainable Systems. The teachers were placed in 12 laboratories (11 laboratories at the

Tempe campus and 1 at the polytechnic campus), (a) Service Oriented Programming, (b) Bio-Nanotechnology Design, (c) Membrane Proteins, (d) Disease Models, (e) Fuel Cells, (f) Ecology CAP_LTER, (g) Telomerase RNP enzyme, (h) Nanobiophysics, (i) Pd Nanoparticles, (j) Nanosurfaces, (k) Protein Film Voltametry, (l) NMR Spider Lab.

Pilot Study (ASU MSTF 2009)

I conducted a pilot study in the third year of the ASU MSTF program. Thirty-seven math and science teachers from rural and urban school districts participated in the third year, summer 2009.

Sample. The teachers were recruited in May 2009. Thirty-seven teachers were selected based on their qualifications and teaching experiences. There were 10 mentor teachers that were selected from the previous cohorts of ASU MSTF programs.

Data collection. I collected qualitative and quantitative data from different sources to get an overall idea of the program and its impact in the classroom. I collected data in two phases, during the summer program and during the school year.

Field notes. I collected 32 pages of field notes during the program. The field notes helped me determine the main features of the program and understand the nature of implementation of the research experience in the classroom.

Program documents and artifacts. I collected data from the program proposal and the program website to learn about the design and intention of the program. I collected the posters and lesson plans prepared by teachers during the program so I could get an understanding of their research experience and its transfer into the classroom.

Interview. I interviewed the teachers at the end of the lesson implementation to gather information regarding their thoughts about the research experience and the lesson they taught. I also interviewed some teachers that I did not observe to find out why they did not implement the lesson.

Observation Protocol. I used the Reformed Teaching Observation Protocol (RTOP) to get an idea of the nature of lessons implemented by the teachers.

Survey. The teachers filled out a pre and post survey to measure their gains from the program administered in the beginning of the summer program and at the end of the summer program. Unfortunately there was a mix up and the version of the survey given for pre was different from the version for the post. The instructor tried to match some of the questions in post with the questions in the pre and conducted a factor analysis. I did not think that kind of analysis would give any valid results since the instruments used were different, thus did not give much attention to the results.

The pilot study informed me regarding the kind of data I should collect in order to have a better understanding of fidelity of implementation of research experience. I observed and made a note of the features that were emphasized upon during the program and compared it with the goals of the ASU MSTF program. I noticed that the lesson template that was provided to the teachers was not very specific to the goals of the program, so I designed a template with more specific goals. I did not have enough evidence of the kind of laboratory experience that the teachers had during the summer. In order to determine the relationship between the kind of research experience the teachers received and the classroom implementation, I gathered that I would need to observe teachers more closely during the summer and collect more information during the summer activities (laboratory and afternoon session). During the classroom visits, I had observed only one class period per teacher and as a consequence, I was not sure how the whole unit was implemented. I ascertained that I would have a better understanding of the implementation if I observed the instruction more often during the course of the whole unit. I also realized that it would be beneficial to observe and interview the teachers before the summer program. That would provide me with baseline data to compare the implementation of the research unit after the program. I did not have enough data to provide information regarding the supports that were available for the teachers. I decided to interview the program director, a couple of laboratory directors, and school principals to determine the supports that were available to the teachers to take the research experience back to the classroom. I decided not to depend on gathering data from instruments used by the program because they might turn out to be unreliable. I also learned a lesson about implementing pre-post instruments and that was to ensure that I use the same version of the instrument on both occasions.

Main Study (ASU MSTF 2010) Data Collection and Analysis

For my final research project I studied the ASU MSTF 2010 program starting from planning for the program until the teachers had implemented their curriculum projects in the classroom.

Sample. My sample consisted of eight teacher participants of the ASU MSTF 2010 program. Teachers from both rural and urban schools were invited to apply for the program. The advertisement was made in early April 2010 through the teachers.net listserv. Seven teachers were selected from a pool of 80 applicants. Teachers were recruited based on their teaching experience and their subject specialties. Only teachers teaching math, physics or chemistry were considered. This was because all the research laboratories that agreed to take teachers for the summer were conducting research in those areas. It took some time to find the mentor teachers for the program. Out of the previous participants that applied, a physics teacher and a biology teacher were found fit to be mentors based on their performance in the previous year. Since there was no biology laboratory available, the program needed mentors from physics or chemistry with possible combinations of mathematics (since it was a math and science program). Emails were sent out to some previous participants asking them if they would be willing to participate in the program as a mentor. Finally, one chemistry teacher was willing to participate. Ultimately, since there was no one else available, a biology teacher was accepted to be a mentor teacher.

The ASU MSTF 2010 had a final cohort of three mentor teachers and five new teachers. One of the eight teachers was from a rural (Indian Reservation

Board) school district, one from a suburban public school district, one from a charter school, and the remaining five teachers were from urban public school districts. They were all high school science teachers with teaching experience ranging from 2 to 20 years. Table 1 gives a brief outline of the demographics of each teacher participant. I assigned pseudonyms to the five new teachers (Emily, Patsy, Lucy, Grace and Brad) and three returning teachers (Wendy, Stacy, and Jack).

The other participants for my study were two research directors (Dr. Lewis and Dr. Lowry) of the laboratories that the teachers were placed in for their research experience during the summer program, the ASU MSTF program director (Dr. Young), and two principals (Mr. Moore and Mr. Hill) of urban public high schools where the participants were teaching.

Data collection. My data collection process for the main study took place in three phases. The first phase focused on understanding the teaching practices of the participants prior to the program. The second phase focused on understanding the structure of the program and the third phase focused on understanding the process of implementation in the classroom. Table 2 gives a quick glance of the interviews and observations conducted before the ASU MSTF program (Phase 1) during the summer program (Phase 2) and during the school year (Phase 3). The interviews were conducted in person except for two interviews. All interviews were audio taped. Videotapes were collected during the summer program during the morning and afternoon sessions. One classroom observation was videotaped.

Table 1
Demographic information of the eight teacher participants of ASU MSTF 2010

Name	Education background	Teaching experience	Teaching subjects	Present school urban/rural	Laboratory assigned
Stacy (mentor)	B.S. -Physics MEd -Secondary education	2yrs	Honors Physics, Physics, Honors Conceptual Physics, Conceptual Physics,Biology	Urban (High SES)	Nanosurfaces
Brad	B.Ed. M.S. -Physics	7yrs	Chem/Physics, Biology, Physics	Urban (High SES)	Biophysics
Grace	Electrical Engineering (incomplete), Bachelor of Science in Mathematics (minor in physics and electrical engineering), Secondary Education in Mathematics & Physics (did not grad),	17yrs	Geometry, Algebra 3-4, Physics Math connections, trigonometry, Precalculus, Calculus, Geometry Pre-algebra, Calculus, Physics, Basic Algebra lab	Urban (High SES)	Nanosurfaces
Lucy	BS Honors Pharmacology& Toxicology, MS molecular & cell biology MS psychology, Graduate education credits-18	6yrs	Physics, Chemistry for grades 11 &12, Algebra grades 9-12, Biology in high school grades 9-10, Math & Science in middle school grades 6-8, Biology grades 9-10	Rural (Indian reservation Board) Low SES	Biophysics
Patsy	BS in Chem. Education (Inter), MS in Chemistry and Education (Inter), Business Administration (US)	20yrs (12 yrs outside US, 8 yrs in the US)	Chemistry, Physical Science AP Chemistry, Chemistry	Urban (Low SES)	Biochemistry
Emily	B.S. Environmental Sc/Microbiology Teacher Certification (Seconday Education) M.A. Teacher Leadership M.Ed. Curriculum & Supervision	13yrs	Chemistry, Biology, General Science	Urban (Low SES)	Biochemistry
Wendy (mentor)	B.S. Health Ed. M.P.H. Public Health	10yrs	AP/IB Biology, Honors Biology	Suburban (High SES)	Biochemistry
Jack (mentor)	B.A.E. Secondary Ed Chemistry Masters of Natural Science (2005-present)	10yrs	Chemistry, Accelerated Chemistry	Urban (Low SES)	Nanomaterials

Table 2
Observations and interviews associated with each teacher conducted during the three phases of data collection

	Phase1		Phase2		Phase3			
Name	Pre observation	Pre interview	Summer observation	Summer interview	Post observation	Post interview	School principal interview	Lab director interview
Emily	1 class period	√	4 times a week	√	7 class periods video taped	✓√	√	√
Patsy	1 class period	√	4 times a week	√	x	Phone interview	√	√
Wendy	1 class period	√	2 times a week	x	4 class periods	✓√	x	√
Jack	1 class period	✓√	Once a week	x	3 class periods	✓√	x	√✓
Stacy	1 class period	✓√	Once a week	x	4 class periods	✓√	x	x
Grace	1 class period	✓√	Once a week	x	1 class period	x	x	x
Brad	1 class period	✓√	Once a week	x	x	x	x	x
Lucy	x	✓√	Once a week	x	x	Phone interview	x	x

Details of the data collected during the three phases is described below:

Phase I. In the first phase, I collected pre-program (baseline) data. In order to understand the teaching practices of the teachers before taking part in the research program, I collected classroom observation data. This helped me compare aspects of the implementation that could be attributed to the research experience with the summative data collected after the research experience. I used the RTOP (Reformed Teaching Observation Protocol), a widely used valid and reliable instrument to measure the use of reformed teaching practices of all the teachers in the program. I reviewed data from the program application forms submitted by teachers to study the demographics and teaching philosophy of the teachers. Teaching philosophy constitutes a rich source of data for determining the existing teaching practices and their ideas on incorporating the research experience.

It was mid April when the decision was made regarding the participants for the program. I contacted the teachers and asked them if they were willing to participate in my study. All the teachers were willing to participate in the study. I got the approval of the district and the school principal before I could contact the teachers. I was having a hard time finding a contact person to get the district approval for one school in the reservation. Lucy, who was teaching on the reservation, said it would be very difficult to get approval from the district for classroom observations, so I was unable to go and observe her classroom. Once I had the consent of the other districts, school principal and the teacher, I scheduled an appointment with the teacher to observe their classroom instruction. With the cooperation of the teachers and administrators I was able to observe each teacher once before the 2009-2010 school year came to an end. I observed one class period of each teacher participant. I used the Reformed Teaching Observation Protocol (RTOP) to record the classroom observations. I also conducted a semi-structured 15 to 20 minutes pre-interview of the teachers to find out why they were interested in the program. I interviewed Lucy on the first day of the program since she was not available before that. I audio taped all the interviews and took notes. I collected the application materials of all the teachers from the program director to get their demographic information.

Phase II. In the second phase of data collection, I focused on the structure of the program, both as conceptualized and as a delivered curriculum, in order to comprehend the program components. I conducted interviews with the program director and two research project directors to get a better understanding of how the program was organized and the supports and challenges of the teachers during the program. I collected field notes and conducted queries at the research laboratories and the afternoon group sessions. I spent substantial time at the biochemistry laboratories where Wendy, Emily, and Patsy were placed so I could get a good sense of the daily activities in the laboratory. I selected the biochemistry laboratory because I had some prior knowledge in that area. I visited the other laboratories twice a week. I also collected the videotapes of afternoon sessions. This helped me ascertain the research experiences of teachers and the activities conducted during the afternoon sessions, which in turn helped me interpret the dimensions and components of the program as delivered. I collected the teacher blogs to capture the thoughts and reflections of the teachers on their laboratory experiences and their ideas regarding transferring their experience to the classroom during the program. I collected the posters that the teachers prepared for a poster presentation at the end of the summer program and the lesson plans of the research unit that the teachers planned to implement during the school year. The blogs, posters, and lesson plans helped me ascertain teachers' thoughts and experiences of the program.

Phase III. The third phase of data collection was documenting the process of implementation of the research experience in the classroom. This helped me determine if the research experience was reflected in the classroom implementation of the research unit. I used the RTOP to measure the use of reformed teaching practice during their research unit implementation. I also interviewed the teachers at the end of the unit to double check their curriculum unit implementation against my field notes and their lesson plans. The interview focused on determining the challenges faced by the teachers in implementing the research experience.

I interviewed principals from Emily's and Patsy's high school to determine the supports and barriers experienced by teachers in implementing the research curriculum.

I did not collect student data because I did not have the means to control other factors that would need to be taken into consideration to make sense of the data. I used the Desimone et al. (2002) assumption that student gains must be mediated by the change in teaching practice affected by the professional development. I did not hope to see immediate substantial gains in student outcomes on evaluative or standardized tests, because research studies have found that student outcomes become evident only after 3 to 4 years (Silverstein et al. 2009).

Theoretical lens. The observations I made at the different research laboratories during the MSTF summer program helped me identify various activities involved in conducting real science in the research laboratories. I witnessed the ASU graduate and undergraduate student researchers actively engaged in activities including some or all of the following components:

1. Formulating *research questions* based on relevant scientific concepts
2. *Background research* on relevant topic of interest

3. Proposing *research hypothesis*
4. *Designing procedures* to test hypothesis
5. Conducting *experimental procedures*
6. *Collecting data* to verify hypothesis
7. *Analyzing data* to draw conclusions
8. *Discussing results* and reporting scientific findings
9. *Presenting findings* to the scientific community
10. *Modifying scientific methods* based on feedback received from experimental findings and discussions

Since I found most of the researchers engaged in these kinds of activities across all the laboratories that I visited at ASU, it was clear that this is how science is done in the real research laboratories. Hence, I decided it was appropriate to call science that was conducted in this manner as “real science” and use that as a lens for my study.

In the context of my research study “real science” is defined as conducting research on an unknown phenomena involving any or all of the ten real science components (background research, research hypothesis, designing procedures, conducting experiment/observation, collecting data, analyzing data, discussing results, presenting findings, modifying methods)

Each of the real science components is explained with examples from the laboratory observations and queries that I conducted during the ASU MSTF summer research program.

1. Formulating *research questions* based on relevant scientific concepts: The researchers at the various laboratories talked about how they formulated their research questions. Some of them had to read articles on the topic of interest before they could think of research ideas. For example, a researcher in the biochemistry laboratory said he had to do extensive reading and that is how he thought about conducting experiments on some solution that will dissolve the spider silk keeping the inner structure intact, making it easier to study the chemical makeup of the silk. In some laboratories such as the nanosurface laboratory, researchers were trying to find solutions to problems that arouse in the laboratory itself. They were researching on better methods to clean certain materials without causing damage to them.
2. *Background research* on relevant topic of interest: I found some researchers in the nanosurface laboratory and biochemistry laboratory reading articles on their area of research. The researchers mentioned that they had to keep abreast of current research. They had to ensure that other scientists have not already discovered what they are trying to discover. They also had to read literature to find out more about the methods that they are employing for their research and to modify their methods.
3. Proposing a *research hypothesis:* The researchers had a tentative idea of the results that the research procedures would lead them to. They were working towards a goal and kept modifying their goals based on the results obtained.
4. *Designing procedures* to test hypothesis: The researchers in the laboratory were designing new methods to conduct their experiments. I found researchers

improvising on the methods in all the laboratories. They were all trying different techniques to make their experiments work. In the Spider silk laboratory, the researchers were found designing procedures to silk the spiders and collect the spider silk. They were cutting a hollow piece of cardboard to wrap the silk around so it would be easier to test the tensile strength of the silk. In the nanoparticle laboratory, I found the researchers debating over the duration to allow the solutions to sit in order to obtain a good yield of nanoparticle alloy.

5. Conducting *experimental procedures:* Researchers in the biochemistry laboratory were engaged in silking spiders and preparing samples for analysis in the semiconductors. Researchers at the nanoparticle laboratory were engaged in running their experiments in fume hoods and vacuum chambers. Everyone seemed to have an assigned station to work on his or her experiment.
6. *Collecting data* to verify hypothesis: I found the researchers at the nanoparticle laboratory collecting graphical data by running the UV-Vis (ultra violet visual spectroscopy) through the solutions that they prepared to obtain the desired nanoparticle alloy. The researchers at the biophysics laboratory were also collecting graphical data obtained from running their samples through the confocal and atomic force microscopes. The researchers at the biochemistry laboratory were collecting graphical data obtained from running their spider silk samples inside the semiconductors. The researchers at the

spider silk laboratory were also collecting observational data on the behavior of the spiders and the new specimens of embiids.

7. *Analyzing data* to draw conclusions: The researchers in the nanoparticle laboratory were analyzing the data obtained from running the samples through UV-Vis. Depending on the peaks they saw they figured that the desired nanoparticle alloy was not forming between copper and silver.
8. *Discussing results* and reporting scientific findings: I found the researchers at the nanoparticle laboratory discussing the graphical data. I found the researchers discussing the peaks. They had different interpretations of the peaks. They were not sure if they were getting the right peaks that would verify their hypothesis. They said they would report their findings to the research director and decide on the next steps.
9. *Presenting findings* to the scientific community: During one of the afternoon sessions, we were invited to a presentation on spider silk by a researcher from an outside university. It was interesting to hear about the finding of her research. The student researchers from the biochemistry lab asked questions and participated in a discussion to share their own research with the visiting scientist.
10. *Modifying scientific methods* based on feedback received from experimental findings and discussions: The researchers at the nanomaterial laboratory were engaged in a discussion on possible chemicals to grow nanoparticles because they had failed to obtain the desired results with the chemicals they were

using. Through discussions they were trying to figure out what other combinations of chemicals would be a better option to grow the nanoparticles.

Research questions. My research questions focused on the aspects of real science experienced by the teachers at the research laboratories and its implementation in the classrooms. I compared the activities at the laboratories where teachers were involved in research and the classrooms activities designed by the teachers based on the ten features of real science that I identified at the research laboratories. My research questions were formulated to describe the nature of real science as evident before the program, during the program, after the program, and to identify possible reasons for not finding evidence of real science when teachers created posters, wrote lesson plans, and taught science in their classrooms.

Q1. Did the classroom teaching reflect real science prior to the ASU MSTF summer research program?

Q2. What were the teachers' expectations of the research experience? Were the expectations geared towards involving students in real science activities?

Q3. What evidence is there that teachers' experienced real science during the research program?

Q4. What evidence do we have regarding the supports and barriers that the teachers experienced in transferring the real science experience to the school settings?

Q5. Did the teachers exhibit reformed science teaching and incorporate real scientific methods in the school settings after undergoing the research program?

Data analysis. I qualitatively analyzed the data that I collected from the research program. I used Erickson's (1986) interpretive, participant observational fieldwork method to report data that I collected by means of detailed descriptions of the research experience and the classroom implementation. I used the way in which real science is done in the research laboratories as a lens to conduct my study. I used some emergent themes and some a-priori themes to analyze the data. I used a-priori themes based on components of real science as observed in the research laboratories.

I used narrative vignettes and direct quotes from interviews, discussions, and blogs to get a clearer picture of the emerging themes in the study. I used analytic charts, summary tables, and descriptive statistics to highlight the themes in the different sources of data collected during the program (blogs, posters, lesson plans, classroom observations). I asked the teachers and program directors for clarifications whenever I was not clear with something they had mentioned in the interview or written in their blogs and when I had questions regarding what I observed. The qualitative methods that I used to analyze data are given below.

Applications and material order forms. I extracted demographic information of each teacher from the applications that the teachers submitted for the program. This information included educational background, years of teaching, present school setting, subjects taught, and choice of research interest. I analyzed the teaching philosophy of teachers to extract themes regarding their current teaching practices and their expectations from the research experience. I collected information regarding the classroom supplies that each teacher had ordered through the program funds.

Videos. I used the video recordings of the program to write the description of the program and identify the various components. I used the videos to calculate the percentage time spent on each component of the program. I transcribed section of audio recordings of the afternoon sessions to write some narratives to highlight certain features.

Field notes. I produced 154 pages of notes during the whole duration of the program. I used Hyper Research software to extract themes of real science as seen during the research laboratory observations and the classroom observations. I also used field notes to identify the supports and barriers that the teachers experienced during the program.

Interviews and personal communications. I transcribed the audio taped interviews using Hyper Transcribe software and coded them using Hyper Research software to extract themes. I used direct quotes from the interviews to explain the emergent themes from the data. I gathered the email conversations and phone communication with the participants regarding the program and clarifications needed while analyzing data.

Blogs. I coded the blogs using the Hyper Research software. The eight teachers generated 134 pages of single spaced text. The blogs included pictures, figures, and tables. I coded each sentence in the blogs according to the real science categories. Each picture, figure, or table was treated as a sentence. Frequencies of each real science category that were identified were displayed in the form of a chart. I used some direct quotes from the blogs to identify themes for supports and barriers and to explain other emerging themes.

Posters. The posters of eight teachers were analyzed using the Hyper Research software to look for real science themes. Sentences on the posters were identified with the real science themes. Each picture, figure, or table on the posters was treated equivalent to a sentence. The posters were also used to extract sentences that pertained to the real science features.

Lesson plans. The lesson plans of the eight teachers were color coded to extract real science themes and identify real science categories that were missing from the lesson plans. This helped ascertain the features of real science that were used more frequently by the teachers in writing their lesson plan activities.

Classroom observation. I used the Reformed Teaching Observation Protocol (RTOP) to record the classroom observations of all teachers before the program and for the teachers that implemented the lesson after the program (Piburn, Sawada, Turley, Falconer, Benford, Bloom, & Judson, 2000). The RTOP is a valid and reliable instrument (Cronbach's alpha = 0.9 and interrater reliability = 0.8). I used the RTOP scores to assess the instruction of teachers. I used the quantitative scores of the pre and post observations to compare the reformed teaching methods of the teachers before and after the research experience. A paired samples t-test was conducted to find out if there were significant difference between the pre RTOP scores and the post RTOP scores.

Results

The results are displayed in two main sections, with the findings of the pilot study followed by the findings of the main study. The information gathered from the pilot study helped in finding a focus for the main study. The ASU MSTF 2010 program was studied through the lens of real science, the definition of which has already been discussed in the methods chapter.

ASU MSTF 2009 Program Description

The teachers went through an orientation on the first day. In the morning, groups of teachers were assigned to different laboratories and introduced to researchers. Each laboratory had their representatives at the orientation. The teachers sat in laboratory groups and the laboratory directors or student researchers introduced their research and told the teachers about the kind of research they were going to be involved in. The researchers also took a few minutes to share their research with the whole group. After the morning session, the teachers either went to the laboratories with the researchers or had lunch with them. In the afternoon, the teachers met in the discussion room. This room was a newly built room that was designed mainly to facilitate discussion classes. The tables were set in groups with four tablet personal computers per table. Each of the tablets was connected to a central computer that would facilitate projection on a video monitor in front of the room. There were five screens on each wall of the room so teachers sitting in any position had a good view of the screen.

The first day of the afternoon session was spent on laying out the program requirements and introducing each other. The instructor of the afternoon session asked the teachers to utilize the first week to get familiarized with researchers and research activities of the laboratory. There was a safety training conducted for the teachers in the first week.

During the following weeks, the teachers were engaged in discussions about research practices in their respective laboratories. The teachers read an article on practical knowledge and apprenticeship and another on tacit knowledge. They did written assignments on the articles and discussed the articles in small and whole groups.

Pedagogy was addressed in a few different ways. There was a discussion on scientific inquiry methods during one of the afternoon sessions. The discussion was mainly focused on why discovery method is not very helpful for student learning. There were discussions on how the graduate students had to work under guidance of their advisors. The instructor emphasized that having students formulate their own research questions, design their own procedures, and draw conclusions all on their own is expecting too much from high school students at their maturity level. The teachers were encouraged to come up with novel ideas for lesson plans related to their research topic. The instructor collected the first drafts of the lesson plan on the fourth week of the program and gave feedback on some of the lessons. The teachers that were having a hard time coming up with ideas for their lessons were paired with mentor teachers so they could help them come up with ideas. The format for the final report on classroom implementation had three main sections:

1. Changes to classroom laboratory learning environment: additional tools so that all student teams can work more efficiently in the time given for a class, system of organization and security that engenders easier student access to scientific tools and equipment.
2. Changes to previous laboratory practices: increasing the amount of time that students spend in laboratory/field work over a semester, engendering continual use of the same tools to build students' proficiency, developing laboratory/field practices designed along a central theme rather than hopping from one topic to another without connection, planning more time to students' analysis of results using higher order thinking skills.
3. Curricular rubric for one project: an in-depth discussion of the particular aspects of the ASU research that was selected to model with students over 4-5 days, overview of translation of the aspects of ASU research into appropriate student activities and thinking, specific objectives for student learning, state standards that the curriculum addresses, learning assessments to be given to students aligned with specific objectives and the state standards, and a full description of each activity. The final draft of the report was due by the Friday of the fifth week.

Thursdays were technology days. The afternoon sessions were spent on learning new technology skills. Teachers and the principal investigator of the program conducted mini workshops on computer software that could be used in the math and science classrooms to enhance teaching and learning. The areas covered were as follows:

- Distance Learning: walkthrough of the Adobe Acrobat Connect Pro video conferencing software, which is one of several platforms for real time distance learning. Reference was made of other similar platforms such as Webex, iLinc, and Wimba.
- Screen Recording: ScreenFlow screen recording software (Macintosh only) was demonstrated while showing how to create and edit a new page on the MSTF wiki site.
- Office Drawing Tools: a guided tour on using Microsoft drawing tools to make diagrams and flowcharts for science handouts and questionnaires.
- Google Documents: a tour on how to use Google documents for purposes of sharing information with students in and out of class.
- IDEAL: a presentation of the Arizona Department of Education website that gives access to professional development, standards based curriculum resources, collaborative tools and school improvement resources.
- Excel: presentation on how to use diagrams and graphs using data.
- Podcasting & Movies: a mentor presented session on how to broadcast video/audio files.
- PowerPoint: this training was broken down into two parts. The first part went over the poster guidelines and how to use PowerPoint to create them. The second part went over some ideas on how to use PowerPoint as an instructional and learning tool.

- Vernier ProbeWare: workshop on how to use Labquest to collect data in a science classroom. The teachers tried out temperature probes in the sun and shade.

On Friday afternoons, teachers were given out of class time to work on their lesson plans, posters, and wikis. A wiki space was created for the 2009 ASU MSTF program. The teachers were trained on creating a page for their own research group. Each group created their wiki page on the area of research including information and pictures on their research activities. The posters were required to be designed based on their research experience at the research laboratories and a brief section on their ideas on transferring the experience into the classroom. The teachers were given in-class time during the last week to work on finishing their posters and lesson plans.

A guest lecturer from ASU, the famous Paul Davies spoke on “The Origin of Life” in the last week of the program. The poster presentation took place during the last week of the program. The teachers were asked to invite friends and relatives to come and see their posters.

The teachers were asked to inform the instructor and me when they were ready to teach the lesson in their classroom so we could observe their lessons. Ten out of the 37 teachers informed us about their plans on teaching the lesson. I was able to coordinate with seven teachers and visited their classrooms when they implemented the planned lesson. I observed each teacher for one class period. The other three teachers informed us after they had taught the lesson.

Teacher 1 was teaching in an urban public high school. She was placed in the nanobiophysics laboratory. She was actively engaged in her lab and was in charge of making the adjustments on the computer to look at images transmitted from the atomic force microscope. She was happy with her research experience but did not think she could translate the research topic into a lesson that was comprehensible for her students in high school. She decided to do a lab on "oobleck" with her freshman chemistry class. Oobleck is a kind of polymer prepared by mixing water, glue, and borax. She had the students prepare the oobleck using a given recipe. She then asked the students to prepare their own oobleck recipe and think of a way of marketing it. The students came up with different variables they could change in order to make a recipe that would produce a strong and durable product that was of marketable quality. She had the students write a letter explaining why one should buy their product. In order to know which variables to change, the students would have to know the properties of each of the variables. I did not see any discussion regarding the properties of the materials. The students were choosing variables at random. That is how the lesson lacked conceptual framework and it was more of just having fun with some interesting material without really knowing what made that material so interesting. The idea of having students write a letter was good, but again the letter would lack in conceptual understanding regarding properties of the material.

Teacher 2 was from an inner city Catholic high school. He was an engineer and worked in the industry before he became a teacher through the alternative certification program. He was a substitute teacher for two years before he started teaching physics and chemistry full-time for the last two years. Teacher 2 was not satisfied with the explanations that he got for the questions that he had asked the researchers during his research experience at ASU. At his placement laboratory, they were involved in research on producing and characterizing Pd nanoparticles using $H_2Pd_2Cl_4$, ATP as ligand, $NaBH_4$ as reductant. UV-Vis Spectrometry and Atomic Force Microscopy, Brillion Scattering techniques were used to characterize the nanoparticles.

Teacher 2 did not think his research experience on nanoparticles was translatable to the freshmen chemistry curriculum. He was mainly a physics teacher and had purchased some equipment that he needed for his physics class through the program funds. He talked about different ideas on chemistry lessons that would be close to his research experience. Initially he had planned to do a conservation of mass lab by precipitating out an ionic compound, such as calcium carbonate, from solution and verifying mass balance, using gravimetric analysis. He did not do the lab because he said the students were not ready for it as yet. He finally found a lab on the Internet on acids and bases of solutions. The students were given the instructions for the lab. They were provided with the materials to conduct the lab. He replaced some solutions that were given in the worksheet because he did not have them in his supplies. The students were divided into two large groups. There were two lab tables with samples of solutions and acid-base indicators. The students filled up the lab sheet with their results. They had to make adjustments in the lab sheets because of the changes in the solutions. He asked the students to draw extra columns to accommodate the results. The students turned in their worksheets at the end of the lab. It did not seem that the teacher was prepared for his lesson. He was still trying to make some changes to the lab sheets a few minutes before class. The class of 20 students was divided into two groups. Only a couple of students were actually testing the solution with the indicators. The rest of the students were standing around the table and talking about unrelated things. The students did not seem to care about what was going on in the lab. I did not observe any discussion about what they were finding and how that was related to anything else.

Teacher 3 and Teacher 4 were placed in the Central Arizona- Phoenix Long-Term Ecological Research (CAP LTER) lab. During the summer, they were taken to a field trip with the research group to collect samples from a stream in Sycamore creek. A part of the CAP LTER project was the ecology explorer program that provided teachers and students with the opportunity of getting involved with real research. They had a website with research protocols and standards based lesson plans for grades K-12. The project also had a main database where the students could enter their collected data. This would help the researchers understand the biodiversity of plants and animals in different areas. The two teachers used one of the units from the curriculum that was suitable for their school settings.

Teacher 3 took the students into the school backyard and had them survey the plants and animals in the ecosystem. She used the oxygen probes that she purchased with ASU MSTF funds. Students used the oxygen probes to measure the oxygen content in the air. She had the students come up with two research questions based on their field observations. Teacher 4 had the students dig holes in the softball field and place foam cups into the holes in order to trap insects. The students set the insect traps and left it there for the weekend. For the following week, she planned to have the students collect the trapped insects, investigate the biodiversity of arthropods, and connect that to how urbanization affects the environment. Both these teachers were in the same school and followed the same lesson plans for their biology classes. Both were organized in the way they conducted the lesson. Both talked about why they were trying to collect and investigate the animals and plants of the area around the school.

Teacher 5 also came into teaching through an alternative certification program. He taught physics in an urban public high school before joining the career academy he was teaching at the time I visited him. He had a small group of students who were at different levels of learning. He was in the robotics laboratory and was enthusiastic about the Alice software that they had learned during the summer.

In the robotics laboratory, the teachers were engaged in a three-part process. Each member of the MSTF Robotics team used Alice (an object-oriented program that imparts a sense of software engineering by removing the software language barrier) to create both a 3-D animated movie and video game. This experience prepared them for the second part of the software engineering research, which was to build and program a competitive robot and then transition into using text-based visual programming language such as C#.

Teacher 5 had a couple of students who he considered to be good in studies work on the Alice program and work out on how to run it on their own. His goal for the lesson was to involve the students in creating animations and in the process utilize computer-programming concepts such as sequence, conditions, loops and subroutines. This would also help students gain experience in defining a problem, generating solutions, deciding a course of action, implementing that action and evaluating the results. The instruction was mostly implicit hoping the students would learn as they go. I did not see how what they were doing was related to anything else in class. There was no guidance from the teacher and the students just tried to figure out how the program worked by trial and error until the end of the period.

Teacher 6 taught chemistry in an urban public high school for students in the International Baccalaureate program. She consulted with her mentor in the summer program and came up with the idea of doing a lab on fruit batteries. She gave the students the materials and procedures to set up the fruit batteries. Then she challenged the students to think about ways to make the batteries more effective to produce current. I did not see any whole group discussions on findings of the lab.

Teacher 7 from the same school as Teacher 6 taught a freshman chemistry class. She was placed in the bioengineering peptide interface laboratory during the summer program. The goal of the research groups was to understand how redox enzymes work and to reproduce their activities in synthetic peptides. These peptides can help energy conversion and chemical transformations in living things. Redox enzymes can also be used in industrial roles such as sensors, energy production (fuel cells) and catalysis. The two teachers in this group were mainly engaged in trying to understand the research and help out with the procedures followed by the student researchers in the laboratory. On the day I went to observe the laboratory activities, I found the teachers sitting and waiting for the student researcher to set up the experiment for them. The teachers were given time after the researchers were done with their own work.

Teacher 7 taught regular chemistry class and did not think she could integrate any of the aspects of the research into her chemistry curriculum. She had initially planned a lesson on density but the instructor rejected the lesson because it was not novel and asked her to think of something more novel. The instructor paired her up with a mentor teacher who taught the same subject. After a discussion with the mentor teacher, she planned on doing a unit on different methods of separating mixtures, such as filtration and chromatography. The mentor teacher had taught a similar lesson in her own chemistry class. Teacher 7 did not inform us about the lesson when she taught that lesson. On contacting, she invited us to observe a lab on moles. The students were given the procedure to do the lab. The students got into assigned groups of three or four. They measured the mass of an iron nail and immersed it in the copper chloride solution that was provided to them. They let the nail sit for 20 minutes and then extracted the copper that had settled on the nail and measured the mass of the nail. They recorded the lab results on the sheet that was provided to them. There was no discussion on the lab during the class period. The focus was on getting the lab done. The teacher went around and made sure everyone was following the procedures properly and had the materials required for the lab.

Out of the eight laboratories that I visited during the summer, there were only three laboratories where teachers were assigned to specific projects. In the remaining five laboratories, the teachers spent time observing the researchers and learning laboratory procedures. Out of the seven lessons I observed, there were three cook-book labs, three were taken from pre-existing lessons, and one was on a couple of students working on a computer program. In the six classrooms that were having labs, I found students engaged in collecting data. I did not find evidence of students engaging in analyzing or discussing data.

There were 12 teachers that were willing to be interviewed. The interviews revealed some challenges that the teachers face while implementing their lessons. The teachers in the nanoparticle laboratory (Teacher 2 and Teacher 6), and teacher 7 who was in the bioengineering peptide interface laboratory did not think that they could directly transfer the research experience into their classroom. They thought the content was beyond the grade level that they were teaching. Teacher 2 said that he wanted to prepare a lesson from scratch but realized that it took a long time to prepare a well-planned lesson. He said that he would take some time the following summer to prepare a good lesson plan. He seemed to be upset about losing his job at the end of the school year. He was busy looking for another job for the following school year. He also seemed to be in a stage of trying to accommodate to the school culture. Three teachers mentioned either changing schools or being given a different assignment the following year. One teacher had an administrative position and was not teaching any classes that year. Teacher 5 lost his job at the public high school and was teaching in a career academy for students who had failed to graduate from high school due to various reasons. Another teacher was interviewing for jobs over the summer and did not know where he would be the following school year. Not having a teaching assignment in place for the following year was challenging for the teachers and they were unable to teach the lesson that they had planned to teach.

Teachers faced challenges acquiring the materials and resources required in implementing the lesson. Four teachers mentioned having some kind of problem in setting up their laboratories for their planned lesson. One inner city public high school teacher said she could not get permission from her school principal to bring in black widow spiders in the school. She had planned to use a stock room that was not being used to set up the spider lab, but unfortunately did not get permission to set it up. However, she said she used the spider as a theme for her biology lessons throughout the year. She used spiders to help students distinguish between living and nonliving things, understand the interactions of organisms and their environment, DNA and protein synthesis, genetics and evolution. Teacher 5 wanted to set up the Alice software that he got from the robotics lab in the school computer lab, but the computers were too old to run the software. He said they would be getting new computers the following year and hoped to have them installed for his students then. Teacher 6 had bought toy solar cars from the program funds but was not sure if she could use them with her students that year because her classes were early in the morning when there is not much sunlight. A teacher from a rural high school wanted to show her students a virtual lab on preparing the sample that they worked with during their research experience. She went back and forth to the university and spoke to her laboratory director regarding the kind of virtual lab she wanted. She waited the whole school year for the virtual lab and did not end up doing the research unit that year. She taught a lesson without the virtual lab the following year.

The observations I made during my pilot study gave me an idea of the kind of research experience teachers were exposed to during the ASU MSTF program and the nature of implementation of research experience in the classrooms of the respective teachers. The research topics that were close to the school curriculum and had ready-made lessons for teachers to use were the ones that had a successful implementation. The research topics that were not close to the school curriculum in content were not implemented successfully, irrespective of teacher involvement in the research laboratories. Keeping in mind the purpose of the research experience to get students interested in science and the information I had gathered from my pilot study, I analyzed data for the following year's program. I investigated the research program based on the evidence of real science found in the various sources of data that I had collected.

ASU MSTF 2010 Program Description

The ASU MSTF program of 2010 was an extension of the three-year regular program that was funded by Science Foundation Arizona. The surplus funds after the end of the third year of the program was utilized to have an additional year with a smaller cohort of teachers. The fourth year of the program was conducted for four weeks in summer 2010 with one week of planning time during the school year.

Program incentives. Among the remunerations that the teachers received from participating in the program was a stipend of $1000.00 per week for four weeks during summer and one week of outside school hours planning time during the school year. Lucy who was from a rural school district was provided on campus accommodation for the duration of the summer program. The new teachers received $2000.00 for materials and supplies. Most of those funds went into purchasing laptops for teachers. Teachers had to choose a PC or a Mac. The mentor teachers had a laptop from the previous year's program. All the teachers had about $500.00 available for purchasing materials for the classroom. The new teachers were also given a choice of registering for a 2-credit course in Chemistry or Physics for fall 2010.

Pre-program planning. There was a change in the organization of the program in the fourth year. One of the organizers, an instructor of the ASU MSTF program and a chemical educator at ASU discontinued in the midst of planning for the fourth year program. This instructor was responsible for most of the pedagogical instruction like conducting discussions, giving assignments, giving feedback on curriculum projects. She had also taken the responsibility of arranging the research laboratories for the selected teachers and getting them registered for the follow-up course for the three previous years of the program. Since there were only a few more weeks left before the program started, there was not enough time to assign the instructor's responsibilities to a new person. The program director assumed the additional responsibility in lieu of the instructor's departure. In the previous years, the program director was involved in introducing new educational technology in the afternoon sessions and helping the teachers with the wiki page, ordering materials, arranging poster presentations, and maintaining accounts for the hours completed by the teachers and payments made to them.

A week before the summer session started, a meeting was held with the mentor teachers and the program instructor Dr. Young where I was also present. Topics to be covered during the four weeks were decided in the meeting. The mentors were asked to take the responsibility of helping the teachers write the curricular plan based on the research experience. At the meeting, I presented the free online software on concept mapping called C-Map tools and the instructor planned to share it with the teachers during the program. As part of enhancing the pedagogical skills of the teachers, a session on learning how to use the Reformed Teaching Observation Protocol (RTOP) (Piburn, Sawada, Turley, Falconer, Benford, Bloom, & Judson, 2000) was planned for the afternoon sessions. The teachers were to watch videos of classroom instruction and use the RTOP to record their observations. This would be followed by a discussion on the scores assigned by the teachers and review of the explanation of categories in the RTOP manual. This was thought to be useful for the teachers in reforming their teaching practice. Dr. Young asked the mentor teachers if they wanted to share the knowledge of some computer software that they had found useful for their classroom instruction. A couple of teachers volunteered to conduct sessions on some computer software that they had been using in their schools and thought would be useful for the other teachers as well. I also shared the lesson plan template that I had designed for teachers to write their lesson plans for the curricular project. I incorporated the changes that were suggested by the teachers. Three suggested articles (two by me and one by another teacher) on the Nature of Science (NOS) were selected for reading and discussion during the afternoon sessions. It was also decided that the teachers would get a chance to give a tour of their respective laboratories to the other teachers in the cohort. The teachers were to take the responsibility of scheduling the tours and getting permission from their project directors.

The distribution of time for various activities during the summer program of the ASU MSTF 2010 is shown in a pie chart in Figure 5. Notice that more time was assigned for laboratory work than the afternoon session. The mornings from 8 am until 12 pm was assigned for laboratory work at the assigned laboratories. In the afternoon session maximum time was spent on introducing teachers to different kinds of software technology, sharing research experiences and ideas on transferring the research experience into curriculum plans. A detailed discussion of the various activities that the teachers were involved during the program is given below.

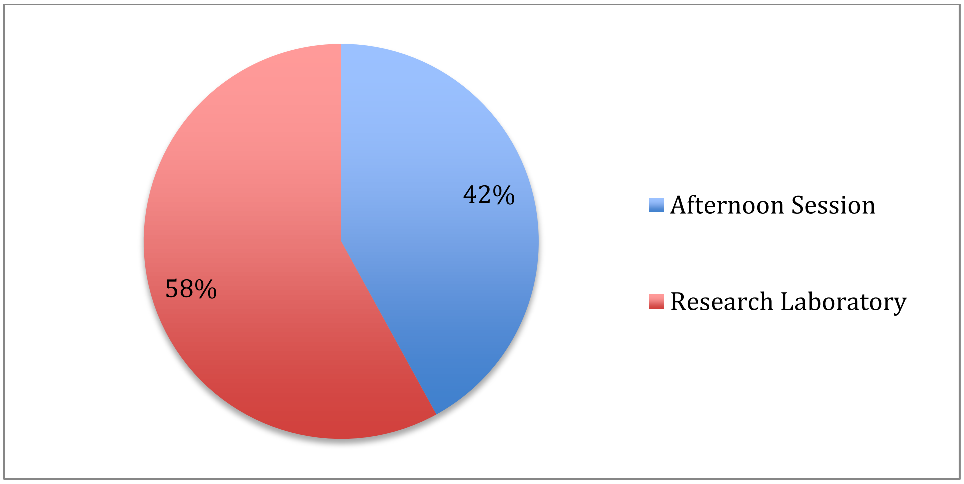

Figure 5. Distribution of percent time for laboratory and afternoon session

Laboratory sessions. The morning sessions were spent in the assigned laboratories. Four research laboratories participated in the 2010 ASU MSTF program. The activities that the teachers were involved in at the laboratories are as follows:

Chemistry/Biochemistry Laboratory (Nuclear Magnetic Resonance Research Center). In this laboratory, studies were conducted in physical chemistry, materials science, and biophysics. The main laboratory was a highly secure area inside the interdisciplinary building. Figure 6 shows a picture of the magnet that is housed in a two-storied space inside the interdisciplinary science building. The researchers had to climb up stairs to reach the insertion point for the sample that is placed in a tiny vial. The computer in front of the structure is used to study the graphs that are generated by the machine. Patsy, Emily, and Wendy were placed in this laboratory. The laboratory specialized in glass forming liquids, fuel cells, nanochemistry, and biological polymers. Teachers had a wide variety of projects to choose from. There were researchers who were trying to raise colonies of embiids (*Antipaluria urichi* from Trinidad), and collect their silk for protein structure analysis. Research was being done on finding a solvent that can dissolve the spider silk properly without destroying its molecular structure, thereafter using the nuclear magnetic resonance (NMR) spectroscopy to see fine details of molecular structure by placing a molecular sample into an ultra-high magnetic field created by the NMR magnet. Once in the magnetic field, atoms in the molecule interacted with the magnetic field, creating an energy, which could then be detected. The researchers observed and measured this energy to determine the molecule's structure and how it interacted with other molecules.

Figure 6. The $3 million magnet at the nuclear magnetic resonance center

Researchers at the pressure lab were conducting research to find out how atoms and molecules react to extreme pressures (in the megabar range). Diamond anvil cells (DAC) were used to compress both solids and liquids to these immense pressures. Once the material had been pressurized, it was analyzed with Raman Spectroscopy, which revealed energy shifts in vibrational and rotational energy of the sample.

On a typical day at the biochemistry laboratory, teachers came into the laboratory by 9 AM. They all had a swipe card to enter the main laboratory. There was a conference desk on one side of the room where the teachers sat around working on their laptops. The graduate students started coming at around 10:30 A.M. Emily needed clarification on the diffraction of light for her classroom project. Dr. Lewis, the director came in around 11 AM to check with the teachers. He gave a brief lecture on diffraction of light and explained the Bragg's law and Fraunhoffer's law by drawing diagrams on the white board. Patsy wanted to try out an experiment on dissolving spider silk in ionic liquid. Dr. Lewis spent some time with Patsy helping her collect the equipment she needed for her experiment. A graduate student came in after he received an email from Patsy and showed her the NMR of some samples that he had already prepared and run that morning. Dr. Lewis spent some time with Wendy talking about the embiids in the laboratory and granted her permission to build a colony of embiids for her classroom.

Nanomaterials Laboratory. The research interests in this group encompassed electrochemistry and materials science. The group employed a suite of tools ranging from atomic force microscope/ scanning tunneling microscope (AFM/STM), various optical and X-ray spectroscopy, to liquid-state and solid-state NMR. Researchers in this laboratory were involved in growing and observing the nanoparticles of different materials like palladium and alloys of silver and copper particles. The process involved dissolving compounds containing metals of interest and capping with a ligand, bubbling the solution with nitrogen, adding a reducing agent, purifying the resulting solution and visualizing it with the help of UV-Vis or XRD. Jack was placed in this research laboratory. Figure 7 gives an idea of the setup of the laboratory. Notice that there was hardly any moving space inside the laboratory with shelves packed with chemicals and glassware. Each researcher had assigned desk space to carry out their research.

Figure 7. Nanoparticle laboratory

Jack worked with two previous year MSTF participants who had their assignments through a different grant. They spent most of the time preparing the samples for analysis. They monitored the change in color of the samples. The student researchers helped them take out the sample for analysis when it was ready. The student researchers ran the samples for UV-Vis analysis, which displays graphs on the computer screen. They analyzed two samples (75% copper with 25% silver and 25% copper with 75% silver) for different concentrations of the two nanoparticles to see which one works best (Figure 8). They tried to make sense of the nanoparticle peaks. The teachers and the student researchers engaged in a discussion on the graphs displayed from running the samples. The peak of silver was easily detected whereas the peak of copper was not very distinguishable because copper oxidizes easily. The group of researchers was hoping that the mixture of the silver and copper nanoparticles would form a very effective use for fuel cells.

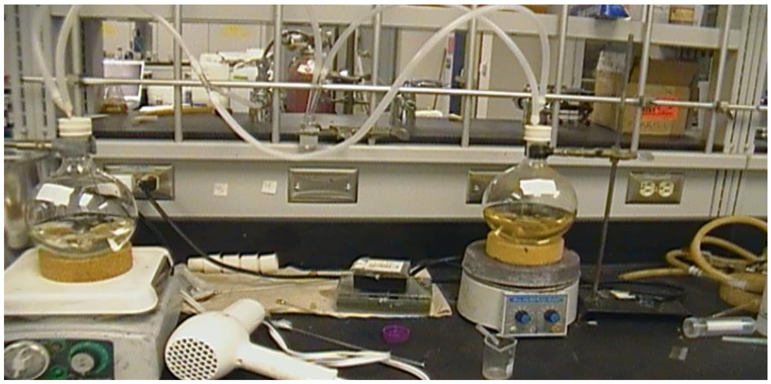

Figure 8. The experimental setup to obtain two samples of copper and silver nanoparticles

Nanosurfaces Laboratory. This group specialized in advanced microscopy and spectroscopy techniques to characterize the growth and properties of thin film interfaces and nanostructures. Researchers in this laboratory were involved in the characterization of new materials that could be used in the semiconductor industry. They made thin films of the material to be studied onto silicon wafers and creating vanadium nano (the SI prefix meaning 10^{-9}) dots on top of a silicon wafer. The process involved placing the material into ultra high vacuum to prevent contamination, and cleaning the sample by placing into an oxygen plasma chamber. The sample was then studied by passing through ultra violet photoemission spectrometer to determine the chemical makeup and energy and band gaps of the wafer. The sample was moved down the molecular beam epitaxy where a thin film was deposited onto the wafer and thickness was measured using a crystal resonator. Stacy and Grace were placed in this laboratory. Figure 9 shows the highly sophisticated vacuum chamber. The teachers were allowed to handle the vacuum chamber only under the supervision of a graduate student.

Figure 9. The 47-feet long transfer line at the nanosurface laboratory

On a typical day at the nanosurface laboratory, Stacy and Grace reached the laboratory before 9 AM. They entered into the sealed room with special shoes and gloves on and started preparing the cell for their experiment. It consisted of a lengthy process of cleaning the chip with acetone and ethanol, drying with compressed nitrogen, and finally fixing the chip with wires on to the holders. They spent an hour trying to fix the silicon chip on the holder, yet failed to do so after a number of attempts. On each try, either the wires would break or the chip would break. Once the cell was prepared and ready, they had to wait their turn to insert their sample into the vacuum chamber. They returned back to their desk in the adjacent room and researched on the topic or pondered on ideas for the curriculum project. They left at lunchtime requesting the student researchers to insert their sample into the vacuum chamber when it was available.

Biophysics Laboratory. This laboratory specialized in structural biology; physics of molecular recognition, and conformational dynamics of single (bio-) molecules with the use of scanning probe methods, force spectroscopy technologies and nanophotonics. The goal of the researchers was to develop and improve nanobiophysical techniques. The technology they were working on improving was a combination of two microscopes, the Atomic Force Microscope (AFM) and the Confocal Fluorescence Microscope (CFM) (Figure 10). These technologies are used to study fundamental biological processes, structures and nanomaterials such as gene regulation, transcription, translation, molecular machines, and charge transfer in bacterial nanowires. The researchers in this laboratory were involved in interpreting the graphs that were obtained from different samples of biological cells. They spent substantial time interpreting graphs obtained from cancer cells. Lucy and Brad were placed in this laboratory.

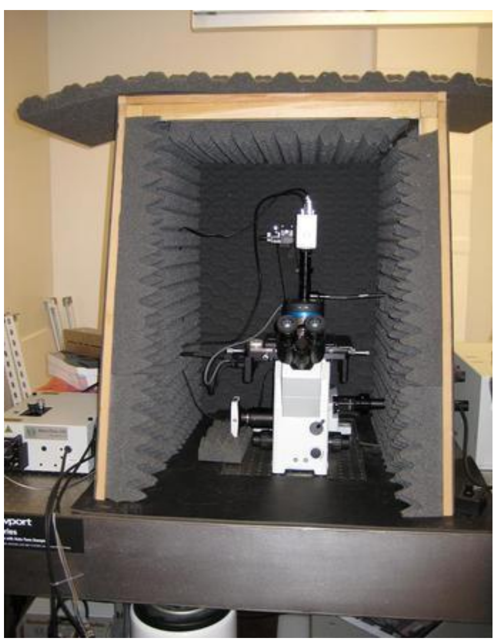

Figure 10. Confocal and atomic force microscope at the biophysics laboratory

On a typical day at the biophysics laboratory, Lucy reached by 9 AM and Brad came in a little later. The graduate students showed up only at 10:30 AM. The teachers worked on their own, researching on the topic or searching for lesson plan ideas. After the graduate students arrived, they prepared some samples and observed them under the powerful microscope that was housed in a small sealed and crammed room with a circular wooden door for entry and exit. The room was designed to prevent airflow in order to protect the sensitive microscopes. The teachers along with the graduate students sat in front of the computer screen for an hour and a half watching the graphical output of the samples and studying the changes in the shapes of the graphs. The graduate students assisted the teachers in recognizing a good curvature in the graph, which depended on the way the cantilever tip moved on the surface of the sample. The group spent time trying to study the force with which the antibody on the tip attached and pulled apart from the antigen on the surface of the cells. The teachers took a few minutes to discuss how they could build a model of a cantilever for a classroom demonstration before it was time for lunch.

Afternoon sessions. Teachers spent the afternoons in whole group sessions to discuss their research experiences and think of ways to transfer the research experience to the classroom. Teachers gathered together in an ASU facility that was equipped with projector, white board, screen, video cameras, sound recording devices, and an audio-visual production studio. The desks were arranged in groups of four to facilitate discussions. Teachers involved in discussions on authentic inquiry, nature of science, and ideas on transferring research experience into the high school curriculum.

The teachers were introduced to various kinds of software technology that they could use in the classroom. Items covered were Google Documents, Google Forms, Google Calendar, Google Site, I-google, Excel, Camtesia, Screenflow, Spreadsheets in Science, C-Map Tools, V-Python, and Tiny-url. The mentor teachers, Stacy and Jack took the responsibility of introducing the Google applications to the group. They demonstrated various functions that could be used for managing work in the classroom. The instructions for using the applications were posted on the MSTF website. Google sites can be used to create a course site for students to log in and find information on assignments and course documents. I-google is a good place to have a course calendar and to get a quick glimpse of something important. Stacy said she used Google forms to do the tests, quizzes, and surveys for the class. Google documents were useful to collect lab reports from the students. Dr. Young introduced a few other computer applications. He gave a demonstration of Camtesia, Screenflow, Excel, Tiny-url, and V-Python. The teachers experimented a little with V-Python and practiced some exercises to see how the program works. A PowerPoint on spreadsheets and 40 different spreadsheet examples was uploaded on the MSTF website for future reference. A list of free or low cost software was also available for reference on the website. The teachers were introduced to the concept mapping software CMap tools and were asked to draw a concept map of the research in their respective research laboratories, one at the beginning of the summer program and one at the end of the program.

There was a safety training that the teachers had to undergo in order to start working in the research laboratories. The personnel from the Environmental Health and Safety department came over to the afternoon session on the third day of the program. They trained the teachers on ways to handle hazardous chemicals and on steps to take during an instance of fire hazard.

There was one formal discussion on the Nature of Science (NOS). Mentor teacher, Wendy led the discussion and teachers raised some points from the readings on NOS. There were other informal discussions on NOS during the curriculum planning sessions on Fridays, when teachers shared their experiences on the everyday practices of the researchers.

The mentor teachers ran the curriculum planning days. They initiated conversations regarding ideas on transferring the research experience into the classroom and helped the teachers with ideas and experiences of their own. The teachers talked about some of their ideas on lesson plans. There was not much in-class time available for teachers to actually plan their lessons. There was more emphasis given by the instructor on creating the posters and wikis during the summer sessions. Therefore, teachers spent the remaining time on Fridays working on the posters and wikis.

Teachers arranged for tours of their respective labs during the afternoon session of the program. Each teacher talked about the research and all the equipments and procedures that were being used in their labs. They answered any questions that the teachers had, to the best of their knowledge. If the teachers thought they did not have enough expertise to explain, they had one of the researchers take over. For instance, the working of the massive superconductors in the Nuclear Magnetic Resonance (NMR) laboratory was explained by one of the post doctorate researcher in the laboratory. The teachers of the biophysics laboratory were unable to arrange a tour of their laboratory. They could not contact the director because everyone in the laboratory was busy with a new consignment of cancer cells. The teachers mentioned that the researchers were busy trying to analyze the data and prepare a report. So, there were only three laboratory tours that the teachers had arranged to visit.

Dr. Young gave a tour of his laboratory on one of the afternoon sessions. He explained the principle behind his Proton Induced X-Ray Emission (PIXE) laboratory. He asked the teachers to bring small pieces of materials to find out what it was made of by scanning them through the X-ray. He walked them through the laboratory and explained how the beam accelerator worked.

The teachers spent some time during the afternoon sessions creating wikis on their research experience. Dr. Young created a wiki site for ASU MSTF 2010. He explained how the teachers could use the wiki site to include their ideas, blog, and create a page with pictures and notes on their research experience. The teachers included pictures of their laboratory activities and laboratory tours; and described the ongoing research.

Teachers were encouraged to write blogs about their daily experiences. They were also encouraged to exchange ideas regarding curriculum plans through the blogs.

The group was introduced to some concept inventories in chemistry, physics, and biology. The teachers who were familiar with the concept inventories took the responsibility of introducing them to the rest of the group. They talked about how the concept inventories were developed and used in past years. Grace went over the Force Concept Inventory (FCI) and the Biology Concept Inventory (BCI) and Jack went over the Chemistry Concept Inventory (CCI). He told them how he used the inventory in his classroom and what kind of information he was able to obtain regarding concepts that the students learned in his class. They said that the concept inventories were generally administered as a pre and post test to find out changes in students' conceptual knowledge. The teachers shared some statistics on pretests and posttests conducted on the concept inventories. The BCI was still being developed and thus there were no statistics available on it to share.

Dr. Young introduced the teachers to a short training on using the RTOP (Reformed Teaching Observation Protocol) that would help them assess their own teaching during the school year. He gave the teachers a brief introduction of the RTOP and had them work in groups to come up with some categories that should be used to measure reformed teaching. The teachers discussed in groups and came up with a list of categories. They were then asked to come up with some specific items to measure those categories. The teachers shared their categories and items with the whole group. Dr. Young went over the categories of the RTOP briefly and asked the teachers to take a look at items in the RTOP that were not in their list of items and vice versa. He passed out a RTOP form and a training guide to all the teachers. He asked them to watch the video that he posted on the wiki and score it using the RTOP. The teachers watched and scored a couple of videos and shared their scores through Google documents, compared their scores with the scores of experts, and discussed some outliers and general thoughts about the RTOP.

As part of the program requirements, the teachers had to design a poster on their research experience and present at a poster presentation at the end of the summer program. The teachers were asked to invite their laboratory directors, research assistants, school principals, colleagues, families, and friends to the poster presentation.

The teachers had to plan a weeklong unit based on their research experience. A lesson plan template was provided to the teachers to help them plan their lessons. Refer to appendix A for the lesson plan template. I walked the teachers through the template and provided clarifications regarding the template. Teachers were asked to implement the lessons in their classroom during the following school year.

On a typical afternoon session, it took 15 minutes for the teachers to settle down at their tables. The teachers arranged themselves according to their placement laboratories. Jack sat with the nanosurface group since he was the only teacher from the program in his laboratory. Dr. Young took 10 minutes to go over some housekeeping regarding the process for ordering materials and teacher stipends. Stacy took an hour to impart training on using Google Forms to create surveys, quizzes, assignments, and tests for the students in the classroom. Teachers took half an hour to create their own surveys and circulate it amongst them and see the results. Dr. Young reminded the teachers to work on their wikis and showed them sample posters from the previous years. Teachers spent the remaining time on posting research information on the wiki and writing their blogs.

The findings from the study of the ASU MSTF 2010 program are arranged according to the research questions. I have looked for themes of confirming and disconfirming evidences based on the real science components in order to answer the research questions. The data sources used for answering each of the questions is given. Similar patterns found across different data sources indicate triangulation of results.

Pre-program Teacher Assessment

In order to answer the first research question (Did the classroom teaching reflect real science prior to the ASU MSTF summer research program?) I analyzed the program applications, pre-program interviews, and the pre-program classroom observations by coding the documents, transcripts and field notes to look for themes across the data sources.

Teacher reflections. The themes that emerged from the program applications and pre-program interviews were scientific process including features of real science, scientific techniques, inquiry/discovery, analytical skills, relevance of science, and hands-on activities.

Theme 1: Scientific process including real science features. The skills and processes that the teachers wrote in their applications and mentioned in their interviews included all the real science components but the ones that were emphasized the most were experimental procedures, data analysis, and conclusion. The components that were touched upon the least were formulating research questions, hypothesizing, discussing results, presenting findings. Teachers did not write or talk about modifying scientific methods.

Patsy wrote, "At the start of each year, I always ask students to think of a research problem and apply the scientific method in trying to come up with a possible answer to that problem. This is better than just discussing the scientific method."

Wendy recorded that she used processes such as posing questions, developing hypothesis, designing procedures, collecting data, analyzing results, and forming conclusions. She wrote,

> Students complete a number of inquiry-based projects, providing an opportunity to pose their own investigational questions, develop hypotheses, design experiments and analyze results. …They test multiple hypotheses, all the while incorporating newly acquired concepts about ecology. …Additionally, all major concepts are paired with labs, giving students the chance to select and manipulate variables, collect and analyze data, and form their own conclusions.

In her interview she stressed on processes such as analyzing and interpreting data. She said,

> I want them to be critical thinkers, problem solvers. I want them to analyze data, interpret data. I don't necessarily care if they can do their own investigation. It's more important that they see data and say, "this is what this means"—to be able to interpret it.

Grace who uses the modeling curriculum recorded using processes such as prediction, data collection, data analysis, discourse, presentations, and applications. She wrote,

> As a long-time participant of the ASU Modeling Instruction Program, I typically strive to implement the Modeling Cycle (or a variation) in all content I teach, whether it is in mathematics or physics. This typically begins with a carefully designed student data collection activity typifying the content and objectives I wish students to acquire. This is followed by student presentation (usually via a "board meeting") of their data and results. The culmination of the board meeting is a class consensus about the patterns in the data, followed by a generalization of results into a possible model. Students then apply this generalized model to a variety of related (but not identical) situations. In the final phase, I require students to use their model to make and test a prediction about some real-world phenomena. White-boarding and student discourse is frequently required throughout this process.

In her interview, she highlighted the importance of being meticulous in designing experimental procedures, collecting data and building models. She stated,

> I want students to be engaged and inquiring and trying to decide how they can measure and collect data to build their own models. So, they should be very active in the process of science. … I think a lot of it is knowledge in just the nature of science—what is inquiry—and how do you design a lab that is controlled—and how do you test things in a fair manner—how do you build models of how things are going to work in the moment. I think those are the big broad ideas. In being meticulous about that is more important than any particular content knowledge.

Jack who also used the modeling curriculum recorded processes such as student discourse, explaining results, refining explanations, application to novel situations. He wrote,

> For the last three years, I have faithfully used the chemistry Modeling curriculum that was developed through the physics Modeling program at Arizona State University. The central idea of this teaching method is student guided learning where students make inferences and draw conclusions about chemistry concepts. Through Socratic questioning and student-generated discourse, students have a direct buy-in to the learning process. At the beginning of a unit, students in my classes perform a laboratory

activity and are then challenged to explain the results of that experiment using their former knowledge. Through the discussion that ensues, they often realize that their current understanding cannot explain the observations made. Thus challenged through teacher guided and student generated Socratic questioning, students see the necessity to refine the explanations they have given. Upon completion of the discussion and refinement, they, in turn, develop a model of an overarching chemical concept. Students can then apply this model to novel situations that further challenges them in the course of the class.

Emily emphasized on collecting data, analyzing data, and conclusions. She wrote, “Lab activities usually begin each unit to give students a chance to gather and analyze data, to form conclusions or just experience and observe chemical phenomena.”

Emily reported in her interview, “It don't matter what field you are in, everything comes down to data, and how to collect data and how to analyze data, and how to then apply it and make it work for you, and in making decisions. So, that's what every student should understand.”

Brad stressed skills such as conducting experiments, analyzing data, and drawing conclusions during his interview. In his opinion,

> I believe they should be able to take away specific skills, maybe not like content knowledge but they should know how to run an experiment, they should know how to analyze data, they should

> know how to draw conclusions based on data that they see. Those are things that are most important for students to be able to take away.

Lucy wrote, “They had learnt to make soaps, various kinds of cheeses, grow different crystals, build model bridges and roller coasters, etc. (*sic*). They use the concepts and laws of physics and chemistry to build better bridges, grow better crystals etc.”

Lucy said she focused on hypothesis, testing, and conclusion. She stated, “I teach them the scientific method of doing any research. …So, I taught my students, you always use the scientific method in the classroom—what are we doing today—hypothesis—testing—does it support what you think— and all that.”

Theme 2: Analytical skills. Wendy said that she focused more on analytical skills. She mentioned,

> So, we spend a lot of time on analytical skills-critical thinking and problem solving. I don't care if they leave with 10,000 facts, because they look on the Internet and find information. I want them to be able to think critically.

Jack stressed analytical skills too. He stated,

> As long as they have a basic understanding of matter—from simple phase changes that they see, down to the atomic level—make those connections in the atomic level and say, “Okay, this desk is this way because of the particles being this way”, or “This liquid is

> behaving this way because of the particles in this”. If I can get my kids to the point where I can give my kids a glass of water and instead of seeing water, they could see the particles, and discuss it in terms of what the particles are doing—I think, that is probably the biggest thing I can get them to come out with—and the other thing I tell them is—you are going to avoid being bamboozled—you are going to have these people sell you something on an informational that is not going to make any sense—because now you can look at it in terms of chemistry and particles, and break it down from there and say, “Well no—this wouldn't happen because this is what's going on here”. So, in terms of science knowledge, what I want them to have is—here’s some pictures of macroscopic property, “what's going on in the macroscopic level—what's going on in the atomic level?” If they can have that spectrum, where they can take a simple process and take it all the way down to the particle level, or take something from the particle level back up, that's what I want them to have.

Stacy emphasized the skills of critical thinking and problem solving in her interview. She said,

> Number one, I think, the biggest thing we can learn from science is problem solving. Number two, to be critical thinker (*sic*). A lot of students are going to walk out of high school and never really do jobs that have to do with science necessarily, but they will problem

> solve in their lives and they will be critical thinkers. I want them to be able to watch the news and realize when somebody puts a scientific study in the news that doesn't make sense. I want them to be able to critically think about that and /or when somebody wants to sell them a product that doesn't make sense. I think, if they can walk away from science, even if they never touch science, and be problem solvers and critical thinkers, that's what they need to walk away with. Those are the two big things for every sciences (*sic*).

Theme 3: Relevance of science. Some teachers documented and talked about helping students see the relevance of science.

Wendy wrote,

> One of the great things about teaching biology is that its dynamic concepts can be related to students' lives on a daily basis. I attempt to connect every concept we learn to the real world and how this new knowledge can enhance not only their lives, but their community and the planet as well. For example, when I teach cellular respiration, students do activities to help them understand how nutrition and exercise affect their body's ability to convert food energy into ATP, and they learn ways to maximize their own production of ATP. Throughout the year students learn about all of the complex energy transfer processes that occur on earth and how our actions affect those processes, both in the short and long term.

Wendy said,

> I think most students learn best … especially if they can apply to their own lives. You need to see how is this important in my life, how does this affect me… they have to see the relevance.

Jack wrote,

> In the past, I have had nuclear energy specialists address my classes during the nuclear energy unit. In addition, I have had engineers in my classroom presenting some of their most current developments thus allowing students to witness the application of the science curriculum they are studying to the real world. Also, I am consistently using current research articles from the ASU publication to supplement the textbook used in my classes. Furthermore, by taking students on field trips to ASU to see the research facilities and expose them to ongoing research, they are exposed to the academic side of research which often serves as the catalyst for major changes in medicine, engineering, technology, etc. Next fall, in cooperation with the University of Arizona, I am hoping to involve my students in active water quality testing of a local urban lake at our neighborhood park.

Emily wrote, “Students are always asking if the skills they are learning are ever really used by “real” scientists.” She wanted to show students the relevance of science. She stated,

> All kids should have an understanding of how to think like a scientist, how the scientific method works and applies in everyday life, and in all facets of everything…I mean, science is a very important thing. It's extremely important to understand every thing they encounter in life that is science. The more computerized we are, and the more advanced we get, technology wise, the more science comes in.

Brad wrote,

> Since students come with a varied amount of personal experience, the activities in my class give students a shared experience that we can continually refer to when discussing concepts. I will try to link everything to the common experience on homework and refer specifically to it on quizzes and tests.

Patsy wrote, “I believe that the students will be more interested in Chemistry or any other sciences if they can see the practical application of the concepts that they are going to learn in the classroom.”

Stacy wrote,

> I encourage my students to dig deeper and to connect the topic they are investigating in my class with content from other classes and the world as a whole. I believe allowing students to experience something in the lab and then connect it with the bigger scientific picture helps them acquire and more importantly retain concepts.

Grace recorded, “Lessons are grounded with real-world application.”

Lucy wrote, “I try to make the lab activities very interesting and practical for the students.”

Theme 4: Hands-on activities. Some teachers said they involve students in hands-on activities. They did not talk specifically about any real science activities.

Lucy said,

> Students learn with a lot of hands on activities—a lot of visuals. If it is just lectures and notes from the board—it's no good, they will not learn—but if you have hands-on then it starts to get in their head. Like—okay lets make some cheese—do you see the precipitation—there is a chemical reaction—all those things. Then they get to learn.

Wendy mentioned, “I think most students learn best by doing things. There is so much in science that can be abstract and difficult, especially for younger thinkers who are not abstract thinkers yet. I think most students learn best by seeing things in action, manipulate things. So, hands-on …”

Brad believed students learn science best through experience. He said, “They have to be able to see it before they can understand it.”

Miscellaneous comments. There were a few other comments on using new technology and inquiry methods that did not fall under any particular theme.

Emily wrote,

> Students are always asking if the skills they are learning are ever really used by “real” scientists. We have recently acquired new digital sensor equipment from Vernier along with a classroom set of laptop computers. … In my classroom I work under the premise of self-discovery through guided instruction…I use a hands-on discovery approach to get students engaged and thinking about a topic before the onset of guided instruction. … My goal is to have the honors chemistry class use the digital sensors in inquiry based lab activities where students move through the scientific investigation process to discover basic chemistry understandings.

Wendy wrote, “Students complete a number of inquiry-based projects…”

Two themes that were found in most of the program applications and the pre-program interviews were the scientific process and the relevance of science. The teachers emphasized certain real science features more than the others (experiments, data analysis, conclusion) and left out others (modifications of methods, background research).

Classroom observation. There was some evidence of real science in three out of the seven teachers’ classrooms that I visited before the summer program. I found the students in these classrooms engaged in making observations and collecting data.

In Wendy’s classroom, the students were engaged in trying to examine the relationships among human traits and determine which characteristics are linked.

They were collecting each other's height, arm span, and reaction time and shared the information with the whole class. The following day, they were going to analyze the collected data.

In Patsy's classroom, students were learning to conduct titrations. Patsy gave students the procedure and asked them to follow the steps and record the equivalence point of the given solution. They were going to process the results the following day.

The instructions in the remaining classrooms were either lecture based or students were engaged in activities demonstrating content knowledge and skills. In the remaining four classrooms that I visited, I did not find evidence of real science activities. The activities that I observed in these classrooms cannot be called real science activities because students were not engaged in trying to figure out an unknown phenomenon by following any of the ten real science features.

In Stacy's classroom, students were involved in an activity where they had to demonstrate knowledge of alpha decay and beta decay by arranging themselves in the order in which radioactive particles decrease after each step in the decay process.

Grace, who was a physics teacher, was planning to change school the following year. She arranged for me to observe her in the new school. She was able to make arrangements with a middle school math teacher. In the lesson she taught, students were engaged in a paper cutting activity to learn geometry concepts. They had to cut "jackets" for "space food packages," which were actually blocks of cubes. For different space armor jackets cut from the grid paper, they had to find the number of days the food supply will last (the volume of the package) and the cost of the jacket (the surface area) and dimensions of the package.

In Jack's classroom, the students arranged balloons to demonstrate the different orbitals in an atom. The students were given a set of six balloons and were asked to tie them together to model the p-orbital so the students could understand the 3-dimensional model of the p-orbital.

In Brad's classroom, the students were working on hypothetical problems involving force and velocity. The students worked on the problem as a group and then shared their answers with the whole class. Brad prodded the students to solve a problem that he wrote on the board for the whole class.

A summary of the real science activities found during the pre-program observations is given in Table 3. In Wendy's and Patsy's classroom, students were found to engage in collecting data as part of an experimental procedure. The other teachers were found to either have discussions and activities based on content matter or revising science concepts for the final exams. Lucy, who was teaching on an Indian reservation in a rural area was not observed because of difficulty in getting research consent.

It is evident from the pre-program teacher interviews and applications that the teachers tried to make science relevant to the students and incorporate real science features such as experimental procedures and data analysis. However, there was very little real science evident during the classroom observations. Real science activities were found in only two classrooms (Table 3).

Table 3
Pre Program classroom observation analysis for evidence of real science

	Wendy	Emily	Patsy	Jack	Stacy	Grace	Brad	Lucy
Formulating questions								
Background research								
Research Hypothesis								
Designing procedures								
Conducting experiments	√		√					
Collecting data	√		√					
Analyzing data								
Discussing results								
Presenting findings								
Modifying procedures								

* Shaded area indicates that the teachers were not observed

Program Expectations of Teachers

In order to answer the second research question (What were the teachers' expectations of the research experience? Were the expectations geared towards involving students in real science activities?) I analyzed data collected from the program applications and pre-program interviews. The themes identified from what the teachers wrote in their program applications and said during the pre interview are as follows:

1. Integrate current research and technology into lessons
2. Integrate real science practices, processes, and skills
3. Integrate interdisciplinary nature of research
4. Incorporate relevant and practical activities
5. Help students pursue science careers
6. Enhance self-knowledge of research
7. Miscellaneous

Given below are the themes with accounts from what teachers wrote and mentioned.

Theme 1: Integrate current research and technology into lessons. Jack wrote,

> Because I am always trying to adapt my classroom to current research and technology, this program offers me the perfect opportunity to experience research first hand and develop a lesson out of the research, not simply around the research. Hopefully, I will be able to seamlessly align a teaching unit by connecting the research and the curriculum at the outset. In this way, I hope develop materials that will involve my students as researchers themselves doing an activity that will parallel those done during actual research. …Rather than bringing in outside experts into the classroom or outside research, I hope to create a unit that can place my students as the experts.

Emily wrote,

> This research experience will provide me with the opportunity to bring current research techniques into the classroom and to bring the world of research science to life in the classroom. I am especially interested in sustainable systems for this is where the future careers are and I want to bring the chemistry of sustainable systems into my classroom. Emily said in her interview, “I wanted to get into a lab. I wanted to get at a Univ. level of thinking, and to

> the research on what's going on now, so that I can bring more current concepts into the classroom."

Patsy wrote, "I would love to impart the laboratory procedures, techniques, and skills that I will gain in this training to the laboratory experiments that we do in class."

Brad wrote, "I am hoping that the activities that my students do in class will give them a taste of current methods and technology…"

Lucy wrote,

> I teach a gifted class in alternative sources of energy and the sustainable resources program would help me develop more ideas and lab activities for these future scientists…I would also like to bring biotechnology to the classroom so that the students can learn modern uses of biosciences in forensics, genetics, and gene therapy techniques.

Jack said,

> Not having that experience, of actually doing research—it is difficult to talk about what is going on at the universities or elsewhere in terms of research when you don't know what is going on and you don't know the process. And so I think, that is what motivated me the first time because here we are talking about what is going on with chemistry in the real world and if we are completely honest and frank with ourselves, we really don't know what is going on out there… Just having a little bit beyond what

you would normally get in the classroom and having it to refer to your students gives me a little more credibility for my students, and it gives me a wider knowledge base to draw from so that I can incorporate some of that stuff that might be more interesting to my kids, more current to my kids, and to what I am teaching, so that I can teach what I have been teaching before but teach it with a little bit different spin and a little bit more current knowledge base, so that the kids will be a little bit, maybe a little bit more challenged, and a little bit more interested in what is going on.

Stacy said,

> I really liked doing research in my undergrad when I got a chance to do research. I think it made science more relevant to the students. And I want to get more chances to do research and see what's going on out there, so I can bring it back to my students, because they get tired of the stuff that's in the book—because its just old stuff. All the old stuff gets boring to them and they need to see what's new so they realize that it not just old stuff. Sometimes I think we are done with science and there is nothing new to learn, and I want to see the new stuff, so I know there is something to learn.

Jack wrote, "I cannot think of a better way to learn what students often consider dry information in a textbook than by learning the information through current research and active participation."

Stacy wrote,

> There are many ways that I might be able to integrate this experience into my classroom. One small was is being able to introduce my students to some of the current research being done in universities and around the world. When students get the opportunity to see and understand some of the research that is being done they get excited about science. Introducing my students to current research is only a very small way that I can incorporate this experience into my classroom.

Jack wrote,

> I hope that I learn enough about the area I am working in that I can incorporate the actual data that was obtained during the research. I want to have my students analyze the actual data and draw their own conclusions about what the data implies much as they would already do in the modeling units I already use…Also, it will let the students experience "new science" and meet the goals of rigor and relevance as set by our district.

Jack said in his interview, “I want to have my students analyze the actual data and draw their own conclusions about what the data implies.”

Theme 2: Integrate real science practices, processes, and skills. Grace wrote,

> Regardless of specific content addressed, materials I develop for classroom use will require students to build a rich scientific model

> using concrete activities and multiple representations (numerical, graphical, verbal, algebraic, and diagrammatic). The big processes and concepts most central to the ASU research I study will inspire the activities developed.

Grace said, “I would like to be able to take that to kids—the skills and ideas necessary—for my students to—eventually in the future—be able to go there themselves.”

Stacy wrote, “This year I integrated the idea of group research meetings into my classroom. I would like to extend these group sessions in addition to creating more laboratory experience that allow the students to design and conduct their own experiments.”

Emily wrote, “Students are always asking if the skills they are learning are ever really used by “real” scientists. With this opportunity I will be able to share first hand experience with my students.”

Brad wrote, “I think that the research experience will give me a better understanding of specific content as well as develop new ideas of how to engage students.”

Theme 3: Integrate interdisciplinary nature of research. Stacy wrote,

> I would also like to take what I learned last year combined with what I would learn this year to create a department wide integrated lesson with my colleagues. I think teaching our students’ how real science is conducted is extremely important. It can help keep them interested and excited about science. Creating an integrated lesson

> will give students the opportunity to see and understand how science is not separated into neat little categories but that each topic has many aspects and can be looked at from many angles. The benefits of creating authentic integrated lessons plans are numerous. The ability to work with my colleagues to create a department wide culture means that the experience I would gain from this fellowship would not only reach the 150 students I teach each year but that we as a department could introduce a thousand students every year to the joys of scientific research.

Grace wrote,

> I hope to take research ideas from MSTF and develop a "modelized" integrated math and science module aligned to state and national standards. Mathematics content addressed can be broad and include any of the Arizona State Mathematics Strands. Science subject matter will definitely include Arizona Strands 1 to 3 (Inquiry Process, Nature of Science, and Science in Personal and Social Perspective). Specific science content will most likely come from Strand 5 on Physical Science or Strand 6 on Earth and Space Science.

Jack wrote,

> In a school you see bio as one piece, physics as one piece, chem as one piece—and that is slowly but surely not becoming the reality in terms of the research that's going on. You see physicists

working with chemists, chemists working with biologists, biologists working with physicists—and not wanting to sound too touchy-feely, every one in these different disciplines has got to come together to make sense of the data that we are pulling out—because chemists are pulling out data that look more like physics data, biologists are pulling out data that looks like physics data, and the physicists need help of the chemists and the biologists to make sense of the data that they are pulling out—so, you really don't get that sense looking at textbooks or in teaching—because we teach our discipline and that's all we teach—so, being able to incorporate biology in my chemistry class or being able to incorporate physics in my chemistry class—I don't think the kids have got a full grasp of that sense—at least the sense that I got out of the summer—but, at least having to give them a taste of this, is what is really going on—not chemistry, physics, and biology but, chem-phy-bio together and you have to know a little bit about each one—because especially for them—I try to impress upon them that, “This is something that is on your horizon. So it's going to be something that's pretty commonplace in future. Some of the stuff that is being developed right now, you are going to be using. If you really want to know what's going on, you are going to have to know a little bit about each of the science discipline to figure out what's going on.”

Theme 4: Incorporate relevant and practical activities. Wendy wrote,

> If selected again as an MSTF participant, I would welcome the opportunity to translate my new research experience into relevant activities for my students. Students are most engaged in learning when they can see a real life application, and the MSTF research opportunities are very applicable to many areas in the biology curriculum.

Emily said,

> So—to bring that component of creating your own activity and make it more meaningful for the students—where they can see more of a real life application to science—it's really hard for them to get the concepts—here are all the concepts and things in the book, but what does it have to do with real life.

Lucy said,

> Well, I think that to teach science or math you need to make alive with practical—with hands on thing. So, I apply for it (*sic*)—because I want to bring research—or tell my students about scientific research, it's not just memorizing all the facts—we do research with science and it's interesting.

Grace said, “I am hoping to gain ideas about how to implement more realistic math and science research into my classrooms.”

Patsy wrote, “I believe that the students will be more interested in chemistry or any other sciences if they can see the practical application of the concepts that they are going to learn in the classroom.”

Theme 5: Help students pursue science careers. Lucy wrote, “Adding new activities, like biotechnology labs and sustainability labs would enhance their scientific education and steer some of these gifted students to scientific careers.”

Emily wrote,

> I work with a wonderful group of underprivileged students who work very hard to make each bit of their education count. The knowledge and experiences I will bring back to the classroom, just by talking about the things I did will motivate my students to reach even higher with their goals. I am new to Arizona and I am eager to get involved with science at ASU so I can continually push talented students towards careers in math, science, and engineering.

Patsy wrote, “I will be more confident in explaining to the students how the concepts and skills that they learn in chemistry can give them that competitive edge in the job market.

Brad wrote, “I am hoping to be able to develop enriching experiences that are memorable for students. I am hoping that the activities that my students do in class will give them a taste of current methods and technology that will get them interested and excited about pursuing science as a career.”

Lucy wrote, “I think once students get a feel of research and practical uses of the concepts that they have learned, they would be interested in a science career.”

Lucy said, “I want to know more and also explain it to my students. Maybe some of them will pursue it and become scientists.”

Emily said, “I wanted to make some connections with people at ASU because our goal is to get the kids into college. If I have more personal direct connections, I can help facilitate that better.”

Theme 6: Enhance self-knowledge of research. Wendy said, “I have always been interested in research and I thought that I probably would not get a job in research, so this was an opportunity to do research, and still remain a teacher. I knew it would enhance my teaching to see how real scientific research is done.”

Grace said, “I think it was two things. One is being just exposed to more high level scientific research is very interesting to me.”

Brad said, “excited about being in a real research lab where they are doing stuff that hasn’t been done million times before (*sic*).”

Lucy said, “I think I would like to do some nanotechnology stuff—that is the modern cutting edge technology.”

Patsy wrote, “Whatever I will learn in this research experience will give me more insights as far as how science is applied in the research industry nowadays.”

Miscellaneous

There were a few more expectations regarding receiving instructional materials and ideas for science fair projects that the teachers expressed in their interviews and program applications.

Patsy was looking forward to receiving some instructional material and hoped the program would help stimulate ideas for science fair projects,

> New teaching materials, new ways, more interesting, more updated labs or something, I hope. … Our school has not had a science fair since I started teaching here in 2006. I hope to initiate one next school year if given the opportunity to immerse myself in research this summer. … I actually wanted to do sustainable energy, how the trend is going green, and all that. Next year I plan to put up a science fair here. They never had a good science program here. I mean, we just teach science. I came from a science high school in the Philippines where we have the NSTA, we participate in the SCI, and all that. Even when I was teaching in Maryland, I could go to Intel and join a science fair, but here the kids haven't had a chance to make projects for science fair… I want to do that one, because when I do science fair, I want the trend to be towards Energy, so I thought it would be a good prep for me.

There were two prominent themes in the program applications and the pre-program interviews (integrate current research and technology into lessons; integrate real science practices, processes, and skills; incorporate relevant topics and activities). This suggests that teachers were hoping to gain understanding of current research techniques used in the laboratories at ASU so they could bring that knowledge back to the students. They were also hoping they could make science more relevant to their students as a result of the research experience.

Evidence of Real Science during Program

In order to answer my third research question (What evidence is there that teachers' experienced real science during the research program?) I identified themes in laboratory observations, blogs and posters that pertained to real science activities. It was evident from the laboratory observations that the teachers were either observing or conducting real research. Five out of the eight teachers were mostly involved in observing the ASU researchers conduct research. These five teachers engaged in asking questions and participated in discussions with the ASU student researchers. Hence, time spent conducting research varied from one laboratory to the other. Figure 11 gives an estimate of average time spent by each teacher engaging in research at the different ASU laboratories.

Evidence from blogs. I analyzed the blogs to identify sentences addressing the real science features that the teachers wrote about in their blogs. The analysis of the blogs revealed that teachers wrote mainly about background knowledge pertaining to the area of the research and about experimental procedures followed in the different laboratories. Three teachers from the nanoparticle and nanosurface laboratory wrote more about analyzing data than any of the other teachers (Figure 12). The components of real science that did not

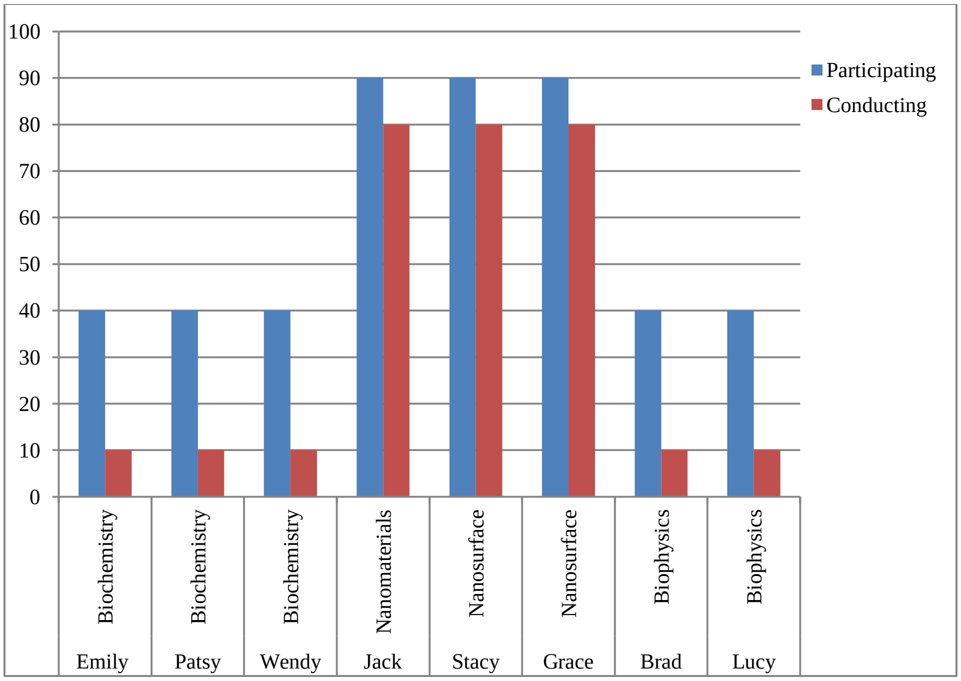

Figure 11. Estimate of average time spent by each teacher engaging in laboratory work

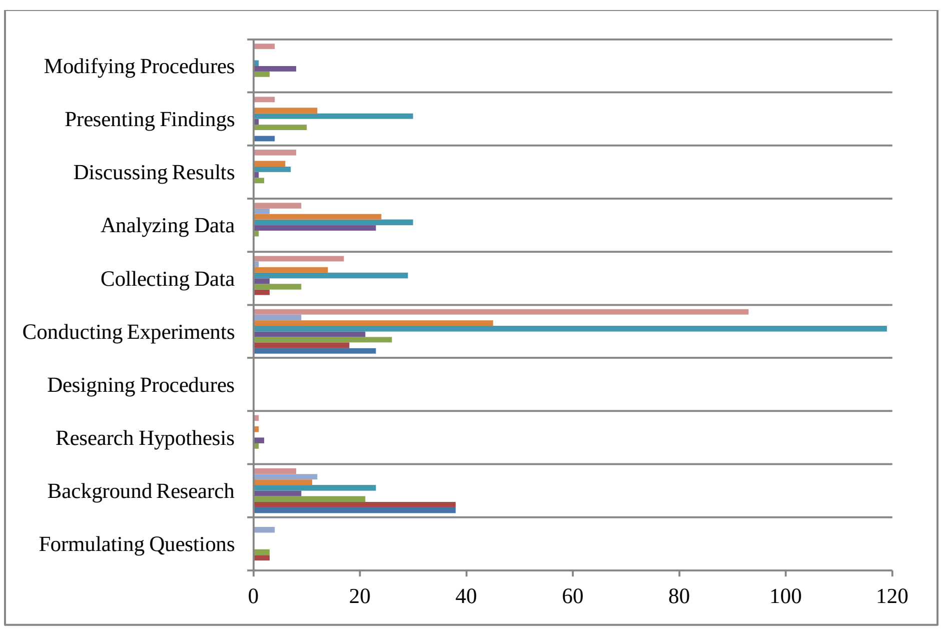

Figure 12. Frequency of sentences in each category in the blogs written by teachers during the research program

find much expression were research question, hypothesis, discussing results, and modifying methods. There were no statements pertaining to designing procedures.

The themes that emerged from the teacher blogs are enumerated below with best examples of statements made by the teachers, giving evidence of the kind of real science experience they had at the four different research laboratories.

Theme 1: Research question. Teachers had experience with listening to how the student researchers had decided on their research questions. They however, did not write anything about their own research questions.

Emily wrote,

> Jim's quest was to figure out how to dissolve the silk, to unfold the protein, yet keep the chain intact. He had read about this class of solvents known as ionic liquids, a liquid below 100 ºC, that can dissolve just about anything. So he made an ionic liquid and gave it try with the silk, it worked.

Wendy wrote about her conversation with one of the ASU graduate students regarding their research on determining the effect of tarantula venom on cell membrane,

> Talked with Lynn about the tarantula venom research project (*sic*). Electrical impulses are used to extract venom from anesthetized tarantulas, the venom is then analyzed by NMR to determine the protein structure (*sic*). The venom will be used to determine its effects on cell membrane.

Brad wrote about his conversation with the ASU graduate students regarding research on figuring out the nature of interaction between the cancer cells and the protein surface,

> Further studies will be needed to show if the cell is simply separating from the proteins on the surface or if the surface proteins are being ripped away. This experiment will require the unique setup in this lab, where the surface proteins will be marked with florescent dye. They will only appear if they are on or near the surface, so they will not appear if they are being ripped away from the cell. The unique setup should be able to show if they are being ripped away, and if the time intervals they are being ripped correspond to the sudden jumps in the graph.

Theme 2: Background research. Four teachers wrote about spending time on reading research articles.

Emily wrote, “I spent the morning reading and researching more about waves, electromagnetic waves, lasers, diffraction, and such.”

Wendy wrote, “Read articles by Janice Edgerly-Rook, a professor from Santa Clara who is an expert on embiids.”

Brad wrote, “Olaf gave me an article that explains it well that I will read tonight.”

Stacy wrote, “This morning we basically had time to review literature that might be helpful to our project. The papers we were reviewing described the production of Germanium nanodots.”

Theme 3: Formulating hypothesis. Wendy had a discussion with Lynn regarding the tarantula venom research project. They talked about the possible use of venom in the medical field. They were working towards a hypothesis that the venom has the ability of entering the ion channels in cells. This research had the potential of breakthroughs in treatment of diseases. She wrote, "It is thought the venom makes the sodium-potassium channels very permeable to the venom."

Lucy wrote, "They hope to find a trend of elasticity across the cell lines."

Theme 4: Experimental procedure. Patsy wrote,

> Jim came and was very helpful. We decided that I will work on Solubility of Spider Silk in Ionic Liquid (*sic*). I will try and dissolve the protein in the spider silk without hydrolyzing it. I am going to use 1-butyl-3-methyl imidazolium chloride or BMim+Cl-. We had a tour of his work-station and he showed me where things are and what I can do. … I worked with Jim trying to get a more homogeneous appearance of our sample from yesterday. I subjected the entire system to vortex four times for 3 seconds at a time but it didn't work. I have to leave the system again in the sand bath. Then I worked with Yin on solid state NMR. I put spider silk in the rotor. I used a 3.2 mm rotor, which can spin at 25 kHz. I learned how to put the rotor inside the probe.

Jack wrote, "I was an active participant in lab today weighing out the reagents for the preparation of the nanoparticles."

Wendy wrote,

> Today, we anesthetized a female embiid and attempted to silk her, but did not have much success. She produced a few short, small fibers, but we were unsuccessful in collecting them in a large enough mass for them to be useful for NMR analysis.
>
> Also cleaned out a bunch of the old black widow habitats from last year to make room for moving some of the Argiopes from the smaller cup habitats into larger domains (*sic*). We also anesthetized one of the Argiopes and silked it. These larger spiders take much longer to anesthetize than the black widows, but are much easier to tape down for silking because of their long legs.

Brad wrote, "Today we scanned images of DNA samples using AFM. Parts of the process included preparing DNA samples, loading and preparing the AFM and then running the scan."

Lucy wrote,

> We first looked at a picture taken of some fluorescent beads that is 10 microns in diameter. Next, we diluted some DNA and dyed it with YOYO, which is a fluorescent dye. The DNA needs to be diluted so that we can see individual strands of DNA instead of a mess of DNA spaghetti stuck together. We have to fix the DNA onto mica. HEPES buffer was added which contains Ni ions. The Ni ion binds to the mica and holds the DNA onto the mica. We

could see the fluorescent DNA under the eyepiece of the microscope.

Theme 5: Collecting data. Wendy wrote,

> Helped with the silking of the new Argiope spiders. … Even though this shipment of spiders came in only four days ago, most of them have already produced elaborate webs, with the characteristic zig-zag lines. They produced large amounts of silk today, and seemed to enjoy their meal of headless crickets while being silked. Also learned how to measure the mass of spider silk samples, then (*sic*) measured the mass of 15 black widow and Argiope silk samples.

Lucy wrote,

> Today, Kelli and David are looking at the data of the precancerous cells that they had collected last week. They probed 4 cell lines with cantilever tip to measure how elastic each cell was. They measure elasticity by indenting the cell with the tip at various regions, especially over the nucleus. The cells auto-fluoresce so they can view the nucleus, nucleolus and cytoplasm easily.

Theme 6: Analyzing data. Jack wrote,

> We ran the UV/Vis for the 50/50 copper that my partners had synthesized last Friday. We are concerned that we saw a strong silver peak at 400nm and no copper peak at 560 nm although we know copper was present in the initial solution. One possibility is

that the copper particles are so small that they are scattering or refracting the light and they are not showing up on UV/Vis. Is the copper nested in a cluster of silver? Is the copper coating on the silver cluster too thin to register as its getting overshadowed by the silver peak?

Brad wrote,

> Today, Van was trying to show that there is a consistency in the cell's adhesive force. The graph shows the force vs. height of the cantilever. The sudden jumps correspond to parts of the cell losing adhesion with the surface, being ripped away.

Lucy wrote,

> Today, we watch Andy repeat his experiments on precancerous cells to get more data on the elasticity or softness of the cells. Basically, you indent the cell at various points with the cantilever tip and pull back the tip and look at the force graph that is plotted. A gentle slope means that the cell is soft. A steep slope means that the cell is more rigid and less elastic.

Theme 7: Discussing results. Jack wrote,

> It turns out that our spectra showed that the Cu and Ag were not forming alloys. This is a little frustrating not only because it didn't work but, because I had mention to my group that Dr. Lowry had told me that an alloy is indicated by an intermediate peak not two

> separate peaks and I let them convince me that this was not the case. Oh well.

Stacy wrote,

> As we discussed our AFM pictures with Kim and Yin we came to the conclusion that on the pictures we could see little white dots. Yang said these dots were too small to be dust particles. She used the software to measure the dots and they were 2nm high and 20nm wide. The longer we discussed it was determined that the only conclusion was that the white dots were indeed vanadium nanodots.

Theme 8: Presenting results. Stacy wrote, “Franz presented his data for his work with diamonds. He presented a few a few graphs and his data nobody in the group really had anything to say but Dr. Lowry said he thought the data looked really good.”

Grace wrote, “This morning we were invited to a presentation about how one group of researchers successfully altered silkworms to produce *spider* silk. The presentation was very detailed, and largely concerned molecular biology…”

Wendy wrote, “The entire MSTF group was invited to attend her formal presentation, which was fascinating. Very high-level cutting edge molecular biology (*sic*). Another part of the authentic research experience that I am so grateful to have experienced.”… Attended a theses presentation by two masters' of natural science students (*sic*). Interesting research they conducted on the impact on single gender groups in physics classes. Based on their results, and other similar research I have read, it does appear that females perform better in math and science when they are in all female groups.

Theme 9: Modifying Methods. Jack wrote,

> It looks like O_2 infiltration may be oxidizing the Ag and Cu before they can oxidize. We will have to brainstorm today as to ways to prevent that.
>
> Today in lab we decided to make stock solutions of the silver and copper nitrates in a variety of ratios and it will improve our using. This will allow us to speed up production of several different alloys of varying ratios, it will allow us a greater variety of ratios and will improve our precision (*sic*). Difficulty is we did not have enough millipore water to make two liters of solution (*sic*). Also we are ordering smaller needles that may help prevent oxygen infiltration. … I am starting to think however, that the problem is not oxygen but the timing. Our samples have sat for 24 hours or more before being tested. This may be giving the particles enough time to ripen causing instability in the alloy. We are preparing to run some test right after particle formation tomorrow. If we are correct we should see alloy tomorrow. …This week we have seen real progress. We gathered what data we could on copper, but soon found out that an alloy between copper and silver is thermodynamically not favorable. A recently published article

from another university confirmed this. Therefore, we have switched to using palladium and silver.

Wendy wrote,

> So far, the embiids have not been successfully silked in the same manner. Today, we anesthetized a female embiid and attempted to silk her, but did not have much success. She produced a few short, small fibers, but we were unsuccessful in collecting them in a large enough mass for them to be useful for NMR analysis. We will continue to work on silk collection methods. The easiest way to collect large amounts of silk is to remove sections of the embiid silken tunnels, but these end up having lots of detritus embedded that is difficult to remove… Also, will bring in Woolite detergent to test how well it cleans embiid silk, which is much dirtier than spider silk collected on a glass cylinder.

Lucy wrote, “Aaron wants to test another way of drying the sample. It is an ACE duster moisture-free for cleaning computers. It contains tetrafluoroethane, which is heavier than air. He intends to spray some of this gas onto samples in petri-dish.”

Stacy wrote, “The consensus was that if we had had time to anneal them longer or at a higher temperature we would have seen larger dots and a larger population of dots.”

Poster analysis. I conducted a coding analysis of the posters to look for real science features. I coded each sentence in the posters according to the different real science components. The analysis of the posters revealed that all the teachers included some information about the experimental procedures and collection of data in the research labs. However, none of the posters had sections on designing procedures or modifying methods (Figure 13). The figure depicts the frequency of sentences on each of the real science features emphasized by the teachers in their posters.

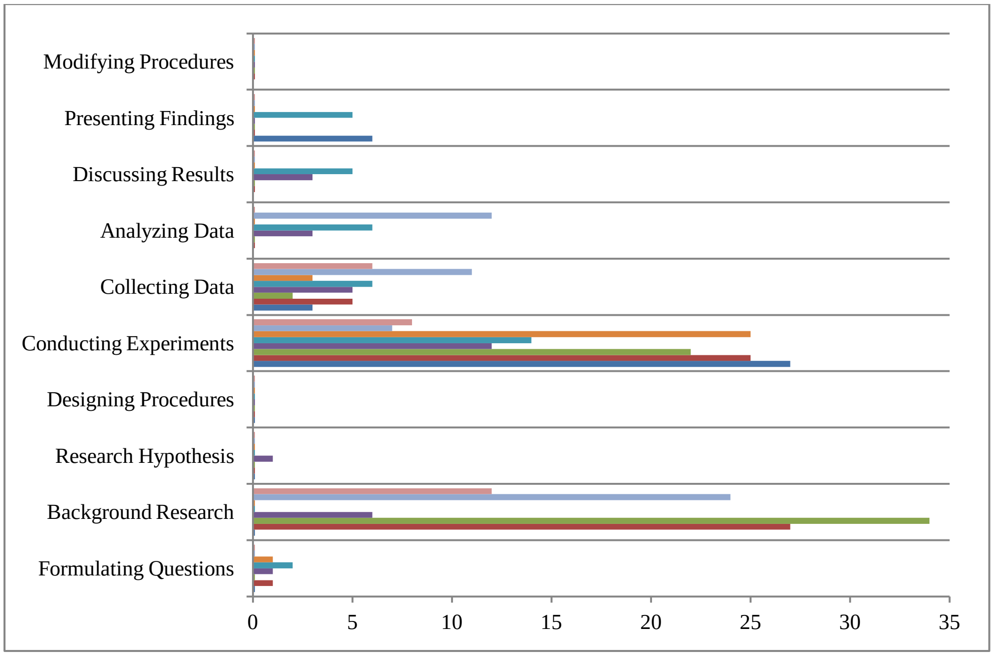

Figure 13. Research laboratory activities highlighted in the posters

Given below are excerpts taken from the posters on themes that were evident. I have selected the best examples from the data to give a sense of the real science features highlighted by the teacher.

Theme 1: Research question. Teachers that worked on a research project had questions based on the research questions, whereas Emily, who was not assigned to a research project, based her question on her curriculum project.

Stacy recorded, "The goal of our experiment was to create vanandium nanodots on the top of silicon wafer. Though nanodots have been achieved in germanium they have not yet been seen in vanadium."

Emily recorded, "How are atoms arranged?"

Theme 2: Research background. The teachers had to read literature in order to understand the working of scientific instruments in laboratories. They were given journal articles to read about ongoing research in the laboratories. Some teachers like Emily searched the web to understand terminologies related to their curricular projects.

Brad recorded,

> Atomic force microscopy, or AFM, is a type of scanning probe microscopy. With AFM a very small, sharp probe is scanned across a surface, and small deflections of the probe are measured to detect changes in the topography of the surface.

Emily recorded,

> Electromagnetic radiation (EMR) is energy, in the form of a photon, released by atoms. Photons travel in oscillating electronic and magnetic fields that move as waves. Duality refers to the idea that EMR exhibits wave-like and particle-like behaviors.

Theme 3: Research hypothesis. The research hypothesis that teachers wrote about was actually formulated by the researchers. Only Jack wrote something about the research hypothesis in his poster.

Jack recorded, “It is hoped that by producing nanoparticle alloys of metals, we can produce a more stable nanoparticle and produce smaller nanoparticles than is possible with pure metals alone.”

Theme 4: Experimental procedures. Teachers that worked on assigned research project, wrote procedures that they followed in their experiment and teachers that only observed, wrote the procedures that they observed being followed by the researchers.

Jack displayed the following experimental procedures:

> Step1: Dissolve compounds containing metals of interest
>
> Step2: Add capping ligand and bubble with nitrogen
>
> Step3: Add a reducing agent
>
> Step 4: Purify/ visualize with UV-Vis or XRD.

Brad recorded,

> The AFM can be used to find the adhesive forces between cells and specific proteins. The cell is fixed to the end of the AFM tip and then placed on a surface that has been prepared with proteins for the cell to bind with. The AFM tip can then be retracted, pulling the cell from the surface until it is detached completely. The resulting data reveals information about the adhesive force between the cell and the binding proteins.

Theme 5: Collecting data. Teachers like Brad wrote about how the researchers were collecting data in his laboratory while the teachers working on assigned projects wrote about how they had collected their data.

Brad recorded,

> This image was taken using AFM. The original image is created by using shades to represent heights from the surface (*sic*). The image is then enhanced by using software that filters out background noise and creates a colored representation (*sic*).

Stacy recorded, “Base line data was taken after the sample was cleaned in the oxygen plasma chamber and data was again taken after the sample was annealed.”

Theme 6: Analyzing data. Stacy recorded, “The sample was analyzed using X-ray photoelectron spectroscopy (XPS).”

Brad recorded,

> The curve is a force vs. depth graph. The slope of the graph represents force per unit of distance pushed or the “squishiness” of the cell. In general, as cells progress from normal to precancerous to cancerous, they become increasingly squishy (the slope is less steep.)

Theme 7: Discussing results. Stacy recorded,

> •Increase in oxygen peaks could indicate oxidation of vanadium. This is due to the imperfections in the vacuum chamber.
>
> •Decrease in silicon peaks is probable due to the vanadium oxide covering up the silicon signal.

Jack recorded,

> Particularly in our early experiments with silver/copper alloys, the oxygen would react very quickly with our copper particles and return them to their ionic (copper II) state that is soluble. Destroying the nanoparticles. … For example, silver nanoparticles have a strong absorbance peak between 380 and 400 nm.

Theme 8: Presenting results. Stacy recorded,

> •Small white dots appeared measuring 2nm in height and 20 nm in width.
>
> •The white dots are to small to be dust.
>
> •The only explanation of the white dots is that they are VANADIUM NANODOTS

Patsy displayed graphs of the results that were found by running samples of an experiment that she had helped a student researcher set up. Figure 14 gives an example of one of the graphs that she had displayed in her poster.

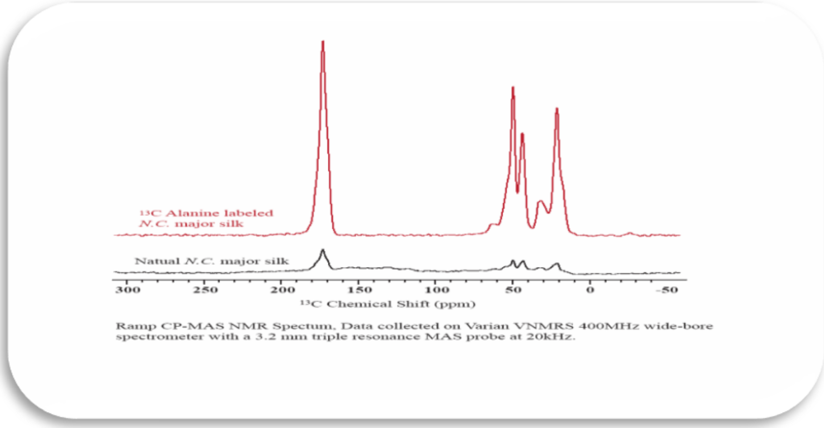

Figure 14. Solid-state NMR results displayed in Patsy's poster

Laboratory observations. During my laboratory observations, I found some teachers conduct research themselves while the others observed research. Three teachers were actively involved in real research. Five out of the eight teachers were mostly involved in observing the ASU researchers conducting research. Given below are the themes of real science that I observed in the laboratories.

Teachers involved in real research. Four teachers that were placed in the nanoparticles and the nanosurfaces laboratories were involved in conducting real science under the guidance of the researchers.

Theme 1: Background literature. I observed the following activities in the biochemistry laboratory: The laboratory director provided the teachers with materials such as journal articles, videos, and website links with information on the research topic. The three teachers Emily, Wendy, and Patsy spent time on reading literature, watching videos, and listening to student researchers talk about their research projects.

Theme 2: Experimental procedure. Wendy prepared a sample of the embiid habitat in a jar for her classroom. She worked with some researchers in silking some spiders. Patsy conducted a trial of the experiment and monitored the dissolution process. She also worked with another student to understand how to prepare a dry sample of spider silk in the rotor. At the nanoparticle laboratory, I found Jack actively involved in setting up the reaction between silver and copper and monitoring the reaction proceed towards formation of an alloy. At the nanosurface laboratory, I found the teachers Stacy and Grace actively involved in preparing the sample before it was ready to go into the vacuum chamber. I observed how meticulous they had to be in setting up the silicon wafer onto the holder. The wires that held the silicon wafer had to be delicately twisted so that it did not crack the wafer. They went through several trials to get one good sample setup. The experiment had multiple steps. Once the sample was ready, they inserted it into the vacuum chamber for the first step of the experiment. On some occasions, the teachers went to the laboratory in the evenings and returned back early in the morning to get the experimental process running.

Theme 3: Data collection. Wendy collected some observations of the embiids and the spider habitat. She engaged in habitat maintenance.

Theme 4: Data analysis. Jack was involved in analyzing the graphs that were displayed on the screen after running the sample through the UV-Vis. The teachers made a few comments on the peaks of graphs obtained from the microscopes on the computer.

Theme 5: Discussing results. Jack was actively involved in the discussion about the peaks that were obtained by running the sample through UV-Vis. I found Jack giving his input on the results obtained. It looked like the researchers were working with the teachers as a team. He was involved in an excited discussion with the researchers when they visited the poster presentations.

Theme 6: Presenting results. During the poster presentations, two teachers Stacy and Jack shared some results from the experiment that they had conducted. Two teachers Emily and Brad presented some results on experiments that they had observed.

Teachers engaged in observing real science. Five teachers that were placed in the biophysics and the biochemistry laboratories were mostly engaged in observing real science conducted by the researchers with a few opportunities of participating in the research.

Theme 1: Research question. At the biophysics laboratory, a student researcher was presenting a research question that she had formulated. She wanted to study the magnitude of jump in the cantilever tip of the atomic force microscope on different cell surfaces. She was explaining why she was interested in that study. The teachers, Lucy and Brad were listening to her and asking questions to get a better understanding about her research interest. At the biochemistry laboratory, Jack was engaged in a discussion involving changes to the research question of their study based on the results they obtained in the previous experimental trials. Stacy and Grace presented the research question that they were experimenting in their laboratory. However, the teachers did not have to formulate their own research questions. The teachers that were assigned to specific projects were given research questions and the remaining teachers just listened to the student researchers discussing their research questions.

Theme 2: Experimental procedure. At the biochemistry laboratory, the teachers, Emily, Wendy, and Patsy observed three ASU researchers demonstrate their research activities and explain their research. One researcher demonstrated the working of the Raman Spectroscopy and how certain wavelengths of light are filtered out and the rest scattered or dispersed onto a detector. Another researcher demonstrated the working of the diamond anvil cell and how it allows compression of a small (sub-millimeter sized) piece of material to extreme pressures, which can exceed 3,000,000 atmospheres. A third researcher gave a demonstration on how he was trying to dissolve spider silk in an ionic liquid to unfold the protein structure while keeping the chain intact. He went through the process of dissolving the spider silk in the ionic liquid. The idea was to study how the protein structure is folded in the silk, which would then help create a synthetic spider silk. At the biophysics laboratory, the teachers Brad and Lucy observed the researchers running samples through the atomic force microscope and the confocal microscope.

Theme 3: Data analysis. At the biophysics laboratory, the teachers observed the researchers analyze data obtained by running samples through the powerful microscopes.

Theme 4: Presenting findings. On one occasion, the teachers at the biochemistry laboratory met a visiting professor. The professor presented her findings on spider silk research and the teachers engaged in discussions with her about her research.

Teachers engaged in planning for curriculum unit, posters, and blogs. Emily was trying to get some materials for her school project from the pressure and the spectrometry laboratory. A student researcher made her a video of the different phases of water under extreme pressure. Emily spent most of her laboratory time on collecting information for her curriculum project on the Internet and from the researchers. On one occasion, the laboratory director delivered a short lecture on the mathematical calculations that were involved in her project. She conducted a trial run of procedures for the project she was planning for her students. Patsy and Wendy were working on posters, blogs, and lesson plans on some occasions. On one occasion, I found Brad absent in his laboratory and he later explained that he had decided to work on his poster because the student researchers were absent on that day. Lucy was working on her poster in the laboratory. During a laboratory visit, I found the teachers at the biophysics laboratory (Stacy and Grace) working on their posters and lesson plans.

To sum up my visits to the research laboratories, I found teachers mostly involved in carrying out experimental procedures. Only four out of the ten real science features were more evident (Table 4). Although I found teachers going over results from experiments they ran themselves or observed the researchers run, I did not find them engaging in rich discussions with the researchers.

Table 4
Evidence of teacher's conducting real science during the research experience

	Wendy	Emily	Patsy	Jack	Stacy	Grace	Brad	Lucy
Formulating questions								
Background research	√	√	√					
Formulating Hypothesis								
Designing Procedures								
Experimental Procedures	√		√	√	√	√		
Collecting Data	√							
Analyzing Data				√			√	√
Discussing Results				√				
Presenting Results		√		√	√		√	
Modifying Methods								

Teacher Supports and Barriers

In order to answer the fourth research question (What evidence do we have regarding the supports and barriers teachers had in transferring real science experience to the school settings?) I analyzed the program applications, transcribed audio of the afternoon sessions, field notes, blogs, lesson plans, and interviews to look for themes pertaining to support and challenges.

The support that teachers received from the research program in terms of transferring real science into the classroom were in terms of laboratory materials, discussions on curriculum ideas and nature of science, lesson plan template, and training on using Excel. Evidence of these can be found in the discussions, field notes and blogs.

Support with ordering curriculum materials. Teachers received some funds from the program to purchase materials for their classroom. One teacher ordered materials specifically for the research project. Other teachers ordered general classroom materials, which they were also planning to use for their project. The materials the teachers ordered and their justification for use with MSTF project or in the classroom are given in Table 5.

It is evident from the material orders that only Patsy had requested materials specific to a real science project. However, she did not implement the lesson in the classroom due to various circumstances mentioned above. The other seven teachers ordered materials for general improvement in classroom instruction. Some of those materials could, no doubt, also be used for real science projects, but the others did not seem to be relevant for real science projects. For example, the projectors could be used for student presentations and discussions of experimental results, whereas the shredder did not seem to be a useful item in doing real science. A couple of teachers used their own funds or department funds to purchase materials that were not very expensive. One teacher used personal funds. Another teacher used department funds at her high school to purchase materials she needed for her lesson. One teacher received materials he needed for his lesson from his placement laboratory at ASU.

Table 5
Curricular materials ordered by teacher participants of ASU MSTF 2010

Teacher	Materials ordered	Justification	Project specific
Wendy	Snow leopard computer operating system, laser pointer, markers	Snow leopard will increase the operating capacity of my computer, which will enhance its usability in the classroom. The laser pointer will be useful in classroom presentations, and the dry erase markers and erasers will be used with the individual student white boards for interactive classroom activities.	No
Emily	Battery charger, rechargeable batteries	Laser pointers and calculators all require AAA batteries to operate.	No
Patsy	Discovering polymers kit, Silk products kit. Camera, camera case, memory card, battery charger	(Not included)	Yes No
Jack	1. Webcam 2. Screen flow 3. Document scanner 4. External hard drive 5. Flash drive	1. Will be used with screen flow to capture classroom activities and discussions and convert to movie format to help improve teaching and to create video for absent students or for review 2. This software will be used to create videos of classroom activities for teacher improvement (RTOP) and to make movies for student review and for absent students 3. Will be used to scan student work and documents to help classroom organization and grading by automatically scanning and organizing work 4. Will be used to store video of class, classroom documents, and samples of student work 5. Will be used to store classroom video and documents	No No No No No
Stacy	(Did not order)	(The material she used for her class project were inexpensive (memory wire) so she did not use the program budget)	
Grace	Projector and Projector Lamp	For my MSTF lesson, I will use the projector to display all of the following for class discussion: Student data, real time graphs generated by a motion detector, classroom handouts, and directions for using both Excel and Logger Pro. I will actually use a projector (beyond just my MSTF lesson) on a daily basis in my classroom and do not currently have one.	No
Brad	Camcorder and memory card	Will be used to record the in-class portions of the engineering process. Will be used to record students work as well as help teacher access the success of the project.	No
Lucy	Printer and Shredder	Printer is used to print worksheets for the students. Shredder is used to shred papers for students to make 3D solid objects for their classroom AFM	No

Support from laboratories regarding curriculum plan. Some teachers received help preparing their lesson plans and obtained materials from their respective research laboratories to use for their curricular projects. Evidence of that can be seen in the blogs and field notes. There was evidence of support provided by the laboratories in an interview with the director of the biochemistry laboratory.

Dr. Lewis talked about ways in which they were available to help the teachers. He said,

> I always let every teacher I come in contact with know that we are federally funded and one of our mandates is broader impact. One of the best broader impacts is to, you know, educate young people in science, technology and engineering. So, I feel it's one of our, you know, duties to get back. Anytime we get any scientifically developed project we try to do that. It can be as simple as finding them substances that are hard to get—or training on how to use those—to doing the demos—or so—like that. …One of the things I communicate when they first come in, and one of the things I communicate when they last leave is that, one of the indelible things they can get from working with us is the connections they make—not only to me but students etc.—but now that they have met some people in the university and know some of the resources we have—then they can email us and say, "Hey, I would really like to do this demo—I can really use this reagent or this chemical—is

> there any way I can get this?" or further help, "I am not comfortable doing this demo, because it involves chemicals that I don't want to house or do myself—would you or some of your colleagues come and do a demo or give an example or something?” and usually if it is once a semester, we can find somebody to go and do the demo for them.

Here are some excerpts from the blogs regarding the kind of support that the teachers received.

Emily wrote,

> I was also able to use the big microscope to measure the distance between the dots on the optical transform slide. This data will be used to check my work with the diffraction activity I will have the students perform. Tuesday I meet with Dr. Lewis to review the questions I have about my class activity and get the details of that nailed down. On Wednesday I will meet with Kathy, a student of Dr. Lewis, to make the film of water under high pressure for use in my classroom.

Patsy wrote,

> Dr. Lewis also came and gave us a quick lecture on Bragg's and Fraunhofer's law in relation to the laser activity that one of us is working on. I got samples of spider egg sacks from him. …Early morning, we had a short meeting with Gary and he gave us pointers on what we can possibly work on and how we can relate

> that to the classroom setting. … Dr. Lewis gave us possible ideas on how we can apply these research ideas to our classroom.

During my laboratory observations at the biochemistry laboratory, I found Patsy collecting some samples of the experiment that she had worked on to show to her students. Patsy received a sample of the spider silk dissolved in ionic liquid in a capillary tube, a dry sample of spider silk in a rotor, and some egg sacs from the laboratory. Those were samples that were ready to go into the semiconductors for analysis. Emily received an optical transform slide from Dr. Lewis for her curriculum project. She also had one of the student researchers prepare a video on the different phases of water under high pressure for her to show her students. All three teachers at the biochemistry laboratory received copies of videos on spider silk research.

Jack did not have the chemicals that were needed for his curriculum project on nanoparticles when he was ready to teach the unit during the school year. I offered to bring him some chemicals from the nanomaterial laboratory. When I contacted the researchers, they were very helpful and immediately arranged for the chemicals.

Mentor support. Every Friday the mentors Stacy, Jack, and Wendy conducted the afternoon sessions and discussed ideas on lesson plans, materials, and scientific discourse.

Discussion on lesson planning. In the first week of the program, the teachers were given a lesson plan template and explained the various categories. Questions and clarifications regarding the template were also addressed. During this session, the teachers exchanged ideas and shared their own experiences. They helped each other with nuggets of ideas that were forming in their minds about transferring the research experience into the classroom. There was evidence of discussions regarding lesson ideas. The excerpt below gives an account of one of the discussions that took place on a Friday afternoon. The teachers had a discussion on one particular lesson idea that the biophysics laboratory teachers were planning for their curricular project. The other teachers contributed with their own ideas on the topic.

> Brad: The researchers in our lab are working with a whole lot of different stuff with the Atomic Force Microscope (AFM). They are working on something different everyday so we were thinking of creating a macroscopic version of the AFM for the class that students could use to collect data and create images like the AFM did at the microscopic scale.
>
> Jack: You could take a large cardboard box, and a 1/4 in. or 1/8th in. dowel and put a grid of holes on the top. Put an object inside the box and have the students by the depths of the dowel try to sketch out what is inside the box. That could approximate the tip of the AFM."
>
> Brad: We were thinking about how the AFM has progressed over time and how they have done the imaging. We thought of putting a mirror on top of the tip that will deflect a laser beam based on the angle of the tip. The reflected laser beam can be projected on a

white board. As that tip moves up or down, students will be able to see the laser beam deflection compared to where it normally is and then they can get information about the height of the object. So they would scan across just like the real AFM does and it would give some topographical image that they can translate over many layers. They could then plot the points on X, Y, and Z coordinates and see how close they could get to what the actual object might look like. So, I thought that would be cool!!"

Grace: I have seen someone make 3D graphs like that on excel before.

Lucy: So maybe they can take their data and put it in there to see what it looks like.

Jack: If you want to know Excel you should talk to Dr. Young because he can do some amazing programs on Excel within minutes.

Grace: That would be cool!

Brad: I think that would translate pretty well at the macroscopic level because that is how the AFM actually works. The computer is actually doing all the calculations based on the angle of deflection. So students can take the same concept and create their own images of what they think the object looks like and in the end see what the real object looks like to see how close they could get to the real object. If I could figure out how to set it up it might be a simple thing that could actually be done in the classroom.

Lucy: You see you can project the image into a vertical thing and different deflection gives different height, so they can plot a graph of the height vs. the deflection. That way they can get the magnification of the height of the object. They can use geometric figures like a square, pyramid, or a cone. Then they do a y-scan. Based on those two they can more or less figure out whether the object is round or flat.

Stacy: You know something you might be able to use for the reflection—this reminds me of something I was shown for a different lab—they were trying to do indirect measurement and again kind of figuring out the shape of object with the help of a laser beam. It is kind of the same theme but it was used for a different idea. What they were using to reflect was plastic mirrors that you can find. But, they said the way they got them was they called the plastic companies that make them and ask for scraps, and they said they got them really-really cheap, and then you can cut them into really thin strips and then help to deflect really easy and nice, instead of a foil or something. It might be able to give a really sharp reflection.

Jack: Yah, you don't want to use foil because foil would give you a scatter.

Lucy: You could take a very flexible ruler for the cantilever and put a one square inch mirror as the reflector.

Stacy: Yah, so the scrap pieces will be really cheap.

Lucy: Oh yah!

Brad: Then the other thing for my curriculum teaching. They were saying the first atomic force microscopes actually used electro potential to actually measure instead of actual optical laser or something like that. They were actually looking at differences in potential as this thing would come closer to the surface there would be an interaction before it actually touch the surface because they were causing force and things like that they could measure. So, I don't know if that's something we might be also able to set up as well on a macroscopic scale where it is not optical—you are following a beam but you are actually able to measure potential differences between the surface. You have to have a surface that is charged.

Lucy: That is too complicated for the kids.

Brad: So that's what we were talking about. Since that's the only common theme amongst all the experiments they are doing in our lab.

Jack: Another idea that I think is easier to reproduce and a little harder to get data from is taking a piece of plywood and building a geometric shape at the bottom of the plywood. The students can roll the tennis balls underneath and get the angle that it bounces off. So, if the angle of incidence is equal to the angle of reflection, they can figure out what angle that surface is at. So, then they can get the shape of whatever. If you put an octagon or whatever shape by looking at the way the ball reflected out of there, knowing that they put it in at 90 degree and it reflected out at this angle.

Discussion on project materials. While talking about the same lesson, the teachers also discussed the kind of laser that would work best for the project. Here is an excerpt from the group discussion that the teachers involved in on that same occasion:

Jack: It's probably easier with the lasers. So if you have enough lasers.

Brad: That's one thing I want to get. I mean I don't think they are that expensive—just red lasers.

Jack: I go green

Emily: I just found them online on Staples for $20 a piece.

Brad: We cannot use Staples as a vendor.

Emily: Yah, but they have it cheap.

Jack: If you go green you get a better visibility with the lasers. But they are a little bit more expensive.

Brad: I can go on e-bay and get a blue laser for like $60.

Stacy: The guy that I saw doing this with the red lasers, he said that he bought the little one, the ones that you use for the cap—the little one dollar ones. Then he made little holders for them. He says, “though they run out, they work really well, and they last for a few years and then you buy a new one—because they are a buck, it's cheaper than buying the $20 one—because how many can you get out of it”.

Brad: We were going to buy some anyways because I have a lesson that compares X-ray diffraction to light diffraction. But you need to have really nice lasers in order to do that.

Jack: You got the budget, so you might as well use the budget to buy the lasers.

Kelli: Use the budget to buy the lasers.

Lucy: Oh yah, I can use that money!

Brad: That's what I was thinking. That's why I was saying you might want to buy the better ones when you have the money. That way you have them around for a while.

Stacy: Yah, if you have multiple purposes for them.

Patsy: You cannot use certain lasers.

Brad: Why not?

Patsy: It's dangerous.

Brad: Is it really!

Patsy: You are only allowed up to class two. (She verifies with Emily) Class 3A right. 3B is not allowed—green lasers are not allowed.

> Emily: No, green lasers are allowed! The class has to do with the wattage that is coming out.
>
> Brad: Yah, the intensity of the beam not the wavelength.
>
> Emily: The blue one is new. I was reading it on Wikipedia. They have a blue one now, and a purple and violet.
>
> Stacy: Look at the blue ones, because some of the blue ones give out a violet light.
>
> Emily: Right, the problem is that. And you can get it to give the right color and the right wavelength at a low enough intensity.

Reflections in blogs. The teachers wrote some reflections addressing what they thought about sharing lesson ideas in their blogs.

Grace wrote,

> Current fellows also shared the ideas they have so far about how they plan to implement the research into their classrooms. Ideas are already rich and varied. Most fellows agree that an exact copy of the research is impossible to implement in the classroom. Therefore, there was great deal of discussion about how to translate the experience into something understandable by our students. Adrian presented a great idea about having students *simulate* the process of using an Atomic Force Microscope, which spurred a great discussion on how to do so.

Stacy wrote, “It was interesting to hear what everyone has come up with for his or her classroom. It sounds like everyone has a pretty clear-cut view of what they want to do and they all sound like great ideas.”

It is evident that the teachers had some rich discussions regarding lesson ideas, the kind of materials they could use, and ways of procuring the materials for their students. The mentors were helpful in sharing ideas and experiences with the new teachers. However, teachers did not spend much time in engaging in such discussions or actually planning the curriculum during the afternoon sessions. The pie chart in Figure 15 indicates that the organizers allocated only 16% time for curriculum planning and the remaining for other activities.

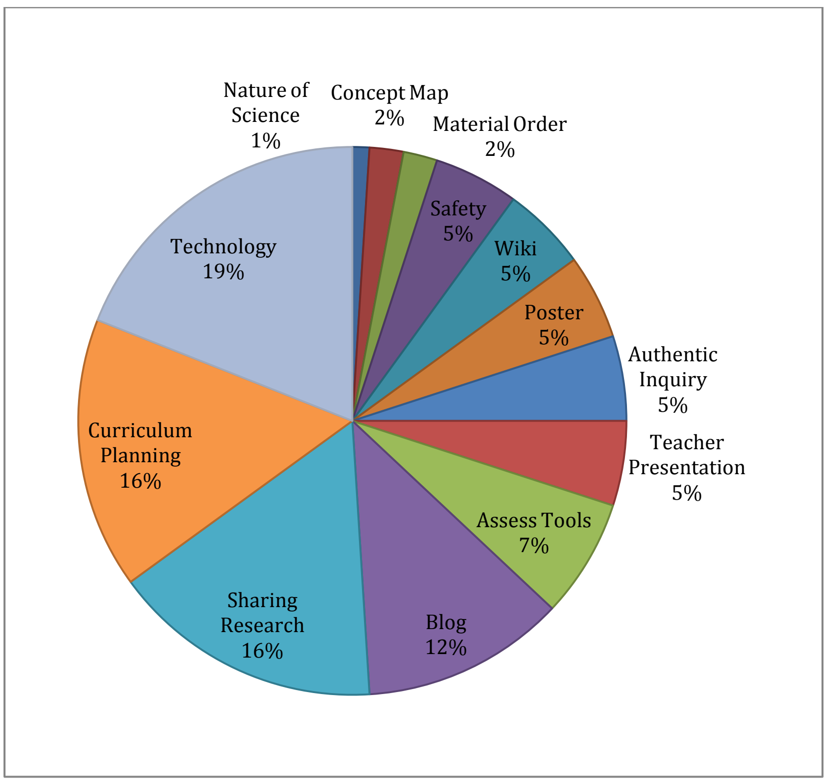

Figure 15. Distribution of time during the afternoon sessions at ASU MSTF 2010 research program

The reason why the mentors were given the responsibility of conducting the curriculum component of the afternoon session was related to what Dr. Young explained in his interview. He said,

> …So, we want the other teachers to be informed about research—so we had a component that talked about research, but the rest was going to be on how to take back to the classroom—so we took an approach of how to develop curriculum—that's what we initially started with—so initial sessions were about developing curriculum and that involved nature of science—and each year the feedback I was getting was a lot of teachers resented and didn’t like to be told how to develop curriculum, because they felt that they already knew how to do that. Whether it was right or not—I think in some cases it was and in some cases it was not—but I decided to go with the flow.

This gives the evidence that Dr. Young was not very comfortable with conducting the curriculum component and decided to have the mentors conduct the curriculum planning sessions.

Discussion on nature of science. The mentors engaged the teachers in discussions on the nature of science and authentic inquiry, which led to sharing some laboratory experiences and their possible transfer into the classroom. Here is an excerpt from one of the afternoon sessions:

Interpreting same data differently.

Jack: I think that was one of my greatest experience this summer was when we had something flop on us and we couldn't do anything for the rest of the day. We argued and we hashed out. Okay, why is this not working? What is going on? We must have had 7 or 8 or 9 different hypothesis by the time we walked out of there. Again, you want to try all of them—but you have to say, "No we are going to try this one and you all have to agree on this one." So, we sat around for four hours and shot ideas back and forth, and then even went through an email discussion. I was getting emails 8:30 or 9:00 at night—what if we try this—or what if we try this—that is something that kids don't normally do—because a lot of what they do—even if they do inquiry—at some point or the other it ends up being more or less, compared to what we are doing here, is cookie cutter—because you are going to a certain—you know where you are going with it—with this, you don't know where you are going with it. So, that's where every possibility then becomes a valid point. So, that's something, if we could somehow get to our kids, then that's the most valuable thing.

Observations and interpretations.

Stacy: I thought when you talked about the discourse. One of the students, yesterday, has been doing research and data—and kept having one problem—and he could not figure out what was going on. Every single person in the group is contributing to—why this problem might be happening. Some of the ideas that came up was—kind of amazed me—things like—the fact that he had to wear his gloves when he is handling the sample. They were—"Are you touching door handles with those gloves and then touching your sample, because then other people may not have been wearing gloves when they touch the door handle. Then you got the hydrocarbons from their hands to your gloves, and then you touch your sample." Things like that, you may not have thought about. Then somebody else thought of a point that—those gloves—when some manufactures make them—they use a release—an oil to release them from the molds. And some manufactures clean that oil off and some don't. If they don't clean that oil off, they may have hydrocarbons on them. That is, maybe, where some of the contamination is coming from. It is so funny, like—how different people have all these ideas, that one person did not have all that. So, that's all the kind of stuff is—that I want to work in. So, my little nugget of curriculum that I am thinking of right now is—I have this week long—like, I have not assigned to anything as yet—I always have my kids do a project—that is going to be my week for this project—that I want to do a nature of science project—that I am going to devote to this week, and I think, I am going to put somewhere in there a lot of what we learn about nanoscience—but a lot of it is going to be nature of science type stuff with nanoscience involved. I just don't exactly know how I am going to do all of that, but a lot of it is going to be nature of science—how do we sit around and discuss—talk…

Collaboration and competition.

Brad: Another fascinating piece of the research is that—so, is this like a unique set up—they are like, “No there is another group in Utah. They are also working on this same stuff and we don't know if they have done it yet or not. They have not yet published it. If we are able to do it, it might not mean anything, because they might have already done it—we just don't know that they have done it.” So, all might be for absolutely nothing—all those hours and hours of work that they have put into their research, because someone might beat them to it and then they are like—“Oh crap!”

Jack: We are not allowed to mess with—there funding might come from a different place or might be a university thing—where, if you are at ASU, you are not allowed to collaborate with what is going on there, because ASU wants the credit if ASU gets it.

Stacy: I am sure there are patent issues.

Jack: That's where, I was saying, if you go to the bio-design institute they are very careful about their lab-books, because lot of their funding comes from industry. If their research can be used by industry, they are not allowed to share them with anybody—it does not leave that building—they have things everywhere that say, “Guard your lab notebook. Put your lab notebook away.”

Brad: It is very non collaborative.

Jack : If you are funding you want to be the first company to get to that point.

Patsy: You want that patent!

Stacy: That's what is interesting about science in general. We talk about collaboration big time—but then on the other end, there is not collaboration.

Brad: It's really not like that at all.

Stacy: Well, inside your group, there is lot of collaboration—sometime within groups—within the university there can be big collaboration, but then also, there is this big competition. So, there is this two-fold thing going on—there is big collaboration and big competition.

Brad: I try in my class to set the atmosphere—like they will work in groups and I will tell them—like, if you get this first you get this grade—if you are the last group to get it you get this grade. So, they are working in groups but there is also that competition involved where they are competing against each other. So, I kind of set a mock thing where they are trying to get the same results within a group of kids—but they still have to be able to have this competition that there is in the real world.

> Stacy: What I found too is—like I was talking about my project last year—I wanted to create the collaboration within the classroom and when you have competition between the groups it is hard to create collaboration within them and again you have—kids need the competition to get motivated but you want to get the collaboration that you see in the real science world. So, I was trying to figure out how to reconcile the two things and what I ended up doing was creating competition between the classes—so I can get the collaboration within and competition between the classroom and when I did that, I got really good discussions within the students, like within student groups. I still had competition because they were fighting to beat the next class. The only way that works—if you have multiple classes of the same type of class—or you can work with another teacher—but again—that has to be that you can work well with that teacher (*sic*)—because I found issues with one of the teachers that I was working with—you have to find good ways of doing it.

It is evident that these discussions instigated teachers to think of ideas on transferring the nature of real scientific research in the classroom. However, only six percent time was spent on such discussions during the afternoon sessions (Figure 15). Jack mentioned during the debriefing session at the end of the program that he would have liked to see more discussions on the nature of science.

Technology support. A major portion of the afternoon session was assigned to computer technology and each teacher was given a laptop from the money allocated for classroom materials. The director of the program Dr. Young's justification for having the technology piece in the program was,

> Well, $2500 per teacher—that is a fair amount of money—and I had a couple of concerns about that—how would the teachers spend? Teachers who are perhaps not used to having any money—how would they find how to spend $2500? We wanted it to go to good use and I was also aware that technology competence of teachers was generally very poor—so I saw this as an opportunity to spend a good chunk of $2500 on teachers' behalves and buy them laptops. Then that would give us another feature for the afternoon session where we would introduce them to technology that they may not be familiar with, but technology that would be very useful for their classroom. I think that worked out pretty well. I think some teachers may have been not so much in need of a laptop—maybe they have a laptop, but they were obligated to get a laptop. The way we would run this thing it would consume a lot of their money. A laptop was $1300-$1500, I think, so that left them a $1000. So, some teachers may have seen it as—gosh! We could have had more money if we didn't have to buy a laptop, but in most cases it was worth it—so, it was kind of leveling off the field—so everyone had a good laptop for the afternoon sessions in whatever

> else they were doing—so, we can conduct things and everybody will be doing along with it.

Nineteen percent time was spent on learning computer applications during the afternoon session, (Figure 15). The training on the Excel spreadsheets was most relevant to real scientific research among all the different software applications introduced. The teachers found it to be a useful tool for analyzing scientific data and would have liked to learn more about Excel. We can find evidence of that in some excerpts from the blogs,

> Grace: Dr. Young led a session full of fun facts about Excel. He shared many ideas about how to utilize spreadsheets in the classroom, including formulas, animations, and grading. He also gave us many ideas about cheaper implementation of spreadsheets if we don't have access to Excel in our classrooms.
>
> Patsy: In the afternoon, we learned much about excel and things that we can do with it… The other excel functions that I thought were relevant to high school teaching are the graphs and plots… I would have wanted to learn to use excel in educational research and statistics such as interpreting what the results of my pretest and post test mean… T-test, z-test, probability and all those forgotten concepts that are applied to scientific interpretation of test scores (*sic*). I also wanted to know how my students could possible use excel in statistical analysis of their science fair projects (*sic*)...

> How do they know which statistical test to use to interpret their data other than mean, median, mode, and standard deviation?
> Stacy: Dr. Young shared his excel secrets with us. Some of them I already knew but there were a few little tricks that were of very interesting to me and I did not know how to do… You can add a second axis and many other formatting options to graphs in excel. I wish we had spent more time on how to do these.

Some of the other software tools like Google applications, Camtesia, Screenflow, V-Python, etc. that was introduced to the teachers was helpful in increasing their effectiveness in general classroom teaching. However, these software applications did not contribute towards transferring real science activities in the classroom.

Administrative support. Analysis of data shows evidence of some schools having more support than others. During my interview with Dr. Moore, I asked him about the kind of supports that are provided to the teachers so they can implement these kinds of experiences. He replied,

> Well, first of all, we have a professional development on campus. Also, I have a person called an instructional specialist (now they have a different name, Professional developer). I think that's the name, or professional instructional developer, that works along with the teachers if they need assistance. Then also, we have PLC (Professional Learning Community) where teachers can work together and plan with department heads or now called instructional leader—from our

> opinions back to the departments and also divide them up by subject area too. Like, all American history teachers together, all biology teachers together. Then also, we have a consultant teacher.

Emily taught her research unit for a length of eight days without any interruption from the administration. She also spoke to one of the physics teachers about building a diffraction grating that she could use for her lesson in future. It was evident that Emily had a lot of support regarding the implementation of her lesson.

Stacy's high school also was supportive of her unit implementation. She had the students put up a poster presentation outside the department and teachers were invited to come and give feedback on the posters that the students had presented. Some teachers came over, listened to the students, and gave their feedback.

Jack did not mention having any problem with inserting his unit into the school curriculum. He followed the modeling curriculum, which every teacher was not following in his school, so he had some flexibility in the way he wanted to do his lessons.

Barriers experienced by teachers. The teachers faced some challenges, frustrations, and disappointments in transferring the real science experience. These included laboratory placements, project assignments, duration of research experience, limited school resources, ordering materials, course enrollment, teaching assignments, and school administration.

Laboratory placements. In order to find out whether the teachers were satisfied with their laboratory placements, I analyzed data collected from the program applications, blogs, audiotapes, field notes and the interviews to look for conforming and non-conforming evidence.

In the program applications, the teachers were asked to enter their choices for laboratory placements. A list of the options that the teachers gave and the final assignment of laboratories is displayed in Table 6. The laboratories were not decided upon before the program was advertised. The laboratories listed on the advertisement were the ones from previous years. Therefore, teachers made their selections based on what was advertised. The laboratories were decided upon after the teachers were selected for the program and the decisions on assigning the laboratories were made based on the background of each teacher. The laboratories

Table 6
Project choices and project assignments of 2010 ASU MSTF teacher participants

Name	Project choice 1	Project choice 2	Project choice 3	Project assigned
Stacy	Biosciences	Information Technology and Advanced Computing	Sustainable Systems	Nanosurfaces/ Physics
Brad	Sustainable Systems	Biosciences		Bio-physics
Grace	Information Technology and Advanced Computing	Biosciences	Sustainable Systems	Nanosurfaces/ Physics
Lucy	Sustainable Systems	Biosciences	Information Technology and Advanced computing	Bio-physics
Patsy	Sustainable Systems	Biosciences	Information Technology and Advanced Computing	Bio-chemistry/ Chemistry
Emily	Sustainable Systems	Biosciences	Information Technology	Bio-chemistry/ Chemistry
Wendy	Biosciences	Sustainable Systems	Information Technology	Bio-chemistry /Biology
Jack	Sustainable Systems	Biosciences		Nanomaterials/ Chemistry

were matched with a research area that was close to the teachers' content background. It may be noted that only one teacher was assigned a laboratory of their first choice. Four teachers who had opted for a bioscience laboratory as a second choice were assigned either a biochemistry or biophysics laboratory.

All the teachers had given sustainable systems as one of their choices. Five teachers had it as their first choice, one had it as a second choice, and two had it as a third choice. However, it turned out that the laboratory was not available. This was a big disappointment for the teachers who had opted for the sustainable systems laboratory. This was evident in the debriefing session that took place at the end of the program. The reason for not getting two of the laboratories that were included in the program advertisement according to Dr. Young was, “The Information Technology group (robotics) required more teachers than we had. The two sustainability projects that we used before (both at the Poly campus) were not very successful, so I did not want to use them again.”

Emily mentioned that she was excited at having an option of joining the sustainability laboratory as advertised on the program website. She said, “There was a sustainable system lab advertised on the website that had got me very excited and everything.” She was disappointed later after learning that the sustainable systems laboratory was not one of the participating laboratories for ASU MSTF 2010.

Patsy said that she thought she was in the PIXI lab, but came to know later that she was going to be in the biochemistry laboratory. She said, “I don’t understand how they placed the teachers, because I would have liked to be in the biophysics lab.” She thought it would be helpful if the organizers could compile a list of projects within a laboratory for the teachers to choose from, before the program began. Then they would know what they were going to work on beforehand.

Lucy mentioned during the debriefing session, "I would have liked to be in the biochemistry lab and work on some spider silk research, because I had a background in microbiology." After listening to a presentation on spider silk by a visiting researcher, she thought she would have had a better experience if placed in the biochemistry laboratory. She wrote in her blog,

> The presentation on spider silk was very interesting. I was a molecular biology graduate student 20 years ago and I understood everything that she was doing. I like watching the silk fibers dropping down from the protein solution and the red eyes silkworm looked like aliens. It would be great if they can make silkworms produce colored silk—like green silk, red silk, blue silk—will be really cool! I could have done some similar molecular biology stuff if I was in the spider lab.

All the other teachers agreed that they should have been told what project they would be working on before they came in the first day. They would have preferred to read some articles to be abreast with the current research, before they came into the program. They thought it was hard to assimilate all the literature after they started the program, considering the short duration of the program.

The two teachers in the nanosurfaces laboratory although placed outside their choice of laboratories, said they were glad that they were assigned to a laboratory that was not in their wish list. They thought it was good to step out of their comfort zone and experience something different for a change. They said it was mainly because they had been assigned to a project and knew what they were going to be doing from the first day itself.

Project assignments. The teachers that were not assigned to projects in their placement laboratories thought they would have benefitted more from the research experience if they were assigned a project to work on rather than having to figure out what to work on, on their own, or watch the researchers the whole time. Evidence of this was found in the debriefing session at the end of the program.

Lucy said "I have problem attending to one thing for a long time. I would have worked better if she had something to do, rather than just listening to people talk." She said that they only had an opportunity to fix a slide on one occasion and the rest of the time they were sitting around watching the researcher work on the samples. She said, "I had already learned the lab procedures in the first two weeks. After that it got boring."

Patsy believed that she would not have to waste so much time deciding on a project if she was assigned a particular project like some of the other teachers. She said,

> I spent two weeks to figure out where I would fit and where I would work. I was confused for two weeks. We would have benefitted if we were given a project from the beginning. It was very frustrating! One week Dr. Lewis was out and then Jim was being protective of his egg sacs (Spider egg sacs for her

> experiment on dissolving silk in ionic liquid). Then I have hardly decided what to work on and I have to come up with an idea to implement in the classroom.

Brad mentioned that he would have preferred a laboratory with a project to work on, but nevertheless gained some valuable experience at the biophysics laboratory. He said he would have liked to be in the same laboratory if it was more organized and he had a project to work on.

Emily felt she could have benefitted from having a balance between having to do some research and having the time to work on the curriculum. She said, "It would have been nice to work on a piece of glass in the pressure lab."

After learning about the experiences of other teachers who were working on assigned projects, Emily thought she would have benefited by having such an experience. She wrote in her blog,

> The summary of every one's research was nice. I feel like I'm missing out in not being a part of a research group. It would have been nice to have been assigned to one of Dr. Lewis's assistants and either shadow that person or to have been given a specific task to accomplish.

One of the laboratory directors agreed that it was better to decide on a project to assign the teachers to when they come into the program. Dr. Lowry said in his interview,

> I think it is a much better idea for a faculty member to think about, okay, "What can I have them work on, that they can work in a

week." After we get started we can tell if it is working or not, because if it is not then we have to make changes. So, they can get something done, because you don't want them to just hang around. I mean, it's okay if they hang around, and help, and do stuff a little, but it is much better if they are actually involved in the discovery process. They are the ones who make; you know, the solution, the new stuff that nobody has ever made before. So, you know, it is much better.

However, Dr. Lewis did not have the same opinion regarding assigning teachers to specific projects. In his interview he said,

> I personally don't feel that, at the level above undergraduate—it's not my job to motivate. Good scientists don't need to be motivated. Almost all good scientists are self-motivated. My job isn't to motivate—my job is to make resources available to them—show them creative outlets for different ideas—taking their ideas and hopefully helping them expand it—just because I have a larger background knowledge—point out things that they might not have realized—*their* initial motivation—that has to drive me.

The teachers that were assigned to specific projects wrote some reactions in their blogs. Stacy wrote, "This morning was the last of our research meetings. It was much like the first meeting with students reporting the status of equipment, papers, research etc. It was again very interesting. I enjoyed both of these meetings a lot. I was sad that it was our last meeting…we were very excited by our findings. We really wish we had more time to spend doing the research and working to get better dots."

Grace wrote, "Despite the early hour, these research meetings are still my favorite part of my summer."

Jack wrote,

> I am extremely excited about the research group I was assigned to for the 2010 MSTF. Along with two other teachers and a grad student we are directly responsible for assisting in a small piece of a larger project. Our data will actually mean something and will be used along the way to drive the direction of future research.

It was evident from the results that only three out of the eight teachers were placed in laboratories that had organized a project for them beforehand. Those three teachers experienced almost all of the ten real science components by being actively engaged in the scientific process. They were involved not only in learning and using new techniques of doing science, but also experienced the nature of scientific research. They experienced how researchers had to be meticulous in setting up experiments so they can minimize errors as much as possible in collecting data. They had to redo their experiments several times until they obtained the desired results. They were involved in analyzing data, discussing results and also modifying procedures when results were not obtained as hypothesized. Jack was even going to come back to see the results of the X-ray diffraction the following week after the program ended. They were the ones that wrote and talked about the nature of scientific research the most. However, more than half the teachers did not have a research experience where they could experience real science hands on. Those teachers were either just observing the researchers engage in conducting experiments, collecting and analyzing data or spending time in the laboratories working on posters, blogs, and reading background information. Therefore, even though the other teachers were interested in the nature of scientific research they did not talk or write much about it because they did not have similar experiences. Three of those teachers who were unhappy with their laboratory placements did not implement the curriculum in the classroom.

Challenge of laboratory timings. The teachers were scheduled to be in the laboratory between 8 AM and noon. However, the researchers who worked in the laboratories did not show up until 10 AM or 11 AM because they worked until late in the evening. Sometimes the researchers were out of town for meetings and conferences. This was a challenge for the teachers because they had to wait for the researchers to arrive or just sit in the laboratory with nothing much to do.

During the afternoon discussion on the last day of the program, the teachers talked about timing issues. They all agreed that that the graduate and undergraduate researchers did not come in to the laboratories before 10 or 11 in the morning. They agreed that it would be better to have the whole group sessions in the morning. In that way the teachers will not have to waste time sitting around and waiting for the researchers or leave undone work behind because they have to leave by noon for the afternoon sessions. The teachers who were actively involved in a project said they missed out on doing certain procedures because they were not there in the afternoons. Jack said he was not able to be there during the TEM (Transmission Electron Microscope) procedure because it was run in the afternoons. The teachers agreed that if they had the afternoons, they could have even stayed back longer if they wanted to finish up some procedures in the laboratory.

We can find evidence in the teacher blogs regarding the various occasions when the teachers had to wait for the researchers in the morning to start work. This is what the teachers wrote in their blogs,

Stacy, "We started the morning waiting as has being come the routine. We had to wait for graduate students to arrive and once they had we had to wait for the O plasma chamber to become available."

Grace, "The morning started bright and early at the 8:00 am meeting of the nanosurfaces research group. Since most of the students in this group generally show up around 10:00 on a normal day…"

Lucy wrote, "Today, we waited on Neal to come and scan precancerous cells on elasticity. He appeared at 10:00 am."

Emily wrote, "Today was a pretty quiet day. Nothing is really happening in the lab, lots of people are out of town."

Patsy wrote, "Got an email from Dr. Lewis canceling our meeting for the day…I hope Dr. Lewis will come tomorrow so I can get started on the actual experiment."

We can also find evidence of the timings when researchers came into the laboratories in the interviews with one of the laboratory directors. In an interview with Dr. Lewis, he mentioned that the time constraints of the teachers were restricting their laboratory experience. He said,

> One thing I would much rather argue is, I don't know what they do for the other half of the day. I can only argue that whatever they do, they could do in two hours, do it first thing in the morning. I would much rather, have teachers start at 9:00 am, do 9:00 to 10:30 or 11:00 as the group together and then spend the time 11:00 on in the lab. Afternoons are just logistically better. Most groups are like mine; they are full of grads and undergrads. In the summer these are people that stay up late at night. They don’t get up early in the morning. They (teachers) come in at 8:00 or 9am. They (students) don't come in at 10:00 or 11:00 am. So, they are just going to get more interaction in the afternoon than they are in the morning. Half of my students come in at 10:00 or 11:00 and the teacher are about to leave at that time. Other thing is that part of the interaction is through lunch. A lot of the groups go and eat together. They eat together at the table and talk about stuff etc. Like, by them coming at 10:00 or 11:00 and being able to start something before, have lunch with the group and have all afternoon, I think will be much more productive than the way they do it.

Challenge of duration of research program. The laboratory directors Dr. Lewis and Dr. Lowry both thought that the teachers should spend more time in the laboratories to get sufficient exposure to scientific research.

> Dr. Lewis: I think this year, the time limitation is very restricting. They don't have time to do or get that immersed in research. In fact, I would say that it was short before, and they made it even shorter. It should really be two to three months. It takes a week or two to get your bearings in the lab. By that time they need to have something tangible and part of research is being able to discover things and try a few things. They are definitely too under the guidance and get working on something immediately to get to the classroom.
>
> Dr. Lowry: Yah, it takes them a week to sort of figure out what they are doing and another week before it, to even happen—couple of weeks in before things start to get going, because they need to get excited about the project, right. So, it takes a while for things to spin out and work properly because they don't know what they are doing. This year I put them on something new and I was not sure it's going to work. So, we were sort of tuning the project as they went along. Then finally, when it starts working, they get excited and they get enthusiastic and they work harder, they think about it more and they learn more. So, to make it a better program it would be good to have earlier contact.

Challenge in translating research content into school curriculum. Four teachers came up with an idea within the first two weeks. The remaining four teachers struggled with their curriculum ideas for three or more weeks and three of them finally settled on a nature of science /scientific method unit. The evidence of their struggles can be traced in their blogs.

Patsy was having a hard time deciding on the topic for research in the beginning of the program when they were introduced to different kinds of research going on in the biochemistry laboratory. On the second day of the program she wrote,

> I am leaning towards activities using lights, as they are most applicable to the high school chemistry topics that we normally cover—law of diffraction, atomic structure, bonding, and shapes of molecules and that kind of stuff.

At the end of the first week, she was debating on whether to go for her own interest in a topic or to go for a topic that will be easy to translate into the school curriculum. She wrote,

> What I found challenging during the week is deciding on the exact research to work on. It's Friday already but I still haven't decided what I will work on. There are several options presented ranging from spider related research at the ISTB, to high-pressure labs, and Raman spectroscopy lab. I have to make a decision to work on the research that I really like and find interesting or the one that I can apply to the first semester lesson on high school chemistry. I personally wanted to work on the Spider lab and figure out what ionic liquid can possibly dissolve the spider silk without destroying it. But at the same time, I also want to work on pressure and laser

> because they are easier to relate to a high school chemistry curriculum.

Stacy's progression of thoughts regarding classroom implementation can be tracked in her blogs. On the second day she wrote,

> I am still unsure where I want to take this in my classroom. I am kind of thinking about something about the AFM but that might be just because that is all I have worked on so far. I am still very open minded and looking for different ways to bring this topic into my class.

At the end of the first week she wrote,

> I am really leaning towards doing a project on the nature of science. I think I might have the students do projects on the type of equipment we use and discuss how the scientists do research.

A day later she wrote,

> I am still trying to figure out exactly what I want to do for my project. I am leaning towards wanting to do a project looking at mainly the nature of science. I will be teaching freshman conceptual physics and teaching them about nanotechnology can be slightly difficult. I however think that helping the students understand how scientific research is conducted and how scientific knowledge is acquired could be of great benefit to the students. In addition I would like to work in parts of the project I am working on here at ASU but I am unsure of how to do that right now.

Four days later she wrote,

> I am slowly getting some rough curriculum ideas and I think I will have a smoother version to put down in words in the next few days. I want to iron out a few things before I try to explain what I am thinking but an idea is starting to form.

At the end of the second week, Stacy discussed her ideas with the other teachers. She was wondering what kind of material to use for an experiment that was analogous to what they were doing in the nanosurface laboratory. She was pleased with the feedback she received from the teachers. She wrote,

> Today was a great discussion day. I also asked for some help with my curriculum project and the other members of the group had some great ideas to help iron out some of my ideas. I plan to try some of these ideas and see if any of them will work.

Four teachers had a curriculum idea by the end of the first week. Lucy and Brad came across an idea after researching on the topic in the first week itself. They decided to implement a similar project on the principal behind the optical microscopes that was used for research in their laboratory. Brad wrote in his blog,

> While everything seems at first to be highly complex and overwhelming, there seems that there are aspects of the research being done that are simple enough to possibly transfer to the high school classroom. On the simplest level, we will be working with

> optical microscopes. Some research being done includes looking at the "squishyness" of cell membranes of cancer cells vs. non-cancer cells. There are basic concepts of Force and springs that seem to be applied at the nano scale.

Emily was initially thinking of doing something related to the high-pressure lab. By the end of the first week she settled on an idea that had interested her on the first day of the program while Dr. Lewis was giving a tour of his laboratories. She focused on laser technology to build a curriculum unit for her students, which she believed would help the students understand how tiny particles like atoms are studied. She wrote in her blog,

> Big Success - I know what the project is I want to work on and I am really excited about it. I can finally help students to understand how scientists discover what atoms and molecules are made of and look like. I am going to use laser diffraction to model how x-ray diffraction works. This will be an inquiry activity.

Jack wanted to replicate the research that he was involved in his laboratory. He wanted to use different kinds of chemicals that were safe to handle and easy to obtain. The equipment that they used in the research laboratory was the kind of equipment he used in his classroom laboratory except the spectrometer, which he did not have. However, he had to decide on the chemicals that would be safe to use with the students. Towards the end of first week he wrote,

> While we wait on the water we discussed a procedure using sodium citrate and silver nitrate to produce silver nanoparticles.

> It's a simple procedure. All I need now is a spectrometer to help students detect nanoparticles of silver…I now have an activity where I can have my students grow nanoparticles in a high school lab.

It was evident that teachers who identified an idea that was easy to implement with respect to the topic and equipment were able to pursue their ideas. The teachers who did not identify ideas that were easy to implement took longer to finalize their ideas. Wendy found it hard to decide which specimens she could use with her biology curriculum. It was also evident that the teachers' who did not find any topic close to their curriculum veered towards lessons on the nature of science.

Challenge of restricted use of materials in the classroom. The teachers had to be mindful of the kind of materials they could use in their classroom. They went for materials that were cheap, easily available, and practical for the classroom.

Cheap and easily available materials. The teachers in the biophysics laboratory found an idea from an article on building a coffee cup cantilever model. They built an AFM model using materials obtained from objects lying around in the laboratory. Figure 16 shows a picture of the coffee-cup cantilever.

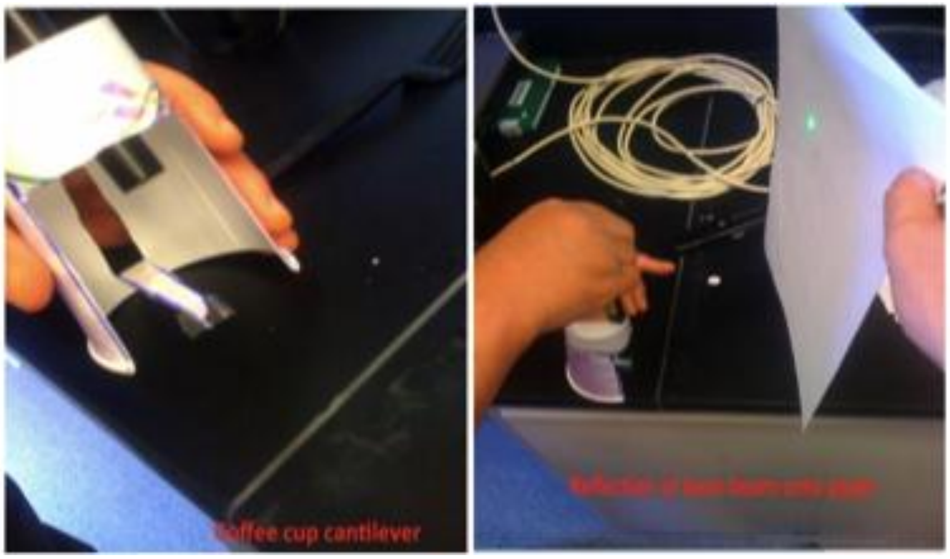

Figure 16. Coffee cup cantilever prepared by the teachers in the Biophysics lab

Lucy wanted to use the cantilever for her math class to determine the shapes of geometrical objects whereas Brad wanted to use this idea with his physics unit on optics to show that objects can be determined by reflection of light rays. Stacy decided to use a memory wire for her nature of science unit because that was a cheap and easily available material and had some interesting features that could be investigated. She decided on using the memory wire after she struggled with the idea of a material until the last week of the program. Emily decided on using the optical transform slides and laser pointers that were easily available through an online store for her project on using diffraction techniques to study shapes of microscopic objects. She found inexpensive ways of setting up the slides. She wrote, “I did get a set-up made to hold the diffraction slide (a shoe box and a rubberband).” Jack discussed with the researchers in the nanomaterial laboratory and decided on chemicals that were safe to use and easy to obtain for his project on making silver nanoparticles. He wrote in his blog,

> I was surprised how simple the techniques are and using glassware I have in my HS (high school) lab. If I share my experience pictures and video with my students, it will help to make science more real for my students and offer a more genuine experience. Often my students feel that because they are using "old" equipment they are not doing real science. I now have an activity where I can have my students grow nanoparticles in a high school lab. New science meets old equipment! … We discussed a procedure using sodium citrate and silver nitrate to produce silver nanoparticles. It’s a simple procedure. All I need now is a spectrometer to help students detect nanoparticles of silver.

Jack was happy that he had found an experiment that would require materials that he already had in his laboratory. He was planning to borrow the spectrometer from another teacher in the program for the duration of his class project.

Practicable materials. Wendy had to decide which specimens to take back with her depending upon the ease of maintenance in the classroom environment. She wrote, “Although these spiders would be fascinating to have in my classroom, they require a sophisticated humidifying system that would not be practical to set up and maintain in my room.”

Therefore it was evident that the teachers were challenged to think of lesson ideas that would require cheap, easily available, and practical materials for use in the classroom laboratory.

Challenge of using technology. In addition to the challenge of selecting laboratory materials, there are schools that do not have good technology support. The principal of Patsy's school was not in favor of using technology in a science classroom. He said,

> …Kids in science want to touch things, they want to do labs, and they want to be in groups—laptops don't offer that—but then, if you look at my science department—you are going to say, "Why are they not using laptops". That's not what kids want to do! Kids will do that in English—they want to type—they want to look things up on the Internet. They might have a research thing in science where they get on the internet and look up stuff, but the success of our science department is creative labs that engage students—fun lab that engage students. The use of technology to produce power point presentation—bring things off of "You tube" to show the kids—in that capacity technology is used in science.

Patsy's and Emily's school did not allow them to bring in their personal laptops. It was evident that teachers had to face technological as well as material challenges in order to plan their science lessons.

Frustration with ordering materials. Some teachers who wanted to purchase materials for their project ended up not being able to buy them because they had to order from fixed vendors if they used the program account. Emily bought her optical transform slides and Stacy bought her memory wire using their school budget because these items were not available with the ASU vendors. Jack wanted to buy a spectrometer, which he could have bought for a price within the allocated budget from ebay. However, the price was much higher when he tried to purchase it from vendors available through the ASU account, so he was unable to get a spectrometer for his lesson.

Enrollment for course offered in the fall semester. The new teachers were offered a two-credit course in the fall semester. Only one teacher out of the five new teachers was able to register for the two-credit course in the fall semester. They were supposed to be teaching their research unit during that semester. There was a problem in setting up the course. Apparently, the person Dr. Young was relying on was not well versed with the system and took too long to set it up. The teachers were into their school year by then and had only a few days before the deadline to register. Since the course was not setup on time, teachers who tried to enroll at the last minute faced a number of problems and lost the non-refundable admission fee.

In an informal phone conversation with Patsy regarding the course enrollment, she mentioned that she had paid the admission fee, but she could not figure out a way to enroll in the non-degree class. She said the enrollment website kept reverting back to the undergrad website. I called the registrar’s office and asked them why she was not able to register. They told me that she was not admitted to the course because they required her visa information.

I enquired Emily regarding her experience with enrolling for the course. She told me that the admissions office needed a lot of paperwork, which she said she was lucky to provide because she happened to be on campus on the last day of enrollment.

I emailed the other teachers asking them if they were successful in registering for the course and to let me know if I could help them in any way. Some of them emailed me back.

Grace wrote,

> No, I did not register for the ASU course. I got admitted as a non-degree grad student in September, but was too late to register for the actual class this semester. I apologized to Dr. Young about this at the September AzAAPT meeting. He said I could probably register for it in the Spring ??? I hope this is true. Because of this, I wasn't sure about when to have you come into my classroom. I didn't know if you should visit this semester, or wait until next semester when I am officially registered at ASU.

Brad wrote, “I am not registered. Do not know what needs to be done. I got an email saying that my application was not accepted but I know it was. Let me know if you can help.”

I forwarded their emails to Dr. Young and asked him to find out why they were not able to register for the course. He said they could not do much about it since the deadline had passed.

I asked Dr. Young what had gone wrong with the course enrollment. He explained,

> Except for this year the tuition went pretty well, because we did the registration during the program. What happened this year was, the persons who had helped to build the course in the past weren't available and some higher-level administrator said she would take care of building the course. She decided that she wanted to know how to do this—very noble of her, but it took for*ever*—and she was very busy. She didn't know how to do it—it took too long, because she was too busy—the courses were not ready—the teachers were long gone—and now the teachers were not even answering emails anymore.

In one of my conversations with Dr. Young, I asked him if he was going to make the course available in the spring semester for the teachers to register. He said he did not think that the teachers who had lost their admission fee in the fall semester would want to register again. He said it would not be feasible to do it for only one teacher (Grace).

The failure to register for the course resulted in the teachers not feeling motivated enough to continue with their plans for the curriculum unit. Grace was planning to implement the unit in the spring semester. She wrote to me saying, "I realized the lesson I wrote for you this summer is probably not advanced enough for the 9th grade students I am teaching this year at JHS. I am going to have to do a lot of re-writing to make it appropriate." Later on in the spring, after she realized she could not register for the course, I had asked her if she was going to still implement the unit. She sounded disappointed at not been able to register for the course and said that she did not feel motivated enough to re-write the unit to fit the 9th grade class.

In a conversation with Patsy at the end of the summer program, she said she was planning to insert her polymer unit into the scientific method topic of her chemistry curriculum. In an informal phone conversation Sally, a teacher from her school who was in the MSTF program in the previous year said she thought Patsy had done a research project in the beginning of the year. However, Patsy did not mention that to us or invite us to come and visit her classroom.

On asking Brad about his plans of implementation, he wrote back, “I was planning on doing my project work with my students December 15-16. Let me know if that works for you.” However, he did not get back to me afterwards. No one at ASU was able to help him with registering for the course. Later, he told me in a phone conversation that he had tried a few things with the unit but it did not work.

It is evident that there were three teachers (Patsy, Brad, and Grace) who were disappointed at the course enrollment not going through. If enrolled, they would have got 2 credit hours towards a physics or chemistry graduate level course (Connecting Research Experiences to Math and Science Curriculum). Emily was able to register only because she was physically present on campus to do the running around for the paperwork. Apparently, the university was not able to help the teachers because they had missed the deadline to apply for the course.

Changes in teaching assignment. One of the reasons that some of the teachers could not implement the lesson was change in teaching assignment. Lucy who was teaching physics in a high school in the Indian reservation said she could not teach the unit because she got a new assignment teaching in the middle school of another reservation. She also complained about the students she had when I spoke to her over the phone one day. She said she was frustrated with having the students work on even the regular curriculum and that there was no way she could try anything outside the curriculum with them. She said she had applied for an administrative job.

Grace had taken up a new assignment teaching high school biology and algebra. She had not planned for that grade level for the research unit.

During a conversation outside school, Patsy said that their school had not met academic yearly progress (AYP), so there were a lot of changes in classes in their school that year. This is how she explained her change in teaching assignment during a post interview,

> I had five classes of chemistry last semester, and this semester I have only four classes. One of the classes was dissolved because of too many students failing, and so, they switched it to Physical Science 2… because the students who failed Chem1 were placed in Earth and Space Science. So they opened a new Earth and Space science—because they can readily go to Earth and Space 2 without going through Earth and Space 1. So, supposedly those who failed Chem1 will go to Earth and Space 2. So, since we needed to create

an Earth and Space, Ms. B needed to get rid of her Physical Science—and that piece was given to me—and she opened a new Earth and Space 2.

In a meeting outside school, Patsy told me that one of her chemistry classes was replaced with a physical chemistry class, and it appeared that the class had students of mixed grade levels, freshman, sophomores, juniors, and seniors. She said that it was very hard for her to teach that class. She mentioned that the students came to the class unmotivated and refused to do any work by themselves. She said, "You press one button, they do one work; and then you press another button, and they do another piece of work. It is very frustrating"

She recently got a Masters in Business Management (MBA) degree from ASU and had been applying for jobs in financial companies. This is what she said in her interview,

I: Why did you go for an MBA?

Patsy: I guess, I am burned out with teaching (Laughs).

I: How long have you been teaching?

Patsy: 20 years already.

I: How long in the US?

Patsy: Since 2002—pretty long—8 years.

I: But, if you were happy with the school...

Patsy: Yah, yah, I probably needed a change after doing the same thing over and over for the last 20 years.

In one of my email conversations with Patsy, I asked her if she was doing her National Board Certification as she had planned. She wrote back, “No. I finished my MBA and decided I will just transition to a business related career or maybe tertiary level teaching.”

It was evident from the conversations that Patsy wanted a change from her teaching job.

Wendy moved on to a different career at the end of the year. She took up a job in the health sector because she had a degree in Public Health.

Stacy decided to become a full time graduate student at ASU to pursue her PhD in Physics.

It is evident that half of the teachers moved on to pursue different careers or intended to change careers hence limiting the implementation of the research experience in the classroom. It was not something that was expected as Dr. Young had mentioned,

> The goal really is to improve the education of our kids out there by giving the teachers some more tools, but I found that it had another effect for teachers who were burned out or needed a distraction, needed something different going on in their career, had this opportunity, really appreciated this opportunity to give them a spark, and I got a few teachers mention that they were just thinking of leaving the field, it was kind of recharge for them. But on the other hand there were teachers, who after having this program, did leave the field, now that was a little disappointing, but not many

> did that, but some teachers changed school, now that is pretty typical.

Therefore, the experience did not give at least four out of the eight teachers a spark to carry on with their teaching job or prevent them from changing their careers. It however, sparked one teacher to become a researcher.

Challenge pertaining to restrictive school curriculum. Structural change in school was an evidence of barrier in the implementation of the curriculum unit. During the post interview, I asked Patsy why she was not able to teach the curriculum unit that she had planned to teach. She said,

> We are our own PLC now in chemistry and we have a SMART goal to be at least around one or two days off of each other's pacing. So, there is no room for putting it in. It's not in the curriculum so I can't inject in.

When I asked Patsy how it was different before when the PLC was at the district level, she said,

> I was on the same page as other teachers' who teach in the traditional way in the district, but in school it is less flexible and more rigid, because evaluators come all the time—and if they come to Ms. C's class—and move on to my class—and I am teaching a totally different thing, then they would know—like last year, I was the only one teaching traditional—the other teacher was teaching the modeling way—then I have more leeway—and

> can insert topics here and there—as long as it is related to, because no one is monitoring me relative to another person.

In an email conversation I asked Emily if she had a science fair in her school as she had planned to do. She wrote back,

> I had the student come up with research projects first semester. They did it at their own time. It was supposed to be a semester project but I only had a handful of students do it so I ended up counting it as an extra credit or else I will have a 95% failure rate. No, I did not have science fair - not enough decent output for a science fair.

Patsy had also mentioned that she had submitted an application for opening a science club in her school. When I asked her about it, she said that there was a lot of politics involved and administration was interested only in clubs that would bring funding for the school. Hence, her application was not accepted. She also mentioned that her school did not have funds to bus students for field trips. This shows that Patsy did not have any support from her school regarding the science fair or the science club. She did not mention contacting Dr. Lewis at ASU either, for any kind of help for the science fair projects.

I interviewed Patsy's school principal and asked him about the changes in the school that were not conducive to implementing the research unit that Patsy had planned. Mr. Hill explained,

> One of the challenges is that the school district is changing its curriculum and Patsy has to follow that as a district employee. The

> district science team has decided to go a different direction with chemistry and the professional learning community for chemistry—they all have to be on the same page—so bringing in stuff from outside programs has to be extra. She needs to do the district curriculum—and then, if she can get to it or find a way to integrate some of the stuff she is picking up from ASU, she will be able to do that.

The PLC in Patsy's school was very rigid. The reason probably has to do with not meeting AYP. The administration in her school wanted to make sure that their curriculum across the classes for a particular course was conducted at the same pace.

However, the PLC in Emily's school did not seem to affect her teaching the curriculum unit, which was eight days long. She also talked to another teacher in her department to help her with building a diffraction grating. So, the PLC in Emily's high school acted as a support in implementing her research unit rather than a hurdle as in Patsy's high school.

Dr. Young made a comment about the limitations of the rigid curriculum in his interview. He said,

> …I think part of the limitation is that, in many cases the teachers' obligations for what they have to teach is so restrictive that even if they make a nice activity—they are not able to implement it, or they have to implement it at the end of year, when everything else is done, and there is nothing else to do—they have some time—so

> now they can do their thing. I am not sure how effective that is—it's not ideal because kids have kind of already tuned out now—ready for the school year to end and know that they are doing something additional now—I don't know—it will be interesting to see.

Challenge of classroom time. The teachers had to be mindful of the time factor when teaching in the classroom, whether it was for the class period or the duration of a particular unit. During my classroom visits, I found teachers rushing the students to finish their work and clean up before the end of the period. I also found teachers' trying to finish the unit in haste because they did not want to spend any more time on that particular unit. They wanted to move on to the next unit.

Some teachers found it difficult to extract time from the curriculum to insert the extra unit. Brad planned to give the students a home assignment of building the macroscopic cantilever because he did not think he would have enough time to do that during class period. Patsy said she did not have time to insert the unit in between the school curriculum because the teachers' in their school had to be on the same page with each other with respect to the chemistry course.

Accountability. Teachers were less accountable for the curriculum implementation. There seemed to be a pressure from funding agencies for using up most of the money allocated for teachers. The program director wanted to give away as much of the funds as possible so he was not left with unspent funds at the end of the program. The teachers were supposed to receive a payment of one week's time during the school year for lesson planning. As far as the program requirements were concerned, the teachers only had to turn in a log of 40 hours spent outside school towards planning the research curriculum. There were no other guidelines given as far as spending those 40 hours of planning time or the lesson implementation. The only accountability was that the teachers would receive a better grade if they implemented the unit in the classroom. There were no expectations from the school administrators either, to make sure that the teachers implement the curriculum unit in the classroom.

Implementation in Classroom

In order to answer the fifth research question (Did the teachers exhibit reformed science teaching and incorporate real scientific methods in the school settings after undergoing the research program?) I analyzed the lesson plans, field notes, and RTOP scores.

Real science in lesson plans. I coded the lesson plans to look for themes on real science (Table 7). Only four teachers had connected their lesson plans to some aspect of the research they were involved in. Even though Wendy's lesson was not connected to the research area, she used a research specimen for a culminating activity in her unit. All the eight teachers had plans of involving the students in conducting experiments, collecting data, and analyzing data. Stacy had all the features of real science listed in the state standards, but she did not include descriptions of specific activities for all the real science components in her unit.

Table 7
Lesson plan analysis for evidence of specific real science activities

	Wendy	Emily	Patsy	Jack	Stacy	Grace	Brad	Lucy
Research content	√	√		√			√	√
Formulating questions		√						
Research hypothesis								
Background research	√	√	√		√			
Designing procedures		√	√				√	
Conducting experiments	√	√	√	√	√	√	√	√
Collecting data	√	√	√	√	√	√	√	√
Analyzing data	√	√	√	√	√	√	√	√
Discussing results				√	√	√		
Presenting findings	√	√	√		√	√		
Modifying procedures								

* Shaded check mark denotes partial representation of the category

Given below are the main themes that emerged from the lesson plans based on the specific real science activities enumerated in the lesson plans. I have picked best examples of each theme from the lesson plans of the teachers.

Theme 1: Conducting experiments. Patsy planned, "Produce some polymers (slime and gluep) in the laboratory. Stacy planned, "My students will be working with memory wire and will have a chance to understand a small amount about nanotechnology." Brad planned,

> Students will work in groups of 3-4. Students will design and construct macroscopic working AFM that can be used to image unknown objects. The AFM must use fundamental properties of a real AFM. Students will create designs of their structure including materials needed and to scale schematic drawings. Included must be a manual that explains how to use their AFM.

Jack planned,

Student activity:

1. Obtain 50 ml of the $AgNO_3$ solution and bring it to a boil on a hot plate while stirring.
2. Add the sodium citrate dropwise until a color change is observed. Stop heating and allow to cool.
3. Label your beaker and place in the designated area for tomorrow.

Wendy planned,

> Open-ended investigation: students will observe the embiid colony (no information will be given to students about what they are seeing) and pose questions for investigation. Working in their lab group, they will be charged with answering the following questions, and recording data, as a scientist would.

Emily planned, "The discovery/engagement portion of lab is all about making observations and reporting findings. Students will need to "see" the right triangle in the laser/slide/wall system in order to be able to use Fraunhofer's equation."

Grace's plan included, "One student walks away from the motion detector and another towards the motion detector."

Theme 2: Collecting data.

Stacy planned, “At what temperature does this metals unique property appear? (Observing a known phenomenon and taking accurate data).”

Brad planned,

> Students will be given an unknown object in a box with a slit cut out for their cantilever arm. Without looking at the object, student will need to use the AFM to create a 3D image of their object by scanning the surface.

Jack planned,

1. Obtain your mixture and a clean cuvette. Place a small sample of your mixture in the cuvette and place it in the spectrophotometer.
2. Print out the resulting graph for your group.

Wendy planned,

> Make a drawing of everything you see in the glass jar; be as detailed as possible.

Emily planned,

- Students will measure distance in meters with accuracy and precision.
- Students will apply the trigonometric relationships of right triangles to calculate the angle of diffraction.
- Students will apply Fraunhofer’s law to determine the distance between barriers too small to be seen.

Grace planned, “All students should record the graphs generated, paying attention to the starting and ending values.”

Theme 3: Analyzing data. Patsy planned, “Observe the properties of Spider silk (egg sack) and compare with other polymer.” Brad planned, “Students will analyze Force vs. distance curves.” Jack planned,

> Post - lab discussion:
>
> 1. What caused the color change?
> 2. Why did we heat the mixture?
> 3. What does the spectrum tell us? What does that mean about particle size?
> 4. What happened when we added salt water? Why do you think that is?
> 5. Have students draw a particle representation of all stages.

Wendy planned,

> If you came across this while hiking in the woods, how would you determine what organism/organisms might be living in this habitat (assuming that in the natural world it would not be contained in a glass jar)?

Emily planned,

> Students will need to read up on the subject matter of waves, interference, diffraction, trigonometry of right triangles in order to answer the prompt question, “What’s on this slide?”

Grace planned,

> …Require students to use the values on their graph to make a numerical estimate that connects directly to the speed of the walkers, in meters every second. If sufficient background knowledge has been established, this may be related to the slope of the line.

There were few instances of the other real science categories found in the lesson plans. Given below are extracts on the other categories that only one or two teachers included in their lesson plans.

Formulating questions. Emily planned, "Students will be given a prompt question, 'What's on this slide?' and will generate their own questions in order to figure out the answer."

Background research. One of Patsy's objectives for the unit was, "Research the history, uses and recycling process of polymers." She had assigned three out of eleven days to textbook and library research in her lesson plan. Stacy planned to start her lesson with having her students answer the following questions: 1) What is this metal? 2) What is the science behind this metals unique property? She added, "(Both questions 1 & 2 require literature research)"

Designing procedures. Patsy planned, "Design an activity that will infer the relative strength of spider silk based on mass." Emily planned, " Students will engage in planning to decide what measurements are needed and how best to get the measurements."

Discussing results. Stacy planned,

> All the research teams within a group will work individually but can ask each other for help and will have research meetings. This simulates the collaboration we see in real world science.

Grace planned,

> Students should then be asked to answer questions 1-4 first with their shoulder partner, and then be given the opportunity to share out answers until they come to a consensus…Again, students should first discuss the answers to the questions with their nearby group, and then share out to the class…Resulting discussion should focus upon the relationship between the steepness of the line and the related motion.

Presenting data. Patsy had three out of eleven days assigned to student presentations in her lesson plan. Stacy planned, "I would like the students to present all of this on a poster and do a poster symposium kind of thing (again something people leave out but something every scientist has to do present their results) (*sic*)." Grace planned, "They should be given the opportunity to deliberate their answers before hearing the opinions of others. Then the questions should be carefully white boarded and presented to classmates for discussion."

It is evident that the teachers were more comfortable with planning specific activities including the real science features of conducting experiments, collecting data, and analyzing data and less comfortable with the remaining features of real science. The most neglected ones were formulating a research question, research hypothesis and modifying procedures.

Real science in classroom observation. The field notes of classroom observations were analyzed to identify components of real science in the classroom implementation of research experience. The themes that I found across the classroom observations were as follows:

Theme1: Background Research. All the teachers that I observed had assigned some time for gathering background information. In some cases the students were asked to carry out a search on the Internet to find out some background information. In other cases, the teachers gave the students some background information in order to prepare the students for the lab activity. Stacy had her students research on the Internet and find out information about the properties of the wire that she had demonstrated to her class. She gave them some research questions to work on. Emily had her students' research on the concepts of wave, diffraction, and interference. Wendy had her students' research about the insect they observed inside the jar. Jack's students did not conduct any research but he presented them with information on atoms and imaging and ultra violet visual spectroscopy (UV-Vis).

Theme 2: Designing procedures. In almost all the lab activities, the procedures were given to the students directly or indirectly. In Stacy's class, the students were asked to research and find out procedures for experiments in order to answer the research question. In Wendy's class, the students were asked to observe the insect and make notes of its habitat and behavior. In Emily's class, the students were given the formula to carry out the calculation, but were asked to find a way of figuring out the variables using the materials provided (laser pointers, optical transform slides, white boards)

Theme 3: Conducting experiments. The students conducted some kind of experiment or observation to reach a conclusion. In Stacy's class, the students carried out experiments to find out at what temperature the memory wire straightens up and how they can overcome that and change the shape of the wire. In Wendy's class, students observed insects kept in a jar and had to figure out what kind of insect it was. In Emily's class, the students had to carry out an experiment to figure out the pattern in the optical transform slides. In Jack's class, the students did an experiment to grown silver nanoparticles.

Theme 4: Collecting data. All the teachers had their students collect data of some nature whether observational or experimental. In Stacy's class, the students recorded the temperature at which the wire straightened up and the temperature at which it could be made to change its shape. In Wendy's class, the students drew sketches of the insect and it's habitat and counted the appendages and other details of the insect for further research. In Emily's class, the students collected data on the length of the distance between the dots on the screen and the distance between the screen and the laser. In Jack's class, the students collected the graph that was obtained from running the sample in the UV-Vis.

Theme 5: Discussing and presenting results. During the lesson, the students got an opportunity to discuss and present something. These discussions and presentations were mostly on science concepts rather than on results found from the real science experiments carried out by the students. Wendy's students discussed different kinds of illusions that they experienced in their daily lives within their groups and then shared their ideas with the whole class. Emily's students got into groups and presented white boards emphasizing the concepts of wave, diffraction, and interference. In Jack's class, the students worked on questions asked about Dalton's atomic theory in their groups and presented their answers on white boards to the class. In Stacy's class, the students presented their posters on findings from conducting the real science experiments on the memory wires.

The classroom observations also revealed that teachers spend most of the time introducing concepts and less time on real science. Three out of four teachers that were observed were found to spend half or more class time in covering concepts and very little time on real science activities. Stacy's class spent about one class period on researching for the properties of the wire and spent two class periods on doing experiments discussing results, refining procedures, and one class period on preparing and presenting the results. Emily's class spent five out of eight days on learning and researching concepts on waves, diffraction, and interference. They spent only two days on doing the diffraction experiment and collecting data, and carrying out some analysis. Jack's class spent one and a half class periods understanding concepts and one and a half class period on real science activities. Wendy's class spent three and a half class periods on activities to understand concepts and less than half a period on real science activities.

I analyzed the classroom observations to look for real science features in the lessons. The results revealed that only one teacher's instruction had evidence of five or more features of real science. The remaining teachers either did not implement the lesson or taught lessons that exhibited very few features of real science (Table 8).

Table 8
Classroom implementation analysis for evidence of real science

Categories	Wendy	Emily	Patsy	Jack	Stacy	Grace	Brad	Lucy
Formulating questions								
Background research	√	√		√	√			
Designing procedures					√			
Conducting experiments		√		√	√			
Collecting data	√	√		√	√			
Analyzing data					√			
Discussing results					√			
Presenting findings	√	√			√			
Modifying procedures					√			

* Shaded area indicates that the teachers were not observed. The light colored ticks indicate partial representation

A quantitative analysis on the classroom observation was carried out to calculate the time distribution of various activities in the lesson (Table 9). The categories are explained as follows:

- Labs / Demo represents time spent on students doing real science labs (conducting experiments, collecting data etc)
- Group activities represented time spent on activities that were related to understanding the concepts in the lesson
- Sharing ideas/ presentations represents time spent on students sharing ideas with each other in their groups or as whole group

- Whiteboard/poster represents time spent working on the white boards or giving a presentation
- Reflection/Reports represents time spent on reflecting on data or results to modify procedures or write reports
- Quiz/bell work is the time spent on doing quizzes and bell work in the beginning of the class
- Instruction is the time the teacher took to lecture on content or give instructions on labs and activities
- Internet search is the time spent by the students to do research and find out information regarding the experiments and activities

Table 9
Distribution of class time in minutes for lesson activities

Teacher	Class Time	Lab/ Demo	Group activity	Sharing ideas/ Presentation	Whiteboard/ Poster	Reflection/ Report	Quiz/Bell Work	Safety	Instruction	Internet search
Stacy	90	24	0	10	8	4	13	3	19	13
Wendy	55	6	14	5	0	4	10	0	16	0
Emily	55	8	3	5	13	4	5	0	6	10
Jack	55	20	6	3	8	3	0	1	14	0

Quantitative analysis of the classroom implementation revealed that teachers tend to spend minimum time reflecting on results and writing lab reports. Teachers spend a lot more time on covering concepts through instructions and activities than on doing real science labs. A comparison of the classroom implementation analysis with the lesson plans analysis reveals that even though the teachers had planned to involve students in analyzing data obtained from the observations and experiments, when implementing the lesson they did not end up spending time on analyzing results as planned.

An observation of the classroom setup revealed that none of the schools had the provision of classroom computers for student work. Two schools had the provision of requesting for laptop carts for planned assignments. Stacy and Emily had used the laptop carts for their unit. In both cases, there were a few laptops that did not work properly. The teachers mentioned that as the school year progresses, fewer of the laptops are found in working condition. Jack said he did not request for the laptop cart for his class because of that very reason. Here's what he said,

> We have two laptop sets that are floating around—unfortunately the laptops are outdated and outmoded—and are poorly maintained. So they don't really function—and when we purchased them, no body ever figured out that the battery was getting bad (*sic*)—which if you have a bad battery—I don't have 30 outlets over here to charge 30 laptops at once. So, without the batteries they are dead in the water—and that's frustrating!

Therefore, there was always a possibility of running into a problem with the computers if teachers were planning a lesson that involved the students using computers.

RTOP scores that were obtained from the classroom observations made before the summer research program and the RTOP scores that were obtained from the teachers who implemented the curriculum unit after the summer research program were analyzed. Classroom observations were conducted for seven teachers before the summer program, but only four teachers implemented the curriculum unit after the program. Therefore a pre to post analysis was conducted for the four teachers. Figure 17 shows the comparison of scores of the four teachers before and after the program. There was an increase of more than 30 score points in Emily's score and about 5 points in Jack's score indicating an improvement in reformed teaching methods after the program. There was a decrease in Wendy's score from before to after the program indicating that her classroom instruction was less reformed after the program in comparison to the instruction that was observed before the program. Stacy's score remained the same from before to after the program indicating that the level of reformed teaching methods exhibited in her classroom instruction remained the same from before to after the program.

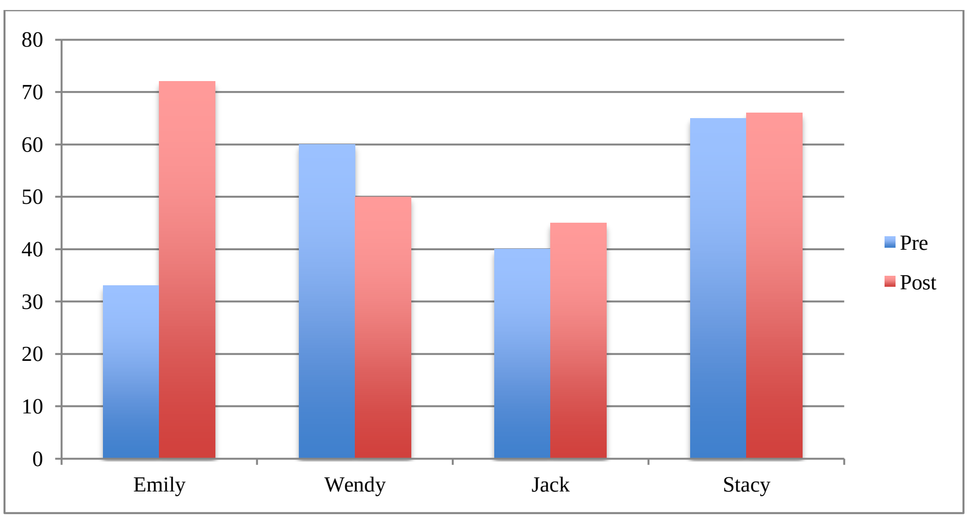

Figure 17. Pre-post RTOP scores of four teachers who implemented the research unit

One reason for the large difference in Emily's score is that when the pre-observation was conducted, she was revising concepts for the final exams. She was not teaching a new lesson. The post observation was a lesson based on the fundamental concept of atoms. She had activities that gave the students an opportunity to research and learn the concepts and conduct a real science activity related to the concept.

Wendy's score decreased from pre to post observation because the real science activity was not tied to the curriculum and was lacking in conceptual understanding. She had some activities on understanding the nature of science, but the students did not get an opportunity to connect that to a real science activity.

Jack's score increased by a few points but his score in general was lower than the scores of the other teachers. The main reason for this was the lack in conceptual understanding. The students followed a given experimental procedure and collected some data analyzed by the spectrometer, but there were no discussions on the results and no opportunity to connect the real science activity to the overarching concept on theory of atoms. The real science activity did not encourage divergent modes of student thinking.

Stacy's scores remained the same because she used similar strategies. She encouraged divergent modes of thinking and student discussions. The difference was that the pre lesson did not have a real science activity whereas the post had one. However, the lessons did not bring together the activities and connect it with the overarching concept. The real science activity that she had planned for the research unit was not connected to the content curriculum. It was planned to incorporate the idea of collaboration and competition in scientific research, an aspect of the nature of science.

After analyzing the results, I found that according to the program applications and the interviews the teachers intended to make science relevant to the students and incorporate real science activities in their science lessons. This was however, not evident when I conducted the classroom observations. The majority of the teachers were either revising concepts or engaged in activities to acquire knowledge of science concepts. This gave an impression that the teachers did not engage in real science activities that frequently. Based on what the teachers said and wrote, it was evident that the teachers expected to learn real science techniques during the research experience, which they wanted to bring back to the students. Unfortunately, there was not much evidence of transfer of real science into the classroom. Only half the teachers (three mentors and one new) implemented the curriculum unit that they had planned. The teachers who implemented the unit were found to incorporate limited components of real science. Teachers did not engage students in developing research questions, generating hypothesis, discussing results, or modifying methods.

Discussion

As evident from the results, the ASU MSTF 2010 program was not effective in transferring real science experience into the classroom. It essentially violated the critical components that constitute an effective science professional development (Supovitz & Turner, 2000). This can be mainly attributed to the weak structure of the program, which can be mostly attributed to break-ups between the organizers, shortage of staff, and shortage of funds. There were not enough personnel to run the program effectively. There was only one expert responsible for organizing the whole program after the science educator left the university close to the start of the program. The science educator was supposed to organize the afternoon sessions and the laboratory placements. Since ASU MSTF 2010 was an extended year, the program was run with leftover funds, which partly came from Science Foundation Arizona and partly from Arizona State University. To make things worse, these funds were locked into fixed accounts by the funding agencies, so they could not be taken from one account and used for a different purpose. These led to various reasons that contributed to lack of the real science when it was time for the teachers to implement the research experience in the classroom. Figure 18 gives a summary of the factors responsible for the implementation of research experience in the classroom. Let's examine the factors in more detail.

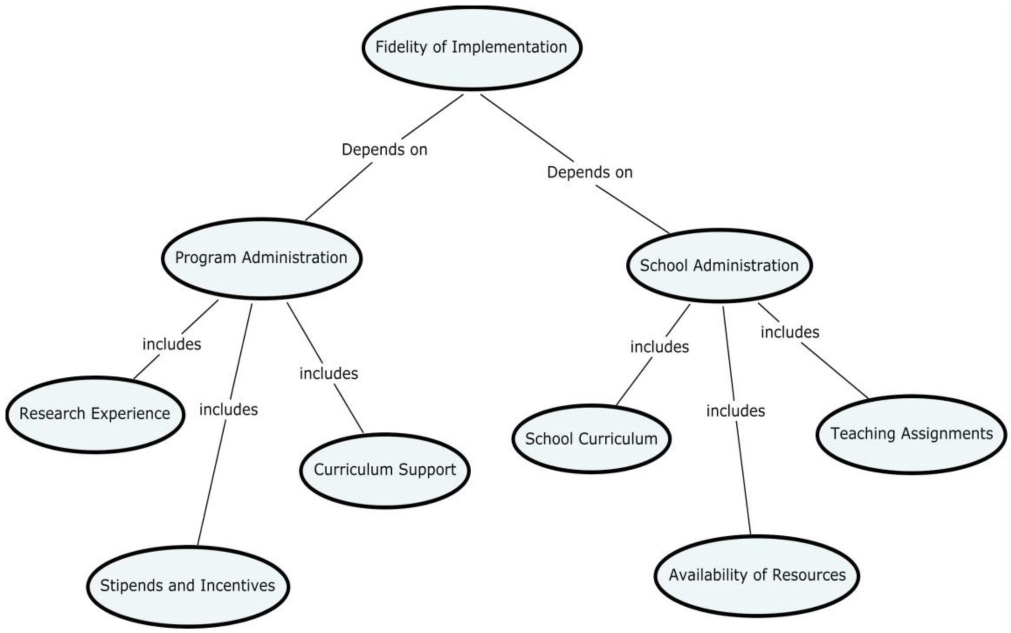

Figure 18. Factors that affect the fidelity of implementation of research experience

Effect of Program Administration

Time is a big factor in a research program. It has been found that effective professional development require intensive and sustained training (Fullan & Pomfret, 1977; Smylie, Bilcer, Greenberg, & Harris, 1998; Hawley & Valli, 1999). Four weeks is not enough time to have a good research experience as emphasized by the research directors. The level of subject matter knowledge that is involved in the research laboratories is far above the high school level. The high school teachers needed some time to understand the research and learn the techniques. Only then can they experience real research. This in itself takes some time. In addition, they have to plan a curriculum unit that would take some more time. To expect teachers to start planning a project from the very first week is unreasonable, especially when they receive minimal help or guidance. Moreover, it would have been beneficial to have follow-up sessions with teachers during the school year. Research has found that teachers need 80 hours or more of professional development spread over 6 to 12 months in order to see changes in teaching practice (Yoon et al., 2007; Corcoran, McVay, & Riordan, 2003; Supovitz & Turner, 2000; Banilower, 2002). The curriculum development sessions during the program added up to about 42 hours. Professional development time was diluted with the addition of the technology component that was thought to be helpful for teachers who were not computer savvy.

The teachers would have benefitted from the research experience if the program had been organized with equal involvement from teachers, science educators, administrators, researchers, and laboratory directors (Van Driel et al., 2001). There were no set expectations as to how the laboratories would arrange the research experience for the teachers. Hence, each laboratory organized it according to their convenience resulting in half the teachers being assigned a research project while others were acting as spectators for the majority of the time.

The afternoon sessions mainly focused on learning strategies to improve general classroom teaching, which contributed very little towards transferring real science into the classroom (computer applications, concept mapping, concept inventories, RTOP training). Although some of the computer technology like Excel would be helpful in doing real science, most of the schools did not have computers in the classroom. In order for students to use computers for analysis, the teacher would have to schedule a time at the computer lab. If the school had mobile carts with laptops, they were not well maintained. There seems to be too many factors acting against the use of technology in the high schools. Although the teachers spent so much time on learning technology, they would most probably not be using the technology except on rare occasions. In this case a meeting with the administrators would have been beneficial. Looking at it from the point of view of applicability, the money spent on buying laptops for the teachers could have been better served if it was used for buying scientific equipment.

Teachers did not have enough support in translating the research content into the school curriculum. There was an inherent assumption that since the teachers already had some teaching experience, they would know how to develop a curriculum unit that was in some way related to the research area. During the afternoon sessions, the teachers were left on their own to figure out how to plan their lessons with some ideas from the mentor teachers. There was more emphasis on completing the posters at the end of the program because the teachers had to participate in a poster presentation. There was very little emphasis on the completion of the curriculum plan. It was also difficult for the teachers to decipher the connection of the research experience to specific standards for student performance (NRC, 1996; Hawley & Valli, 1999) without much guidance. The involvement of the previous year teachers (mentors) in running the afternoon sessions was helpful to some extent. They shared some valuable lesson ideas as well as some useful teaching tools. However, they were not able to help with the specifics of the curriculum plans or executing an effective real science lesson. The teachers would have benefitted from receiving guidance from curriculum developers and experienced science educators.

The program was developed with an assumption that teachers would gain understanding of the nature of science and incorporate that in their school curriculum by simply observing research in the laboratories and reading articles on the nature of science without any explicit instruction. However, research has shown that implicit methods are not effective in enhancing teacher conceptions of the nature of science. Abd-el-khalick and Lederman (2000) have emphasized the need of explicit and reflective activities in attempting to improve teachers' concepts of nature of science.

The teachers seemed to be very interested in the nature of science as was evident in their pre-program applications, reflections in the blogs regarding their individual experiences at the research laboratories, discussions during the afternoon sessions, planning lessons for implementing research experience, and delivering lessons during the school year. However, from their discussions and comments in the blogs, it was evident that most of the teachers seemed to have a limited view of the nature of science. Most of their discussions about the nature of science were around the processes of science or the nature of research activities that they saw at the laboratories. That was because there was only one session of formal discussion on the nature of science. There were no sessions where teachers were involved in identifying aspects of the nature of science or spent time on aspects of the nature of science in their respective lessons. The teachers who planned their research unit on the nature of science did so mainly because they decided that the research content was not within the scope of their school curriculum. They had to depend on the Internet to find lessons on the nature of science.

The program would have been more effective if teachers were selected collectively from the same school and involving them in active learning opportunities. That way they could have observed each other's lessons and obtained feedback from each other regarding their lessons (House, 1975; Fullan & Pomfret, 1977; Desimone et al., 2002). The project would have been more successful if the curriculum unit was built on teachers' prior knowledge and one that was already included in the school curriculum (Desimone et al., 2002). In order to ensure major changes in teaching instruction, continuing support is required during planning, implementing, and reflecting on instruction (Hewson, 2007). Unfortunately, things fell apart in the very beginning of the execution of the program. All the support regarding the curriculum planning failed to materialize because the science educator who was responsible for conducting the afternoon sessions left the university. She was also in charge of the laboratory placements that had to be taken care by the program director at the last minute. In addition, there was a problem with the course enrollment. Therefore, administratively the program was not able to function smoothly, which made it worse for the teachers to implement the research experience in the classroom.

Effect of School Administration

The program should have taken into consideration the school infrastructure during the planning phase in order to make it effective (Fullan, 1991; O' Day & Smith, 1993; Corcoran & Goertz, 1995). Research has shown that teachers face a number of difficulties such as time constraints, equipment, and financial resources in transferring research experience to the classrooms (Boser et al., 1988; Brown & Melear, 2007).

Schools do not have expensive science equipments like the ones the teachers work with in the research laboratories. Most schools even lack funds to buy inexpensive equipment. Inaccessibility of material resources plays an important role in the implementation of the lesson. As in Jack's case, sometimes teachers have to make arrangements from outside school to get materials they need for their lesson. That delays the lesson implementation and if they cannot do it within the planned time period, there is a high chance that teachers may decide not to implement the unit.

There is also the factor of inserting the research unit into the school curriculum. If teachers plan their research unit on topics that are not related to any of the topics in their school curriculum, it becomes difficult for them to find the time to implement the unit. Research suggests that if teachers sense a disconnect between what they are asked to do as part of the professional development and what is in the school curriculum guidelines, or if the school administrators are not supportive of the new initiative, then the professional development tends to have little impact (Elmore & Burney, 1997; Cohen & Hill, 2001; Garet et al., 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Supovitz, Mayer & Kahle, 2000).

Changes in teaching assignments of science teachers in the new school year were high. However, this was not taken into consideration while planning the curriculum component of the program. This resulted in teachers being stuck with a unit that they thought they could teach in their classrooms only to find out later that it did not fit into their new curriculum or teaching assignment. This situation could have been avoided if the teachers were guided to modify lessons to incorporate real science components. In that case, they would have an experience, which they could apply to any situation.

Pedagogical Content Knowledge of Research Experience

Let's examine the implementation of research experience from the point of view of pedagogical content knowledge (PCK) as defined by Schulman (1986). The teachers have to take into consideration many different factors in order to plan and implement a unit. Figure 19 displays the kinds of knowledge that a teacher needs to gather in order to plan a unit for implementing the research experience.

The ASU MSTF project was designed to give teachers a real life experience of a research laboratory. These teachers were expected to take the research experience and translate it into a classroom experience for their students. The topic that was researched in the research laboratory was of a much higher cognitive level than the high school level and was quite remote from the topics that they had in their school curriculum. The teachers encountered research specific content area that they had never taught before in their classroom. The background knowledge needed by the students to comprehend the research topic was far beyond the scope of high school curriculum. So, invariably designing a curriculum for the students based on the research experience came as a big challenge.

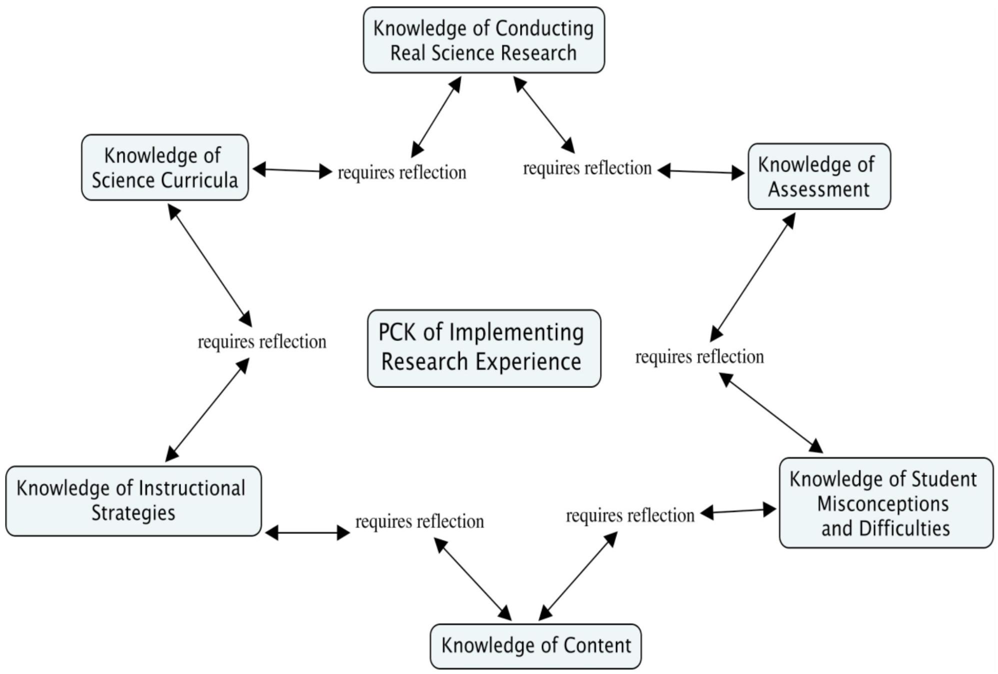

Figure 19. Knowledge structures for implementing ASU MSTF research experience (based on Schulman's idea of PCK, 1986)

The essential prerequisite of PCK is content knowledge (Schulman, 1986). As evident in my study, the teachers required time to understand the content of research. They were given different articles to read on the research done in the laboratories, but much of the terminology that they encountered in those articles was new to them. The laboratory assistants and researchers helped the teachers in understanding the content and procedures of the research being conducted. The teachers that were placed in laboratories with projects planned for them experienced some hands on research making it easier for them to understand the research. The interesting point is that in most cases, they were trying to learn content that was not related to the school curriculum.

In order to plan a unit, the teachers have to know the science standards. The teachers also need to know the curricular materials that are available and the horizontal and vertical curricula for the subject (Grossman, 1990). Based on this knowledge, the teachers can think about the research area and make appropriate adaptations to design a unit that will be appropriate for their students. Before they start planning their lessons they need to have a clear idea about the goals and objectives for the lesson. It is important that the teachers focus on conceptual understanding of the unit by giving concrete examples and making it relevant to the lives of the students. Students don't gain proper knowledge when lessons are detached from the science curriculum.

Next, the teachers have to take into consideration the prior knowledge, needs, and interests of the students. They have to think about the preconceptions, conceptions, or misconception that the students might have on the content that they plan to teach (Schulman, 1986). Understanding students' misconceptions impact the decisions teachers make throughout the entire process of teaching from planning to assessment and as a result their PCK becomes more sophisticated (Park & Oliver, 2008). The teachers have to know how students vary in their approaches to learning as they relate to developing specific understanding based on developmental levels, ability levels, and learning styles (Magnusson, et al., 1999). Some schools have a diverse background of students and hence the teachers have to take into consideration the cultural implications of the content that they are trying to introduce to the students. Considering this while planning a curriculum requires substantial amount of thought and time. Moreover, high school students have difficulty connecting with research material of graduate level because they do not have the necessary prior knowledge to understand the concepts. As was evident in my study, with the shortage of time and the unreasonable expectations, the teachers had no choice left other than doing a unit that was disjointed from the high school science content.

Teachers require a predetermined set of strategies to work with. According to Schulman (1986), for the topics that teachers teach regularly in their subject area, they should have a repertoire of powerful analogies, illustrations, examples, explanations, and demonstrations that would increase the comprehensibility of the subject to the others and help in reorganizing the preexisting understandings of the learners. Since the teachers in the ASU MSTF program were trying to plan something completely new, they had to think of new forms of representations, analogies, examples, and activities that students will be interested in and strategies to help clear misconceptions. The program required teachers to plan guided inquiry activities for the research unit. The infrastructure in most of the laboratories that the teachers worked in during their research experience was quite elaborate. In most cases, it was practically impossible to use the same equipment and materials as the ones used in their placement laboratories. They had to think of materials and equipment that would be appropriate for use in their school science laboratories. In order to do that, they had to take into consideration safety issues, cost, setup, etc. If teachers do not have a well setup science laboratory in their schools, they have to plan a laboratory activity that can be setup in the classroom itself. The teachers also have to think about the district and school policies. They have to get an approval before they plan any activity with materials that may be prohibited in the school or the classroom. For example, some teachers in this program wanted to bring in black widow spiders, or if they wanted to install new software in the school computers for the students to use, they had to make sure that they had the permission to use them. They found it very challenging to deal with the situation and were frustrated when the administration was not supportive.

Assessment is an important component of PCK. Teachers have to be assessing their students throughout the unit. An effective teacher is one, who constantly assesses, reflects and makes changes to their lessons at every phase of the teaching learning process. It is through assessments that the teachers become aware of the students' misconceptions and the level of understanding that the students are acquiring from the lesson. Unless a teacher reflects on the misconceptions and confronts them, they will miss the opportunity to stimulate a conceptual change (Park & Oliver, 2008). A teacher who is not reflective tends to miss the teachable moments in the classroom. Moreover, since the research topic is new for the teachers themselves, it becomes harder for them to understand student misconceptions. Teachers need to have a good grasp of the content in order to make their lessons effective for the students. They have to keep thinking of ways to improve their lessons. Teachers also have to decide how to assess the students at various points during the progress of the unit. The teachers can use diagnostic assessments to figure out the knowledge the students have about a particular instrument that they will be using or the particular topic that they will be learning about. During the unit, the teachers can use formative assessments to assess student understanding while they are engaged in lab activities, small group discussions, whole group discussions or presentations. Summative assessments can be used in the form of laboratory reports or end of unit evaluations. An important point to keep in mind during assessments is the objectives and goals for the unit. Preparing good assessments takes a considerable amount of time and needs multiple revisions based on feedback from students and experts. It is unreasonable to expect teachers to plan good assessments within a short period of time.

Therefore, it is evident that a combination of different knowledge structures is integral to any kind of lesson planning. In planning a unit related to the research topic, the teachers face an additional challenge of translating graduate level knowledge to the high school level or adaptation of certain aspects into the school curriculum within a short span of time. This adds a heavy cognitive load on the teachers, especially when there is not much guidance with the planning of the curriculum. Another reason why connecting to the school curriculum seems difficult is because major part of the high school science curriculum is based on what is already known whereas at the research laboratories, scientists are working on what is not known. It does not make a lot of sense to spend such huge amounts of funds for programs that benefit so little in terms of actual transfer into the classroom.

There seems to be a huge disconnect between the objective of the funding agencies for teacher programs and the kind of programs they fund. It does not make much sense to have teachers spend time doing something that is so remotely connected to the school curriculum. In their website, Science Foundation Arizona (SFAz) claim, "We establish research, internship and professional development opportunities for mathematics, science and Career & Technical Education (CTE) teachers to build content knowledge and bring new techniques & approaches that translate to the classroom." Neither the content nor the techniques are anywhere close to the school curriculum. In most cases the teachers end up doing a unit in the beginning of the year when they teach the scientific method. So, how is the objective being accomplished when teachers are spending most of the time on something that is not transferable to the classroom and if that is the case then why bring in teachers for such experiences? SFAz is pleased to find out that the program is rated as outstanding by 75% of the teachers, but what should actually matter more is how much of the experience was implemented in the classrooms.

There were certain limitations of the study. The sample size is small and it is hard to generalize the findings to a larger population. Also, I was able to observe only one day's lesson for the pre-program classroom observations. The final selections of the teachers for the program went late into the March and I had a short period of time before the school closing to make the observations. Hence, I was able to schedule only one class period per teacher. Therefore the pre-program observation data might not be a good representation of a typical science unit. The RTOP scores may not be reliable to look at gains in reformed teaching. For the teachers who did not implement the lesson, there could be other factors that were responsible, which I was not able to identify in my investigation.

Implications and Recommendations

This research study was able to throw light on a number of points that would be beneficial to note for development of research programs in the future. Figure 20 gives a summary of the factors that would be helpful in ensuring implementation of research experience in the classroom. There are two main components of the research experience that need to go hand in hand for teachers to obtain the most out of the program, research experience and curriculum planning.

The duration of the research program seems to be crucial so that the teachers can take away something substantial to the classroom. Teachers should have experience of a whole day's activity in order to get an overall idea of how research is conducted in the laboratories. In order to have a good research experience, the teachers should be given a list of the ongoing projects in the participating laboratories before hand, so they can choose one that they are interested to work on. The teachers need to be assigned to research projects right from the beginning of the program so that they do not have to spend time during the program to decide on a project to work on. It is imperative that the teachers receive hands on experience of the research and are involved in the process of real

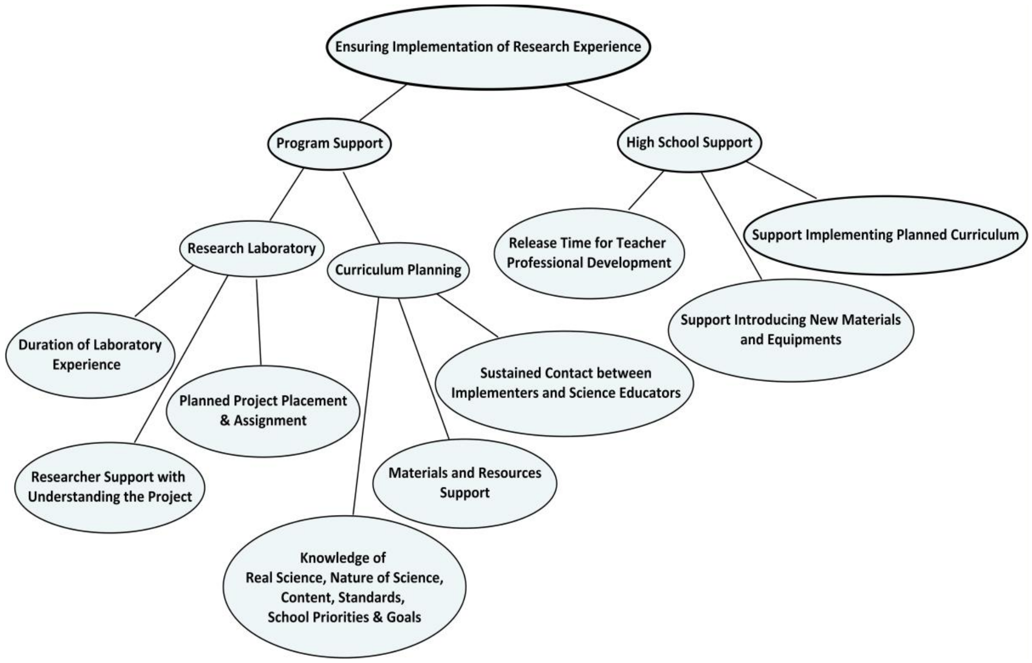

Figure 20. Factors responsible for ensuring implementation of research experience

science. It is essential that teachers are included in the research meetings and discussions regarding the research. They should be able to experience all the components of real science in order to have a full experience of scientific research. It is also imperative that an initial meeting with the research directors is organized in order to educate them about the needs of the teachers, the school curriculum, and the expectations of the program. Teachers do not need to know the specifics of the research. What they need to focus on is building an enriched science curriculum for their students. Therefore, teachers should be engaged in small research projects that can be done in three weeks time by spending all day in the laboratory. I would recommend that teachers be involved in identifying the real science activities and the nature of science they experience and observe at the laboratories. As evident in my study, there are many instances pertaining to the nature of science like tentativeness, creativity, skepticism, competition, collaboration, observations, scientific method, etc. that can be identified in the laboratories, especially during the rich discussions that take place at the research meetings where the researchers share the progress of their work. In order to make the research experience worthwhile for teachers, the researchers have to be given some guidelines regarding the nature of emphasis during the research experience for the teachers. The researchers obviously do not know what teachers need for their classroom and need to be educated about the curriculum and the set up at the schools. Researchers will then be in a better position to enlighten teachers with concrete examples of the nature of science. When teachers are involved in the experience and are able to relate to something concrete, they will find it easier to understand the concepts. That will in turn help them communicate those concepts to their students with confidence.

A major component of the program should be curriculum development which will ensure that teachers take something substantive from the research experience into the classroom. However, a single unit related to the research experience does not seem to work. There are too many factors that come into play when the teachers return to the school environment. There are timing issues, assignment issues, administrator approvals, etc. that does not seem to work very well. In addition, it was evident that most of the time the teachers were not very confident about teaching the topic. Teachers were found to leave out the essential piece of the unit where the activity needed to be connected to the conceptual framework, leaving the students wondering what that unit had to do with anything they had already learned or will be learning which did more harm than good. My recommendations are in accordance with the suggestions of Fullan and Pomfret (1977) and House (1975) in terms of having many real science lessons spread over the school year, more contact time among the participants during the school year for an effective implementation of the research experience.

To make the program effective in terms of transfer to the classroom, teachers should be provided support and guidance in planning real science laboratories that link to their school curriculum, rather than working on inserting one particular unit into their curriculum. Teachers should spend at least four weeks on building curriculums that incorporate real science and the nature of science. This time should be spread over the whole year with an intensive two-week workshop during summer and two days a month during the school year. The program should make sure that teachers have approval for professional development hours during the school year. There should be enough funds to have subject specialists and education specialists who can provide help and guidance with the content and the curriculum development. This way, the teachers can come out of the program with three to four enriched units, which have been implemented and improved with feedback from peers and experts. It is not enough for students to be influenced by merely listening to the teacher about cutting edge research. Students should have firsthand experience of cutting-edge research in order to be influenced by it and make their career decisions. Field trips to the research laboratories, virtual tours of research laboratories, or short-term projects at research laboratories may influence students in taking up science as a career. Incorporating such changes into the high school curriculum will help teachers and students gain something substantial out of the research experience and ensure that the program meets its true purpose.

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APPENDIX A

APPLICATION FOR ASU MATH AND SCIENCE TEACHING FELLOW PROGRAM

Applicant Information

Full Name:

Address : Work Phone : Home Phone: Cell Phone :

Email Address: Alternate Email :

Project Choice: Please choose only from the following: (1) Biosciences, (2) Information Technology and Advanced Com (3) Sustainable Systems.

Choice 1: Choice 2: Choice 3:

Education

College: From: To:

Did you graduate? Yes | No

Degree: Major:

College: From: To:

Did you graduate? Yes | No

Degree: Major:

Graduate School: From: To:

Did you graduate? Yes | No

Degree: Major:

Graduate School: From: To:

Did you graduate? Yes | No

Degree: Major:

References

Please list three professional references.

Full Name: Relationship:

School or Company:

Phone: Address and email:

Full Name: Relationship:

School or Company:

Phone: Address and email:

Full Name: Relationship:

School or Company:

Phone: Address and email:

Teaching (last 5 years)

Present School: City: State:

From: To: Courses Taught:

Previous School: City: State:

From: To: Courses Taught:

Previous School: City: State:

From: To: Courses Taught:

Laptop Computer Preference

A laptop computer will be provided (unless ASU has previously provided a computer)

Have you received a laptop from ASU in the last three (3) years? Yes | No

Laptop preference: PC | Macintosh | Already have one

Approach to Teaching and Curriculum Development

Please describe how you expect to transfer the key ideas from what you learn in this research experience to original classroom activities for your students.

What do you presently do to guide students to link their actions in activities with the concepts you want them to acquire in the activity?

Program Requirements

I understand that participation in this program involves the following:

1. Full day attendance at ASU from June 21 through July 16, 2010 (excluding July 4).

2. Learning new computer skills.

3. Enrollment in a tuition-free three-credit Fall semester graduate course and completion of course requirements by December 9.

4. Testing of newly developed module in my classroom.

5. Approximately 40 hours of curriculum work between July 16, 2010 and March 31, 2011. ($1000 will be paid for 40 hours of work.)

6. One or two possible return visits to ASU on a Saturday between July 16, 2010 and March 31, 2011. (Time spent during such visits will count toward the 40 hours mentioned above.)

7. Photographs and video recordings of MSTFs and MSTF activities will be made for use by ASU.

Please describe any concerns or exceptions you may have to the above:

Disclaimer and Signature

I certify that my answers are true and complete to the best of my knowledge. I understand that false or misleading information in my application or interview may result in my release from the program.

Email Address:

Confirm Email Address:

Date:

We will try to place teachers from the same school or district into the same research group. Preference may be given to groups of teachers from the same school or district, so please encourage other math and science teachers from your school or district to apply.

Submit

APPENDIX B

LESSON PLAN TEMPLATE

Name of Teacher: School:

Years of Teaching : Teaching

Certification:

Subject: Grade level:

Topic : Duration:

A. Conceptual framework of your unit (what are the major concepts and connections emphasized on):

B. Prior knowledge of students (what previous conceptions or misconceptions do you think the students have on the topic):

C. Specific objectives for student learning:

D. The Arizona standards that the curriculum addresses:

E. Use of technology (introduced during the program):

F. Use of materials (purchased with MSTF funds):

G. Use of strategies to enhance content knowledge of students:

H. Aspects of Nature of Science you intend to address:

I. Give a full description of each activity. Explain the teacher's role and the student's role in the 5 phases of the learning cycle (Engage, Explore, Explain, Elaborate, & Evaluate)

J. The learning assessments to be given to students aligned with your specific objectives and the Arizona state standards (Attach a copy of a summative assessment).

APPENDIX C

INTERVIEW QUESTIONS

Before Summer Program

1. What motivated you to apply for the research program? What do you hope to gain from the program?
2. What kind of science knowledge do you believe students should acquire in high school?
3. What skills do you want your students to take away from your science class?
4. How do you think students learn best?
5. Do you expect the activities in a research lab to be different from your high school science lab? Explain.

After Unit Implementation

1. How do you feel about having taught the research unit? What did the students think about the research unit?
2. Did you notice any significant changes in your teaching practice as a result of the research experience?
3. How did you assess student understanding?
4. Did you face any difficulties in implementing the unit? Explain
5. Will you teach the unit next year? What changes, if any, would you make?

Program Coordinators

1. What do you think the program will provide for the teachers?
2. How do you think the program will impact their teaching practices?

Lab Directors

1. What kind of lab experience will the teachers have in your lab setting?

2. What are some skills that you think that they can take back to their school settings?

Principal

What kind of support do you provide for the teachers so they can implement the research unit effectively?

APPENDIX D

IRB APPROVAL FOR PILOT STUDY

ARIZONA STATE UNIVERSITY
RESEARCH AND ECONOMIC AFFAIRS

Office of Research Integrity and Assurance

To:	Dale Baker EDB
From:	Mark Roosa, Chair Soc Beh IRB
Date:	11/10/2009
Committee Action:	**Exemption Granted**
IRB Action Date:	11/10/2009
IRB Protocol #:	0910004487
Study Title:	Impact of Research Experience for Teachers on Science Instruction in High Schools

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

APPENDIX E

IRB APPROVAL FOR MAIN STUDY

ASU Arizona State University
Research and Economic Affairs

Office of Research Integrity and Assurance

To:	Dale Baker EDB
for **From:**	Mark Roosa, Chair SM Soc Beh IRB
Date:	04/19/2010
Committee Action:	**Exemption Granted**
IRB Action Date:	04/19/2010
IRB Protocol #:	1004005076
Study Title:	Impact of research experience for teachers on science instruction in high schools

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) (2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.