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This study illustrates how one summer science institute focused on Genes, Heredity, and Mutation has evolved into a holistic program, the Oklahoma Science Project (OSP), for addressing the needs of secondary school science teachers.[1] *Identified needs include authentic research experiences wherein teachers construct conceptual knowledge of science content, continued practical support throughout the academic year, and development of manual and cognitive skills necessary to understand the nature and process of scientific inquiry. The study spans eight years of interaction among teachers and research scientist Philip Silverman and presents vignettes to illustrate the complexity and individuality of the projects. Qualitative data over the eight years produced case studies of 33 individual teachers from 32 of Oklahoma's 431 school districts. The manifest impact of the OSP on teachers' classroom practices varies greatly, but some generalities appear: (a) More significant changes in classroom practices were observed in teachers in small schools; (b) teachers in both small and large schools tended to utilize the techniques and activities abducted directly from their OSP experiences with individual students or small groups rather than entire classes; (c) teachers exhibited inquiry skills more effectively when familiar laboratory and/or classroom activities were revised in collaboration with OSP staff rather than attempting to introduce new activities; and (d) teachers progressively manifested a deeper understanding of the content and nature of science over time when collaboration continued with OSP staff and director. The report concludes with a discussion of strengths and offers suggestions for continued growth and enhancement of the OSP and its evaluation techniques.*

Introduction

Improving the quality of professional development in order to implement standards-based teaching practices in U.S. schools turns out to be a remarkably subtle and lengthy process. At the crux of this complexity is the uniqueness of each school district, classroom, and teacher, all functioning within a single educational model.

Science education reform efforts have been ongoing for nearly half a century, and many scientists became involved in the reform efforts during the 1960s as the first wave of summer science institutes for teachers were funded by the National

1. I would like to acknowledge grant support from the Howard Hughes Medical Institution (HHMI) for funding the research. I also would like to acknowledge Phil Silverman's contribution to the work; without his candor and willingness to discuss all aspects of his program, my insight into the workings of this complex program would have been extremely limited. Our conversations throughout the years have stretched my intellectual limits and contributed greatly to my personal and professional growth.

Science Foundation. And yet no large-scale sustained change resulted from this movement (Hurd, 1995). Two salient obstacles to change are the type of and quality of professional development offered to teachers. In her address to the House of Representatives Committee on Science, J. B. Kahle (1997) described the majority of professional development experiences as built upon a "training paradigm: short term, standardized sessions designed to impart discrete skills and/or techniques." Thus, the professional development experiences that were intended to move teachers to implement more constructivist classroom practices continued to model the more traditional, transmissive type of teaching and learning. In addition, many of these professional development programs were not accompanied by research that could have more clearly identified program strengths and shortcomings (Snyder & Frechtling, 1997) and drive future efforts in the desired direction. New paradigms for professional development, designed within the framework of the National Science Education Standards (NRC, 1996), were clearly needed in order to better prepare teachers to guide students through active and extended scientific investigations.

Project 2061, and its related documents, began to address these needs in 1985, but even after a decade of workshops researchers found that "relatively few teachers strongly agreed with some central reform ideas ... teachers did not perceive a very strong linkage of the workshop ideas to classroom practice" (Zucker, Young, & Luczak, 1996, p. 5).

In response to these findings, the National Science Foundation funded systemic initiatives. Many of these systemic initiatives involved scientists in academic, industrial, and/or biomedical settings and were designed to enhance standards-based teaching practices by offering teachers experiences that included a historical perspective of scientific discovery, engagement in science processes, and meaty science content. Studies related to the systemic initiatives indicated that "sustained professional development, focused on content, affects teaching practice and that the changes are retained" (Kahle, 1997). The National Science Education Standards (NRC, 1996) related to professional development also place strong emphasis on the teacher as a member of a collegial professional community and as the source and facilitator of change (NRC, 1996, p. 72). Therefore, programs that offer authentic research experiences, focus on teachers, and aim to embrace teachers of science as part of the larger scientific community are especially warranted.

This report is intended to provide a vivid picture of one such program, the Oklahoma Science Project (OSP). The narrative is designed to illustrate clearly how the OSP is in a constant state of transformation; its evolution is driven by the iterative quest to determine how the program is/is not serving the needs of teachers and how to serve them better. The evaluation of the OSP, therefore, is as dynamic as the program itself.

The report consists of four levels of evaluation: (a) reactions and feelings of participants, (b) learning (attitudes, perceptions, or knowledge) of all partners, (c) changes in skills and or abilities (applied what was learned to enhance the OSP and/or classroom practices), and (d) effectiveness (improved performance because of enhanced behaviors). The units of analysis progressed from individual case studies at level one, to yearly case sets for levels two and three, and finally to a holistic analysis of all eight case sets for level four.

Program Conceptualization

The Oklahoma Science Project (OSP) had its origins in the Foundation Scholar Program which was initiated at the Oklahoma Medical Research Foundation in 1988 to provide research experiences for Oklahoma public high school science teachers. The Oklahoma Medical Research Foundation Scholar program was one of the second wave of summer science institutes that emerged in the late 1980s and 1990s, as such institutes were encouraged and funded by a variety of scientific professional entities. The resurgence of summer institutes came about largely as a result of reform movements linked to science literacy (AAAS, 1993).

Because teachers are expected to create rich learning environments where their students can develop the thinking skills of scientists (Roth & Roychoudhury, 1993), and the majority of teachers have never experienced such environments (Dondt, Telsch, & Tucker, 2000), the need for scientists to become actively involved in science education was well recognized.

While many summer institutes for teachers implemented in the 1980s were didactic or workshop-oriented, the Oklahoma Medical Research Foundation recognized that teachers needed authentic research experiences if they were to have any chance of conceptualizing the true nature of scientific endeavor. The program was based on a standard model in which a teacher is placed in a research laboratory for eight weeks during the summer to engage in work related to an ongoing medical research problem, under the tutelage of a professional research scientist. The theory of action for this model was that teachers immersed in the scientific culture of a research laboratory would gain a more thorough understanding of science content and process and, in turn, be able to provide more authentic experiences for their students.

In 1993, Dr. Philip Silverman, then a relative newcomer to the Oklahoma Medical Research Foundation and a non-participating observer of the Foundation Scholar Program, took notice of and began to reflect upon several aspects of the program. In his opinion, the most positive aspect of this approach was that some of the teachers were genuinely inspired by their experience. Contrary to the assumption underlying the model however, he observed that the teachers interacted with technicians on a daily basis rather than with the researcher who headed the project; teachers engaged in science processes and their *technical skills* increased.

As for content, eight weeks relative to the exorbitant amount of time necessary for advances in biomedical research is a very short time indeed; the time constraints limited a teacher's focus to only a very small portion of the overall research problem. But the major drawback was that the experience invariably left teachers with nothing to take back to their students except enthusiasm, which Dr. Silverman suspected would quickly fade in the face of classroom reality, and a set of technical skills rather than cognitive ones. As he devoted considerable thought to the types of experiences that might actually be useful in pre-college biology or chemistry, he realized that there was no direct connection between the research strengths of the Oklahoma Medical Research Foundation and the kinds of research that might be optimal for the pre-college science classroom. Science education and scientific research are overlapping, but clearly separate, activities. If the goal of the program was to renew the teachers' excitement for science, then carry on. However, if the Foundation genuinely desired to impact the classrooms of the teachers, a model experience must be developed that would not only allow teachers to enhance their own scientific knowledge and develop a "felt meaning" (Caine & Caine, 2001) for the history and nature of science, but that would also provide the impetus for teachers to develop mental models to assist them in designing experiences/environments wherein their students could construct scientific knowledge rather than classrooms where students are taught about scientific knowledge. Clearly, science education was going to have to be addressed on its own terms.

Schools have content-laden curricula, limited budgets, severe time constraints, and generally only the simplest of scientific apparatus available for experiments. Recognizing this, Silverman reasoned that the techniques used to address specific science content for pre-college courses must be simple, economical, and result in data that lead clearly to basic biological principles.

Working on a solution for the specific content to be addressed proved to be a fruitful exercise indeed. As Silverman meditated upon the most critical content issues, certain facts loomed large before him. Each science is organized around one or a few central concepts without which the science itself becomes incoherent. Often we can point to one or a few key events in the history of the science that gave rise to the central concept. For chemistry, the periodic table first organized the structure and properties of the elements. For physics, energy, its conservation, and its transformations are central organizing concepts. Pedagogically, these organizing concepts are crucial to understanding, much as they were in the historical development of the subject. This is especially important in the pre-college curriculum because adolescents will retain only very few concepts and facts. It therefore makes sense to select only those concepts and facts that are central to the subject and to develop them in depth. Indeed, this appears to be the organizing concept of the National Science Education Standards (NRC, 1996). Genetic inheritance is the organizing concept for biology. It permits the evolution of life in ways that are not observed with purely physical/chemical systems. This is not to argue that transformations of matter and energy do not occur in biological systems, as certainly they do, but such transformations in biological systems have been tailored by time and circumstance to increase fitness. This tailoring is recorded in the genes common to each species. Thus, genetic inheritance is the gateway to biology, no less than matter and energy are the gateways to chemistry and physics.

Following this reasoning, Silverman based the focus of the summer experiences on genes, mutations, and heredity. As already noted, this topic area more than any other differentiates biology from the other natural sciences. Further, this choice is consistent with emerging standards for science education, as described in the National Science Education Standards (NRC, 1996) and Benchmarks for Science Literacy (AAAS, 1993). Silverman realized that the history of mid-20th century molecular genetics research is perfectly suited to an approach that recognizes the transitional nature of the intellectual tools available to adolescents. The prominent scientists are invariably interesting, if for no other reason than the magnitude of their discoveries. Further, the subject matter is seminal to any understanding of biology. The discoveries have shaped modern biomedical research and reach back to Darwin and Mendel, placing their ideas on as firm an experimental footing as any idea can hope to achieve. The experiments themselves were technically simple and inexpensive, with transparent rationale and logic. These experiments met every criterion established by Dr. Silverman: economy, technical simplicity, intellectual richness, and conceptual transparency. Furthermore, the environment in which these experiments were performed and taught to other scientists beginning in 1945 at the Cold Spring Harbor laboratory on New York's Long Island was the same environment Dr. Silverman felt was necessary to allow teachers to develop the technical skills and confidence they needed. Finally, the outcome of these experiments led almost directly to contemporary accomplishments in biomedical research, including the human genome project. These experiments could clearly provide a path for teachers to build cognitive bridges between the historical establishment of fundamental biological principles and the cutting edge science so often in the news today.

Program Design

While the focus on teachers remained, the inherent knowledge that science is a social activity led Silverman to make a major change in the original Foundation Scholar Program. He felt that this social aspect of science was lacking and felt that teachers should be working in a collaborative, collegial environment on their own projects directly with a researcher/mentor rather than isolated in individual laboratories on projects that they would see from a very limited perspective. Silverman's main goal here was to bring secondary school science teachers into the professional scientific community. Although originally led by intuition, Silverman's goal directly addressed the professional development standard emphasizing the teacher as a member of a professional community related to his/her content area, as "Teachers of science will be the representatives of the science community in their classrooms" (NRC, 1996, p.61). Further, developments in neuroscience reinforce this need for social interaction (Brothers, 1997; Gopnik, Meltsoff, & Kuhl, 1999). Silverman began this process by making his own laboratory available to all of the Foundation Scholars chosen in 1993, rather than the traditional one. Silverman noted:

> It's that kind of peer interaction that actually formed the basis of science. You don't practice science in a tower all by yourself. Science is a very social activity, very community-oriented. It's extremely important to have contact every day all day with your peers … The total of what they [teachers and/or scientists] can accomplish together is much greater than what they could accomplish separately because of these interactions.
>
> (personal communication, June 8, 1993)

Initially, the teachers' laboratory consisted of a single bay and, while it was crowded, the teachers knew that this space was theirs for the full eight weeks they would be at the Oklahoma Medical Research Foundation. Later, the Merrick Foundation equipped a separate laboratory available to teachers and their students year round. This change allowed for continuous peer interactions, and relationships were built among the teachers, Silverman, and other researchers and technicians at the Oklahoma Medical Research Foundation; the teachers had their own community of professional educators from the beginning and were brought into the larger scientific community of the Foundation over time.

The strategy for developing the teachers' projects was to avoid having them intentionally repeat historical experiments in a scripted fashion, but for them to rediscover fundamental principles in much the same way the original researchers had. Kieran Egan is a strong proponent of this approach. In the introductory remarks to *The Educated Mind: How Cognitive Tools Shape Our Understanding* (1997), he states "education can best be conceived as the individual's acquiring these kinds [Somatic, Mythic, Romantic, Philosophic, and Ironic] of understanding as fully as possible in the sequence in which each developed historically."

In order to accomplish this, Silverman's habit was to establish the conditions under which the teachers could observe a specific phenomenon, tease their imaginations with questions, and lead them to develop alternative, testable ideas. This is where the opportunity for peer interactions is absolutely essential, as is the presence of a mentor who can keep the discussion from straying too far from productive pathways without giving up the answers. It is this mentor role that teachers must be prepared to assume in their classrooms. Learners (at any age) tend to emulate those individuals they view as experts; Silverman provides a new frame of reference for teachers who have been inundated with laudations about "inquiry" but may have heretofore learned science facts from texts and lectures. Silverman then provided materials and introduced teachers to techniques that would yield the necessary data for testing their hypotheses. Continued data collection, analysis, discourse, and questioning led teachers to continually ask: "What do I know? How do I know it? What is the next logical question to ask?"

This strategy is in parallel with R. K. Merton's account of the three social aspects of science: (a) Establishing the existence of a phenomenon and observing it, (b) using strategic research materials and/or a strategic research site, and (c) specifying one's ignorance (Merton, 1987), and is illustrated clearly in the case records collected throughout the project. A detailed account of the first year is provided in this report to vivify the teachers' experiences and to make transparent the intertwining of processes, content, and historical significance.

Processes

The first summer, three public high school science teachers were chosen from a pool of applicants. (In general, 7-8 applications are received for each slot available.) The three teachers were introduced to the laboratory, taught how to prepare biological media, and provided with a laboratory strain of Escherichia coli K-12 (a common and harmless microorganism) and some mud and water from a local lake. Using samples of water and mud treated with chloroform to destroy endogenous bacteria, Silverman showed the teachers how to apply small samples mixed with E. coli to the surface of a petri plate in a thin layer of agar. After overnight incubation, the plates had small clear zones, in an otherwise confluent, opaque "lawn" of bacteria. As observations were recorded, the questions began. What could be causing these clear zones? Is there something chemical or biological that causes the otherwise confluent growth to be inhibited in certain areas? What experiments would distinguish among the competing hypotheses?

As it happens, all of these questions have vexed scientists interested in this phenomenon since its discovery in 1916. Indeed, only in the late 1930s did the field settle on the explanation that these clear zones were "plaques" containing concentrated virus particles. They arose from a single virus that infected a cell in its vicinity and replicated in that cell, ultimately destroying it. The 50-200 progeny viruses then infected other nearby cells and so on, eventually forming a macroscopic clear zone, or plaque.

Silverman cajoled and questioned until, eventually, the teachers decided that if the plaques were indeed caused by a virus that had replicated at the expense of the bacterial cells, then each plaque must contain many viruses presumably like the first. So, why not pick a plug of agar containing one plaque and see if more plaques could be produced? Silverman taught the teachers how to perform serial dilutions, and with only two basic techniques (serial dilution and the plaque assay), the teachers deposited the plaques into a small volume of sterile saline, diluted the suspension serially, mixed with bacteria, and plated just as in the original plate. If each plaque indeed contains many viruses, each of these should be able to start a plaque of its own. If this is so, there should be one or more serial dilutions that yield a countable number of plaques. Knowing the dilution and the plaque count, one can back-calculate to determine the number of plaque-forming units in the original plaque.

Content Outcomes

The teachers' experiments supported their hypotheses. (However, in subsequent years, one teacher found clear zones that were produced by a colicin, and others experimented with killing zones resulting from the application of antibiotics and/or natural antimicrobials found in garlic, tea tree oil, and other herbal solutions.) In addition, the teachers found that when they picked plaques that were large and turbid only large, turbid plaques resulted; when they picked plaques that were small and clear, then only the small clear plaques resulted from subsequent platings. They discovered that plaque morphology breeds true. Another way of saying this is that plaque morphology is a heritable trait attributed to the different plaque-forming units, since the bacteria were the same in both experiments. This does not prove that plaque-forming units have genes, but it is a very good indication. The teachers went on to use these techniques to characterize the lytic cycle of the small, clear plaque-forming units, and gained a deeper, conceptual understanding of processes that they had all been teaching from textbook accounts only. The following snippets of conversation, recorded in the laboratory and later transcribed, serve as an illustration.

> Silverman: It is the simplest system that provides evidence of inheritability. The essence of all biological systems is contained right in those plaques. The ability to replicate and the ability to replicate faithfully is evidenced right here.

> Teacher 1: I have a question. I've got bacteria spread out over here. I've got virus spread out over here. Now, each one of the clear places represents a place where a virus infected a bacterial cell. We would not be able to see just one virus infecting one cell, right? What happened is that [one] virus replicated and the viruses that were produced from that replication went out and infected

more cells. Or, got out and ate those other bacteria.

Silverman: Yes, that's why they are called bacteriophages. The name means 'to eat' and that's exactly what they do. They eat the bacteria.

Teacher 1: Oh, that's good! My question, and this is what the kids are going to ask me and I'm kind of wondering myself, is why they don't just keep on eating? Or, why is that not clear by now?

Silverman: So, what you want to know is why the whole plate's not clear?

Teacher 1: Right! If I put it in the incubator and just left it, would the whole plate just be clear?

Silverman: That depends on the virus.

Teacher 2: Then they would, right?

Silverman: The reason that a plaque size is limited, as I mentioned before, is that some of the cells almost die. They're overcrowded, they've got nowhere to go, they're running out of nutrients. They're not really dead, but they're not happy cells. Therefore, the virus just can't replicate because, in fact, the cells aren't even replicating.

Teacher 2: Would you go back just a minute to what you said earlier about the viruses and their lack of sensitivity to chloroform?

Silverman: Yes?

Teacher 2: Now, you said it denatured the protein of the virus?

Silverman: No. What chloroform mostly does in this situation is it dissolves the membrane of the cell.

Teacher 2: The cell?

Silverman: Chloroform *will* have an effect on viruses with a membranous coat. Some viruses do have a membranous coat. But for viruses composed of protein and nucleic acid they can get away with being in chloroform as it has no effect due to the fact that the chloroform dissolves the lipids in the membrane of the cell.

Teacher 2: Wow! I have been teaching in biology that viruses are just nucleic acids with protein coats, and that 'like dissolves like' in chemistry, and it just now made real sense to me.

(audiotape, OSP lab, June 12, 1993)

Historical Significance

Now, as they engaged in these fundamental experiments, the teachers also examined the work of the scientists involved in the original discoveries. To their delight, they discovered that, although the techniques they were using and the questions they had asked were not original, the research was uniquely their own because the specific plaque-forming units came from their own samples. These experiments were indeed technically simple and cost less than $10. But consider all they entailed in terms of new knowledge, quantitative skills (e.g., serial dilutions), and, most important, critical reasoning. It is worth emphasizing that these three teachers, beginning with a bit of lake mud, defined two organisms without ever laying eyes on either. All of their conclusions were inferential and based on reasoning and experiment. But their conclusions were nonetheless sound.

Research Design

Formative evaluation resulted in the co-evolution of the Oklahoma Science Project (OSP), in its current form, and its accompanying overall evaluation. The OSP's formative evaluation relied heavily on naturalistic (qualitative) inquiry. "In judging the value of this approach, it is useful to recall that many major contributions to our understanding of the world have come from scientists' personal experiences" (Patton, 1980, p. 17). Indeed, the philosophical and theoretical roots of such inquiry grew out of the quest for anthropologists and sociologists to understand human behavior. An integrating theme running through all qualitative methods is that the study of human beings is fundamentally different from other scientific inquiries (Bruyn, 1966; Carini, 1975; Garfinkel, 1967; Glaser & Strauss, 1967; Jenson, 1969; Kotulak, 1997; Patton, 1980; Pelto & Pelto, 1978; Pert, 1997; Strike, 1972).

In agreement with this theme, the early exploratory years of the OSP evaluation sought to determine how teachers perceived the value of their experiences and the degree to which they were satisfied with the program. As only three or four teachers were accommodated each summer, statistical analysis or other quantitative measures were impractical to consider on a yearly basis; the small sample number, the individual and unique research projects in which the teachers engaged, and differences in teaching responsibilities and classroom demographics were factors that further supported a qualitative research design. In short, the evaluation goal each year was primarily to document unique outcomes of individual human beings rather than standardized measures of outcomes across all teachers. It is imperative to note, however, that the types and quantities of qualitative data have varied over the years in order to develop a more rigorous and complete scrutiny of the program's real-world impacts.

The OSP evolved as the project director and staff made a concerted effort to be responsive to the needs of individual teachers rather than prescribing what they should do in their classrooms. A collection of qualitative data for each teacher began the summer of his/her research experience at the Oklahoma Medical Research Foundation; data collection has continued to the present. Such qualitative data collected over a period of 8 years (1993, 1995-2001) produced case studies of 33 individual teachers from 32 of Oklahoma's 431 school districts serving students in grades K-12. Each year's data is treated as a case set; the first case set of data from the experiential experiment of 1993, and two interim studies (also considered formative evaluations) are discussed below. Then, findings resulting from a search for patterns among the eight case sets are discussed.

The first summer research experience established several important facts and anticipated several others, established only later. The first was that the phage experiments engaged the teachers, both technically and intellectually. The second was that peer interactions were a crucial component. It mattered a great deal that the teachers were all together and able to discuss not only their experiments and results but also how they might apply what they were learning to their classroom situations when they returned. One of the teachers compared her previous summer experiences as the sole teacher in a similar laboratory setting with her OSP experience.

> Working in a lab is kind of, you hate to say it but, when you're at the low end of it, it is routine. You're doing the same process, and they'd [full-time laboratory staff and researchers] get kind of tired of doing that kind of stuff too, but there was just that interest there. It was neat because I was in with those people who love science. But with the teachers, we were looking at "How can we do this? How can we use this in our class? How can we implement some of these processes? How can we implement this idea into a class?" And, I didn't really think that much about doing that [anticipating how the laboratory experience could influence the classroom] when I was in the other labs. We [teachers] learned off of each other about how we did other things that had nothing to do with what we were doing in the lab.
>
> (personal communication, July 15, 1993)

The third lesson was that, as simple as the experiments were, the teachers still needed a great deal of support and encouragement to develop (a) ***conceptual*** and deep understandings of the biological principles, and (b) the ***self-efficacy*** (defined by Bandura in 1994 as a combination of confidence/belief in one's own capacity to take charge of a situation and possessing the knowledge and skills necessary to do it) necessary to "teach against the grain" (Bass, 1999) and resist the tendency to "downshift" (Hart, 1983) when returning to the classroom. "When people downshift they revert back to early programmed behaviors and/or to more primitive and instinctive ways of behaving" (Caine & Caine, 2001, p. 48). This has turned out to be the most crucial and the most difficult challenge we face. The major lesson from our experience is that the proper goal of a program like ours can be nothing less than teacher transformation. We must explore mechanisms to transform the way pre-college science teachers view science, science education, and their place in the larger scientific community. Without this transformative component, programs like ours must ultimately fail; with it, they must succeed no matter how else they are organized.

Findings of a study by Harris, Green, Frisby, and Wendling (2000) indicated, "The data collected clearly show that teachers who participated in the TeleScience Project [now the OSP] believe they have been changed both personally and educationally by their experiences" (p. 50). The method of data collection was via surveys sent to 16 science teachers who were previous Foundation Scholars. Fifteen of those teachers responded, and responses were analyzed, using descriptive statistics, to determine the OSP's impact on the teachers and their classroom practices. Thirteen (86.7%) teachers reported that they had permanently changed their teaching styles and methods. Prior to their participation in the OSP, 12 (80%) teachers felt very prepared to teach science; however, after their OSP experience 7 (46.7%) felt very prepared and 8 (53.3%) felt *extremely* prepared to teach science. In other words, 9 of the 15 participants (60%) reported that they were more prepared to teach after their participation in the OSP. Finally, all of the teachers (15/15, 100%) stated that they could now provide a new understanding of science to their students.

Although the study by Harris et al. relied heavily on teacher-reported data in the form of a survey and an open-ended questionnaire administered via e-mail, it was a valuable step in identifying emergent themes. In order to support or refute teachers' claims, McCarty (2001) engaged in an in-depth study of four teachers who participated in the OSP during the summer of 1999, after the completion of Harris' study. Acting as a participant-observer, McCarty collected field notes and audiotapes of daily discourses among the teachers, Silverman, and additional OSP staff and technicians over a period of eight weeks. Additional data sets included sequential (informal and semi-structured) interviews with Silverman and each of the teachers individually and collectively that extended throughout the following academic year. Bringing in an outside researcher to assure triangulation, McCarty and her colleague independently coded and categorized the data in one case after another, until profiles for all four teachers were constructed. Emergent categories from all four profiles were then subjected to scrutiny by an additional external researcher and finally presented to participants for validity checks.

Initially, descriptions of participants' feelings, rather than facts and specific experiments, dominated the discourses related to teachers' experiences. Teachers felt a sense of ownership regarding their individual projects and felt valued; each felt that her experiences were intellectually and emotionally safe, yet challenging. Interestingly, this is exactly the environment that is described by Caine & Caine (2001) as "An optimal state of mind in the learner and the teacher that we call *relaxed alertness*" (p. 54). One teacher described the social exchange this way:

> We interacted! We worked with each other and questioned each other's data, and tried to figure out—I still—I don't remember what it was, but I think we argued on one topic for days. It was fun! We were playing. Playing within parameters.
>
> (personal communication, July 28, 1999)

Silverman was delighted with this description. He explained:

> When I hear two teachers arguing with each other, it doesn't matter to me whether they're arguing about the biology they're doing or arguing about their own profession. Then I know there is intellectual stimulation and exchange. Always! That has to be exciting. Even if they don't change anything, there's a new perspective that wasn't there before. An intellectual exchange of that kind, with a colleague or a peer, it's an addiction. It's fun, it's always fun! And, this business about play is also something that recurs very often [in biographical accounts of scientists]; the outcomes, but also the process of science is very aesthetically pleasing. [Max] Delbruck gave a talk at the Connecticut Academy of Sciences [1949], where he referred to work on bacterial viruses as "a fine playground for serious children who ask ambitious questions." I think that's one of the best descriptions of science … to me the term *play* implies a certain intellectual freedom.
>
> (personal communication, August 2, 1999)

This actually turns out to be extremely important, as "the brain does not naturally separate emotions from cognition, either anatomically or perceptually" (Caine & Caine, 1994, p. 45). Neuroscience supports the notion that enjoyable experiences contribute to meaningful learning; as people learn about the world through such experiences, they are literally changed physiologically and psychologically (Bransford, Brown, & Cocking, 1999; Jensen, 1998; Kenny, 1984). "When we feel valued and cared for, our brain releases the neurotransmitters of pleasure: endorphins and dopamine" (Jensen, 1998, p. 33). Feelings of pleasure are inextricably interwoven with the activities and artifacts that produced them, and individuals' brains are literally reshaped and reformed (Bransford, Brown, & Cocking, 1999). Piaget (1964) theorized this restructuring and labeled it "assimilation," new schema being constantly incorporated into existing cognitive structures. Zajonc (1993) declares that our language, tools, and actions are internalized and we "make ourselves dwell in them. By dwelling in them, new organs of cognition arise" (p. 184). In other words, there is a physical transformation as neural connections are made within the brain itself and one perceives the world *differently.* Thus, we construe that this is what occurred to cause teachers to report that they were "changed."

Although information regarding the feelings and emotions of participants is generally the first level of evaluation in any program, feelings and emotions may be poor indicators of whether or not a program has made a lasting impact (McNamara, 1998). (Indeed, follow up interviews indicated that teachers could sustain their renewed excitement regarding science only to the extent that they were supported by administrators and/or OSP staff throughout the academic year.) Therefore, McCarty's study also investigated teachers' learning. That is, conceptual learning of biological principles evident in the experiments, but also attitudes and perceptions of the nature of science itself.

One of the first indications of true learning is the acquisition and appropriate use of a culture's language. This is especially true in the scientific culture, and there are subsets of terms and jargon for each area of specialization within the scientific culture. Part of understanding and becoming a part of a culture is explained elegantly in *The Scientist in the Crib* (Gopnik, Meltsoff, & Kuhl, 1999). As part of the innate search for meaning, there is a striving for an individual to "find out what the folks around here do and learn how to do it yourself. The other folks are crucial" (p. 101). So, the language itself is a social phenomenon, and the individual grapples with the way to use this language in the society in which it finds itself. This type of knowing the language of science is intimate, and far removed from the type of surface knowledge that students learn from defining textbook terms. It is experiential.

At the close of each summer, teachers present their research to scientific staff, Fleming Scholars (students involved in summer research), parents, and community members. Following their presentations, questions are invited from the audience. In preparing for this event, teachers refine, reinforce, and solidify what they have learned and are able to present experimental processes, analytic methods, and findings on a level sophisticated enough for them to be comfortable with professional research scientists in the audience while simultaneously being able to clarify their work in laymen's terms for the other members of the audience. Brief descriptions of the research accomplished by the four teachers, who are each given pseudonyms, in McCarty's study follow in order to illustrate the complexity and individuality of the projects.

Julia engaged in work involving the isolation and characterization of bacteria from the creek close to her cabin. She found an unusual purple-pigmented bacterium that became the focus of her experiments. She successfully mutagenized a culture of this bacterium, selected a mutant that was not pigmented, performed nutritional studies, isolated the pigment, and analyzed it through chromatographic techniques.

Sherry and Martha worked on a project culminating in experiments that demonstrated recombination in bacterial viruses. The process started with the mutagenesis of a T4 phage stock and then proceeded through a series of selection experiments. They selected for both R2 and temperature-sensitive mutants and, at the end of the project, they had constructed a simple genetic map.

Diane's project, like Julia's, related to a body of water. The high school where she was employed at the time of the study adopted a nearby lake as a field site, and each teacher in the high school was involved with projects learning about biotic and abiotic factors in the area. Diane examined a variety of environmental samples (soil, water, and manure) to learn the procedures to use the following school year when she would collect similar samples from different animals at the lake. Initial tests compared the quantity and type of antibiotic-resistant organisms in each sample. Further experiments involved the extraction of a plasmid from several of the samples, transformation of a laboratory host strain of bacteria using one of the smaller extracted environmental plasmids, and gel electrophoresis to determine the numbers and relative sizes of the plasmids. Diane also engaged in hunting for bacterial viruses and bactericidal proteins, called colicins, from these natural sources. She produced lysates (liquid cultures) of bacteriaphages in high concentration, and with the help of scientific staff successfully obtained electron micrographs of the phages she isolated.

(McCarty, 2001)

It is clear from these descriptions that the teachers each engaged in authentic research experiences, although the techniques and biological principles were established historically. In fact, there were aspects of each project that Silverman himself had no pat answer for (i.e., the purple bacterium); these unique aspects added to the originality of the projects and to the excitement of the investigators.

In a true partnership, each member recognizes the expertise of the other(s) in a specific domain, and the partnership is formed to create an alliance through which each individual's expertise is shared. One must ask, then, if the scientist involved in such interactions gains a clearer understanding of what constitutes classroom science. If so, is the scientist better able to visualize ways to help teachers overcome obstacles to best practices (as described by the National Science Education Standards [NRC, 1996]), as the teachers themselves perceive those obstacles? When asked what he actually learned from the teachers Silverman replied:

> I'm grateful to them for taking the veil away from something that was a complete mystery to me and I think to most people. What happens in a high school biology classroom? Everybody says that it isn't good, but most people don't have a clue about what actually

> happens there. Exactly what do teachers have to contend with? Just the range of abilities of the students in these classes is huge ... many of our teachers have five or six different classes to teach each day. Preparing each class for an optimal learning experience must be a huge responsibility. And I never, before I did this [directed the OSP], I never really appreciated exactly why or what it is that's going on. My role is to accommodate my interactions with each of them [the teachers] according to each of their own interests, abilities, and preferences [during the eight weeks of the summer]. Every summer, I get so encouraged to see once again the quality and professionalism of Oklahoma's public school teachers ... and, if a teacher needs supplies [for classroom use during the academic year], it's got to be sent out the very next day. You know, the teachers can't wait a whole week once they get started.
>
> (personal communication, August 2, 1999)

Through collaborative inquiry and continued interaction we have identified teachers' needs and perceptions of obstacles to implementing best teaching practices, then developed strategies to assist teachers in overcoming those obstacles. The loan of equipment and the availability of OSP staff as classroom consultants, both electronically and on site, were established to address two of the largest obstacles: (a) little or no budget for equipment and supplies and (b) lack of confidence to engage in the activities under the severe time constraints of the school culture.

When the unit of analysis is expanded to search for patterns among all case sets, findings are in agreement with the case set of 1999 investigated by McCarty and with a subsequent study by McCarty & Pedersen (2002) that investigated case sets from 2000 and 2001. We found that the manifest impact of the OSP on teachers' classroom practices is as varied as the teachers and the classroom contexts in which they teach. In general, these variances appear to align themselves according to common aspects of the OSP laboratory and individual classroom contexts and provide support to the hypothesis that successful learning environments are those that closely resemble that of the collegial OSP experiences: small number, or individual students; flexible scheduling; and/or non-traditional classroom environment.

1. More significant changes in classroom practices that reflected a true sense of inquiry and the nature of science (NOS) were observed in teachers in smaller schools (averaging 500 students in grades K-12) than in larger schools (>500 students in grades K-12). At least half a dozen teachers in these smaller schools have gone so far as to design specific classes that engage students in guided inquiry to develop conceptual understandings of basic biological principles.
2. Teachers in both small and large schools tended to utilize the techniques and activities abducted directly from their OSP experiences more when guiding their students through science fair investigations than when teaching entire classes.
3. Teachers exhibited inquiry skills more effectively when familiar laboratory and/or classroom activities were revised in collaboration with OSP staff than when attempting to introduce new

activities. Unless a new activity could replace an old one, or enhance understanding of a concept previously addressed didactically in the limited time available, it went on the "back burner."

4. Teachers progressively manifested a deeper understanding of the content and NOS over time when discourses and relationships established through the summer experiences continued throughout the school year(s). Almost all (96%) of the teachers indicate that they added collaborative group learning to their classroom strategies and encouraged students to ask more complex questions than before their OSP experiences. Having the ability to electronically communicate with the OSP scientific director and staff appears to have given the teachers and their students the freedom to investigate a wider range of scientific concepts.

In addition to these findings, the OSP seems to have a "ripple effect." By that we mean that the activities and/or achievements of these teachers have impacted teachers who have not personally participated in the OSP. Five of the thirty teachers of science in Oklahoma who have earned National Board Certification have been participants in the OSP. Four of these teachers achieved this high level of recognition after participating in the OSP, and three of those four teachers point to their OSP experiences as either having an influence on, or being directly responsible for, the confidence and ability they needed to even apply for this credential. As Nationally Board Certified teachers, they are approached frequently by district, regional, and/or state organizations when new assessment instruments are developed. These activities directly affect their colleagues at different levels.

Approximately one-third of the participants have received honors and awards (such as the Presidential Award for Excellence in Science and Mathematics and the National Association of Biology Teachers (NABT) Outstanding Biology Teacher Award for the State of Oklahoma), and several have received grants for a variety of projects. These grants vary from $5,000 to $68,500 and come from a variety of state and business entities. As awardees, the teachers frequently make presentations to school boards, Rotarians, and colleagues at regional, state, or national conferences for educators. Students of these teachers have won honors in science fair competitions at the regional, state, and national levels, and some have competed and placed at the international level. In addition, teacher-developed lesson plans have appeared in peer-reviewed education journals (McCarty & Marek, 1997; McCarty & Marek, 1998) and also in collections of favorite lessons from Outstanding Biology Teacher awardees collated by the NABT.

Over forty teachers who have come in contact with OSP participants outside of the Oklahoma Medical Research Foundation have requested supplies, technical information, and/or critical responses to research. Two former scholars conducted quadrant workshops aimed at incorporating rural Oklahoma's secondary teachers from agriscience, tech-prep, and general science classes into Oklahoma's scientific community; a community to which they had a real sense of belonging. These workshops were held at vocational facilities and provided a more structured approach to some of the experiments and concepts learned from their OSP experiences. These participating teachers were encouraged by the interest and conceptual changes that appeared to take place among the teachers. As a direct result, media, bacterial cultures, and supplies were sent to attendees; the teachers served as advisors to many of the workshop attendees as well. The benefits of these workshops were described in a letter to the Chairman of the Board, Oklahoma Farm Bureau, as follows:

> We have sent media and offered advising via e-mail to attendee Fran Betz (a pseudonym) and colleagues for use in the nursing classes at one technology center; we have sent media, bacterial cultures, and supplies to another attendee for use in an applied biology class at one of the high schools in southwest Oklahoma and set up e-mail advising with her; we have established ongoing correspondence with Sam Grover (a pseudonym), an attendee who is an agricultural science teacher at one of the rural schools in north-central Oklahoma. His sample of probiotics was tested during the weeklong session and appeared to be both heat sensitive and tetracycline sensitive. Since many animals are given prophylactic doses of tetracycline, the question was raised as to the number of probiotic organisms that survive the prophylactic treatment. While this is not a health issue for the animals, it is certainly a monetary one. This question is being considered as a possible science fair project; a question that most likely would not have been asked without the workshop experience.
>
> Agricultural science teachers at another site introduced us to the problem of pleural pneumonia-like organisms (PPLO) among hogs. When tested against lab strains of bacteria, the effectiveness of the medication decreased when the feed had been stored in outdoor areas and exposed to fluctuations in temperature and humidity. We certainly realize that PPLO is a complex disease and it is likely to have both viral and bacterial components; this certainly raised our level of awareness concerning a real problem for hog farmers.
>
> (Personal communication, January 1999; Source: Associate Director's Communication Files, December 1998)

One teacher traveled to a remote part of the state, equipment and supplies in tow, to help a teacher she had never met engage her students in a laboratory experience involving gel electrophoresis; four additional teachers report assisting teachers in their district and/ or region with laboratory setup and assessment. In addition, several teachers have brought their classes to use the teaching laboratory funded by the Merrick Foundation in order to give their students a "felt meaning" for doing science in a research lab. In these and other mentoring activities of its teacher-partners, the impact of the OSP has been amplified.

Conclusions

The OSP has clearly been successful at incorporating a number of secondary school science teachers into Oklahoma's scientific community, as evidence by continued interactions among teachers and the OSP director and staff.

Teachers engaged in authentic research experiences wherein they increased both conceptual content knowledge of basic biological principles and a deep understanding of the nature of science. Participants developed constructs concerning science as science was done, through the processes of argument, challenge, and dissention, but ultimately settled by the appropriate experiment: an iterative process of logic and action. The negotiations and debate were required elements of interaction, for it is through these energetic exchanges, and through the examination of the related and historically significant experiments, that the next logical question was articulated and the appropriate experiment to act upon was identified. Teachers stated that they understood concepts that they had taught from textbooks at a deeper level than ever before. Teachers have reported personal and professional growth/change; the truth to these claims is validated by documentation of the many achievements and mentoring activities of the teachers.

The OSP continues to be responsive to the needs of its education partners by listening to the teachers' perceived needs and making every attempt to meet them. As interactions have continued, the OSP has begun to develop a framework of guided inquiry lessons that will allow teachers to engage students in open-ended research while addressing curricular requirements and specific time limitations. Work in progress includes the development of an interactive web site where teachers can seek and offer information, post data from class experiments, utilize electronic lab notebooks, and collaborate with one another.

Project Strengths/Weaknesses

The main strength of the OSP lies in the model of learning that it presents. Experiential learning in a state of relaxed alertness is indeed the optimal environment for individuals to acquire knowledge at the deepest level of being. Discovering the biological principles involved in understanding genes, mutation, and heredity in the same sequence as the original researchers is not a manipulation; the data collected and the questions that come to mind as one engages in these explorations flow as naturally today as they did then. For this reason utilizing experiments and techniques that literally laid the foundation for the new science of molecular biology, and therefore have historical significance, is outstanding; the fact that these same experiences provide the stuff for building intellectual bridges between the past and the cutting edge science of today is genius.

Another strength of the OSP lies in the project director's responsiveness to the teachers. Silverman clearly desires to assist these teachers in transforming themselves, and their own classrooms, rather than prescribing what teachers should do. It is this attitude that makes the partnership *full* and goes a long way to assure the success of the program.

In critically discussing the weaknesses of the OSP, I find three areas that need work. I believe that the first two are already being addressed.

1. I believe that fuller advantage could be taken of the cadre of mentor teachers that the OSP has established. Mentoring activities are varied and unstructured to a large extent; with a proper framework in place the OSP could multiply its impact and address the needs of novice and alternatively certified teachers.
2. The program needs to continue to collect teacher-reported data and certainly construct individual case studies for each teacher. However, classroom observations have been done on only one case set of teachers; the OSP must increase its

presence in the classroom and, if possible, collect pre- and post-OSP participation data. Questionnaires, while useful in the early stages of evaluation, may distort and confound the study findings, as "research subjects' knowledge and awareness that they are part of a study as they complete questionnaires may have a reactive measurement effect" (Webb, Campbell, Schwartz, & Sechrest, 1966). The habit of making frequent, sequential, informal classroom visits and interviews is seen as collegial and therefore decreases the feelings of threat.

3. The one true weakness that I see in the OSP to date is the assumptions it makes about student learning. While there is some teacher-reported information about student learning in the classroom, and certainly documented cases of students having success with science fair projects, there is no hard data to document an increase in student conceptual knowledge and/or attitudes about the nature of scientific endeavor. Educational theorists agree that this approach, which clearly works for teachers in the laboratory environment of the OSP, *should* work beautifully with adolescents. In order to collect the data necessary to support its assumptions, I suggest that the OSP engage in pilot projects wherein students are the subjects for case studies, in an environment other than the OSP.

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