CHAPTER 5: CONCLUSIONS

A multicase qualitative study was conducted to examine the impact of problem finding on the quality of extended open-inquiry science research projects. Students participating in the 2007 Connecticut Science Fair (CSF) and the 2007 International Science and Engineering Fair (ISEF) served as subjects. These students, in conjunction with mentors, teachers, and fair directors, via interviews, surveys, and documents, provided the data sources for the study.

The traditional science classroom provides a strong emphasis on problem solving. Students are regularly challenged to be critical thinkers when analyzing problems provided by their teachers (Costenson & Lawson, 1986; Metz, 2006; Prince, 2004). Students' logical-analytical processes of problem solving are enhanced by the use of inquiry. However, there is often a disconnect between the way inquiry is taught in schools and the creative aspect of science: problem finding. Students are rarely given the opportunity to define and determine their own problems. In essence, by using guided inquiry strategies for very specific curricular purposes, student creativity in science is stifled.

The opportunity for open inquiry is used on a much more limited basis. This strategy allows students to determine their own problems for study then design their own methodologies and data analysis strategies to observe, explain, or discover phenomena. Since the 1957 launch of *Sputnik*, there has been a greater push to promote science education through research opportunities. Science fairs have promoted open inquiry experiences for students by providing them with a forum for them to present their extended research projects to an authentic audience of practicing scientists, doctors, and engineers.

In this paradigm, the teacher's role changes, becoming more of a facilitator than a content expert who disseminates knowledge. Thus exists the challenge: how do teachers effectively assist their students to independently problem find in a situated setting?

This study examined 20 of these young, budding scientists, 12 from the CSF and 8 from the ISEF. The students were purposefully selected based on the fairs' judging criteria. For CSF, students who were ranked as finalists (approximately 35 students), or top quartile, and those ranked as third honors (approximately 50 students), or bottom third were recruited for possible participation. At ISEF, the top 17 category winners (see Appendix A) were recruited for participation. Participating students completed the USRT Scale (see Appendix G), a demographic survey (Appendix H), and a semi-structured interview (Appendix B). CSF interviews were conducted face to face, while ISEF interviews were conducted by telephone.

All interviews were recorded and transcribed verbatim using digital media. Interviews were analyzed for categorical themes using *The Ethnograph*, computer software designed to make qualitative data analysis research easier, more efficient, and more effective (Qualis Research Associates, 2006). Categories were retrieved throughout a single case and across all cases. Categories were axially ordered into category clusters to construct overarching themes.

The categories and patterns from student interviews were triangulated with interviews with mentors, teachers, and science fair directors as well as content analysis of popular press and media, CSF, and ISEF documents. Triangulation of data was achieved through methods (interviews, document analysis, surveys) and sources (students, teachers, mentors, fair directors, documents).

The purpose of the study was to address the following two research questions:

1. What are the distinguishing problem finding features of externally-evaluated, exemplary, open-inquiry science research projects?
2. How do parents, teachers, and mentors influence student problem finding?

Major findings

The technical versus novel problem. Each project fell into one of four categories: literature review, technical problem, technical problem with value, and novel approach to the problem. Students who conducted a literature review project used sources for all information and organized it into a report. These projects did not analyze any data, but rather examined primary and secondary sources of research and then organized the information for a presentation. Little, if any, inquiry took place during the process. These types of projects would not meet the classification schema of Herron (1971) or Martin-Hansen (2002) for inquiry learning. The project would, however, fit the Renzulli (1977) Type I definition, and possibly the Type II definition if the student used advanced literature searching and analysis techniques. This type of project is contrary to the expectations of the science fair process which anticipates that students conduct an inquiry project (CSF, 2006; Science Service, 2006a). However, since teachers and students at their respective schools are responsible for determining which projects attend the fair, this category of project often subterfuges the suggested fair guidelines.

Technical projects met the next strata of classification. A technical project examined a well known question with well known outcomes. These types of projects used predetermined procedures and often have predictable results. These students engaged in an inquiry activity. The projects met the criteria for a Herron 0, 1, or 2 activity, a Martin-Hansen structured or guided inquiry, or a Renzulli Type II. Although students participated in inquiry learning, these projects are often poorly received by the community of practice (i.e. practicing scientists and engineers), because they lack any new contribution to the scientific knowledge base. An authentic audience of judges from industry and academia, while appreciating a student's effort, rarely valued the contribution of this type of work (Bellipanni, 1994; Grobman, 1993). All too often, perhaps, these types of projects are very common at local and regional science fairs.

Students who completed a technical project with value started with a predetermined methodology, but generated new data that had the potential to contribute to the scientific knowledge base. Students had positive results in the science fair process when their technical projects had value, meaning there was application of their data beyond the scope of the learning experience. Generally their projects produced a subset of data that filled a small, but unique niche. They collected data from a locale or source that has not previously or recently been studied or perhaps they optimized a process to make it work more efficiently. These projects would be classified as Herron Level 1, 2, or 3, Martin-Hansen guided or open inquiry, and Renzulli Type II or III. These projects most often fell on the higher ends of all of these scales. These projects had value, because there was an authentic community that appreciated, required, or used the data generated by the students. In this case, "community" may be defined in multiple ways; however a common denominator to the definition is that it transcends the walls of the science classroom.

Finally, the most successful types of projects tended to be those with a novel approach. Students who completed a novel approach project are at Herron Level 3, Martin-Hansen open inquiry, or Renzulli Type III. A novel approach project asked a novel question or determined a novel method to solve a preexisting problem. Students demonstrated an elegant insight to solving their novel problems and utilized creativity factors such as fluency and flexibiltity more effectively than their technical with value counterparts (Torrence, 1965).

Situated project classification. There is overlap and noncongruity in the other classification schemas (e.g., Herron, Martin-Hansen, Renzulli) and the one developed by this study. The schema presented here stresses the situated nature of successful open-inquiry coupled with creativity. Members of the scientific and engineering communities of practice resolved the differences between a technical project with value and a novel approach project with little ambiguity. In fact, CSF judges awarded novel approach projects statistically higher creativity scores than technical with value projects (LaBanca, unpublished data).

Perhaps most important, students understood how to classify their projects without prompting or presentation of a classification scheme. They recognized that projects that had novel questions or methodologies would be received in a more positive light than those that did not. They also recognized that projects that had applicability, value to the general public, or were current hot topics would also be rewarded more positively.

Previous experience. Most students reported that they had participated in activities related to conducting a project prior to actually selecting their project. These experiences were often extensive and built the necessary, specialized, prerequisite skills for conducting a significant, innovative project. In essence the students engaged in Type I or Type II activities (Renzulli & Reis, 1986) and moved beyond peripheral situated trajectory to inbound trajectory (Wenger, 1998). These experiences were extensive, sometimes lasting more than a year and were always beyond the scope of the traditional science classroom curriculum.

Due to their previous experience, the students had a more sophisticated sense of emerging problems (Dillon, 1982) that might exist related to their topics of interest. Since the problems were more refined than existent problems, the students had a strong understanding of the domain culture (Csikszentmihalyi, 1990) associated with their particular field of interest and were, therefore able to develop a meaningful, applicable project.

Since many students participated in a sophisticated, meaningful cognitive apprenticeship (Brown, et al., 1989) prior to developing their problems, they were able to problem find with more expertise than students who developed projects without this experience. These results for science students are in agreement with the results of Ericsson and Lehmann (1996) and Glaser (1984).

Students' temperament for science research. The USRT Scale was used to measure students' temperament for science. The affective instrument measures personality characteristics in dichotomous pairs based on Cattell's (1949) lists of traits (LaBanca, 2006). Scores on the USRT were used descriptively. Fifteen of the 20 subjects (75%) scored higher than the instrument's mean average for science majors. Of the 15, 10 were in the top quartile (50% of the total sample), and 1 was above the 99th percentile. There did not appear to be a difference between top CSF students and ISEF students in their temperament to science research. The majority of the students had an affirmative indication to their positive temperament to science research, both by the USRT and through their interview comments.

Students were asked to use three adjectives to describe themselves in terms of their inquiry projects. Using Renzulli's (1986) three-ring conception of giftedness as a comment classification framework, the students rarely referred to themselves in terms of their above average ability. They commonly used creativity terms in very similar frequency to their task commitment terms. Several students commented outside of the Renzulli domains, but their comments were focused on the application of their projects to an authentic audience, which is a goal of gifted behavior (Renzulli & Reis, 1986). This distribution was fairly stable, regardless of the quality of the project, but it should be noted that there were very few projects in this study outside of the high-quality classification.

Mentors and teachers were asked to describe their students using adjectives, and the same classification scheme was used to interpret the results. Over two-thirds of the responses of the adults were in terms of task commitment. Above average ability and creativity equally split the remaining responses. Students were more willing to describe themselves as creative, while the adults recognized their task commitment.

Students having a positive self concept of their creativity was seen as important. Indeed the student and adult definition of creativity was almost exclusively defined as problem finding. Since the community of practice used a common definition and interpretation of creativity in open inquiry research, the problem finding process is an important, critical aspect.

The creativity associated with problem finding appeared to spill over to student self-regulation (Bandura, 1997; Pintrich, 2000; Tytler, 1992). Students, regardless of science fair rankings, demonstrated high motivation because they were allowed to be independent, self-directed learners. They recognized the value of their work for its own worth, and the experience they had that was not part of traditional classroom learning. This alternative, situated learning strategy gave students an autonomous stature to be directors of learning, utilizing teachers and mentors as facilitators rather than knowledge disseminators.

Defining inquiry. A structured or guided inquiry approach to research is often bound by procedural frameworks which compromise the independence and creativity of students. Students who engaged in open-inquiry experiences were not bound by these confines. They had an intuitive understanding of the idiosyncratic nature of inquiry and did not feel obligated to follow a linear, hypothesis-based testing strategy to solve their problems. This is important, because using a step-by-step strategy limits the types of problems that can be posed. Specific cause-and-effect problems where one variable is tested in relation to another are the hallmarks of hypothesis-based testing, but only represent a small facet of open-inquiry options. Other problem solving strategies were employed with many of these projects, because students' problem finding was not restricted by one type of problem solving method. Students recognized that inquiry was learning by questioning, which is very different from knowledge garnered from a textbook, as indicated by Shymansky, Hedges, & Woodworth (1990).

Inbound and boundary interaction with the community of practice. Students in this study demonstrated an exceptional ability to communicate well with others. Although communication with others transcends all facets of the research process, it was critical during the problem finding phase when students were attempting to develop an idea. It was important because students must determine the feasibility of a project in terms of time, resources, skill, personal expertise, and the expertise of others. These students realized that an incredible network of professionals was available to them by a cordial, professionally presented request. They tended to broker relationships (Wenger, 1998) that best suited the person assisting them, whether it was full-fledged mentorships, or electronic communications to clarify understandings or ideas.

There almost appears to be a paradox between the "one person to a project" schema of the science fair and the social nature of situated learning (Brown, et al., 1989). This has sometimes been a major criticism of the science fair process: the science fair promotes competition and deters collaboration (Grubman, 1993; McBride & Silverman, 1988). These conflicts resolved themselves well, because the students in this study demonstrated that they did not work in isolation. They acted as project managers and facilitated the assistance of peers, expert adults, and not-expert adults to garner success in their projects. These students, as members of a community of practice (science researchers or engineers) especially from the perspective of boundary trajectory, brokered relationships that were necessary based on their understanding, needs, and expertise, similar to the Wenger (1998) study. They realized that it was nearly impossible to conduct a quality project in seclusion: they needed the expertise of others who could foster and promote the knowledge, skills, or dispositions necessary to be successful. The community of practice of judges and fair directors duly rewarded the projects that involved this type of collaboration.

Rarely were parents members of the community of practice, and as such, rarely were parents employed in the problem finding process. Grubman (1993) and Shore, Delcourt, Syre, and Shapiro (2007) suggested the negative effects that parents may have played in the science fair process. The students in this study demonstrated that quality projects began with quality ideas derived from the student’s extensive and meaningful problem finding. The process was not convoluted by parents, and when parents interacted, it generally was to casually point their children towards perceived valuable information that might be associated with potential project interests.

Even when parents were members of the scientific community, they played a very minor role in the problem finding and problem solving stages of the project. When involved, they were often relegated to menial tasks such as constructing a poster or grammar checking written work. However, parents provided emotional and financial support while nurturing an environment to support their child’s passion for science.

When student projects have a more authentic audience and address questions that will fill a niche in the scientific knowledge base, they are better received. These “technical with value” and “novel approach” project questions appeared to be more ill-structured than were the well-structured technical projects or literature review projects. Interestingly, well-structured problems tended to be executed in a more linear fashion. Students who studied well-structured problems were more likely to use an information processing learning strategy, while an ill-structured problem, exploited a situated cognition learning strategy. Jonassen (1997) also suggested this difference in the structure of problems compared to the learning strategy employed. This situated learning strategy allowed the students to engage in cognitive apprenticeships and act as members of the community of practice (Brown, et al., 1989).

Summary. This study provided support for the contention that a successful open-inquiry experience fostered creativity in students by allowing them to problem find. The problem finding process was idiosyncratic and required an extensive amount of time. Students worked through this process independently, but brokered and managed relations with others to advance their understanding and knowledge, and ultimately their projects.

Limitations

The benefits of this qualitative research study support the opportunity to develop a descriptive, rich understanding and insight into the attitudes, beliefs, concerns, and motivations regarding the problem finding phenomenon. The methodology allowed for exploration of scientific problem finding to gain insight into the descriptions, motivations, and perceptions that underlie it.

Attempts to increase trustworthiness were achieved through multiple strategies. To improve credibility the following strategies were employed: prolonged involvement, pilot interviews, reflexivity, triangulation of sources and methods, member checking, and data audits. To ensure dependability, interview question checking, triangulation, and cross validation were utilized. Finally, to improve confirmability, a confirmability audit, triangulation, and reflexivity were used.

The trustworthiness of every research design is subject to both internal and external impacts. Qualitative research does not produce quantitative data from a representative sample, and as a result, cannot be statistically analyzed to determine the extent the ideas expressed by the subjects mirror the population studied. Therefore, conclusions derived from this study are reflective of the sample, and may not represent the student population involved with open-inquiry experiences.

In this study, purposeful selection of subjects decreased the representativeness of the sample. Subjects were not chosen randomly. Those who participated in the study were recruited based on criteria which introduced a selection bias for specific project quality. Participant recruitment was targeted because these individuals might have been somewhat different from the typical science fair student profile, based on their success at an adjudicated event. Because the sample was small (student n=20), it cannot extend the quantitative statistical assumptions to project results accurately or reliably to the entire student research population.

The fundamental limitation to this study is that the findings cannot be directly generalized to the larger population. Because there is no expectation of generalizability when conducting multi-case study qualitative research, it is left to the reader to determine the transferability of the study (Merriam, 1998). Transferability suggests that the burden of demonstrating applicability of the study rests with the investigator (or teacher) who would make the transfer rather than the original investigator (Lincoln & Guba, 1985). It is therefore recommended that the findings of this study be subject to the individual interpretation and use of other researchers and teachers of science research. Problem finding strategies and behaviors exhibited by the subjects in this study are intended to provide a framework for possible methods that might improve science research projects of other students.

Implications

The findings presented in this study amply demonstrate that outstanding student research is almost always the work of creative students who have found and formulated their own problem areas of research. These students are bright, eager to learn, resourceful and persistent, and manifest an intellectual curiosity that drives and sustains their efforts to know and understand. They are self-motivated self-starters capable of independent learning. Indeed, two important attributes they all possess is first the ability to recognize when they lack information, techniques, or instrumentation needed to cope with their problems and second the exceptional ability to teach themselves the requisite knowledge and skills.

All of these students equate and define creativity as the ability to problem find. In order to elicit creative behaviors from students and nurture them, teachers might consider ways to provide learning environments and resources conducive to independent learning and problem doing. This conception of situated creativity suggests that creative behaviors will manifest more readily when students garner more expertise and exposure to not only scientific content, but to the processes of scientific research. Thus, the following observations and suggestions, derived from the findings of this study, are presented with the hope they will provide useful insights to teachers and other adults interested in helping students to (a) problem find, and (b) engage in the independent, authentic research that follows.

Teachers and students as researchers. Science teachers are more likely to be effective guides and mentors for students engaging in research if the teachers themselves value and have had first-hand experience with research projects. Based on the tenets of situated cognition, in order to become a member of the community of practice, a member needs to participate in some form of cognitive apprenticeship. It is reasonable to hypothesize that teachers, previously not exposed to an authentic research experience, would benefit from participation in such apprenticeships also to more accurately provide their students with genuine opportunities. Unlike traditional college courses with structured 3-hour laboratory periods, and high school courses with double-period laboratory exercises, working on an authentic research project for an extended period of time requires skills, temperament, and attitudes that can best be acquired by first-hand research experiences.

Thus, pre-service and in-service teachers might derive great value from seeking out and participating in research opportunities. These can come in many forms, including: (a) formal summer-institute apprenticeships for teachers, (b) informally or formally partnering with a university professor or industry professional to conduct research with or without students, as well as (c) attending regional and state science conferences, science fairs, and symposia. This is, by no means a comprehensive list of potential teacher opportunities. It does suggest, however, that mentoring research students is very different from teaching a traditional science course.

In a similar fashion, students can also benefit from externship opportunities. Externships can range from single-day job shadowing, summer enrichment activities, to full-fledged extended research laboratory internships. Indeed, many of the top finalists at state and national science fairs and symposia got their start by an enrichment program at such places as the Rockefeller Institute, the Jackson Memorial Laboratory, local hospitals, medical schools (e.g., the Yale School of Medicine, the University of Connecticut Medical Center), and university summer mentorship programs. Many students have acquired valuable skills and investigative techniques in such programs and, perhaps even more importantly, they have had first hand contact with scientists and with fresh ideas, intriguing problems, and exciting challenges.

Surely, then, when teachers make themselves aware of such opportunities, and then introduce such prospects to their students, they are opening new horizons for students and may well introduce them to life-changing experiences. State and national professional science teaching organizations regularly publish bountiful lists of opportunities for both teachers and students.

Nurturing problem finding. The problem finding stage is a critical first step that cannot be hurried. Considerable time, thought, and resources are needed during this phase of research. When students discover ideas or phenomena that interest them, time and support are then needed to refine their interests and to formulate meaningful and manageable research topics. At this critical juncture teachers may find a Socratic approach the most effective course of action. Student autonomy is crucial here. In a situated learning setting, students must assume the responsibility for their projects. Teachers can function as facilitators by helping students realize that they must set their own priorities, schedules, and deadlines. For example, success for students in this study was demonstrated by their ability to monitor and adjust their learning, as well as their ability to interact in collaborative ways with teachers, mentors, and scientists.

Teachers often live under the “tyranny of the bell.” They work hard to make things go to completion in a 45-minute instructional hour. But, of course, this is not how science works. Often a long progression of brilliant and dedicated women and men worked for centuries to formulate an important idea or theory. Independent student research often follows a similar path. Authentic problem finding, and the research that follows, can take an extraordinary amount of time so opportunities to engage in research experience for multiple years has great potential value.

A program that allows students to conduct one or more projects over multiple years has the advantage of truly allowing students to fully develop and explore their creative ideas as well as perpetuating a classroom culture of varying levels of expertise. Older students with more experience might then have the opportunity to assume leadership roles within the classroom research environment. Here, again, teachers can play an important role by introducing their students to such opportunities and by encouraging them to participate in multi-year projects in collaboration with other students or as individual researchers.

Special research courses. An increasing number of science teachers offer special research courses in which students have opportunities to pursue open-inquiry activities that transcend the traditional science course offerings (see Pavlica, 2004; Robinson, 2004). Clearly, these are initiatives that merit praise and support from administrators, parents, and school board members.

Fairs and symposia. A great many private corporations and organizations sponsor events for students to present their research to an authentic audience of industry and academic scientists and engineers. Numerous studies demonstrate that students have an extremely positive experience by participating in these events (Olsen, 1985; Gifford & Wiygul, 1987; Pyle, 1996). If students and teachers collaboratively choose to participate in an event, they need to be sensitive to the expectations of the audience that will receive their presentations. The quality and nature of the product produced should meet the expected rigors and standards of the sponsoring organization. Science fairs, for example, often evaluate projects in terms of four dimensions or categories, as defined by this study: literature review, technical, technical with value, novel approach. The greatest value and most favorably received go to projects that are “technical with value” and “novel approach.”

Facilitating communication and sharing. High quality problem finding and problem solving require high quality communication. It is a truism that all teachers are English teachers and this is particularly true for teachers seeking to guide and support students engaged in independent research. Teachers can be helpful by modeling effective oral and written communication skills and by coaching their students through practice presentations and rehearsals.

Teachers can also encourage students to become members of the community of practice, and as such, can encourage students to seek the expertise of professionals when developing their project ideas. Teachers may need to remind students that communication with practicing scientists and engineers should be conducted professionally and appropriately. For example, strategies for phone calls and electronic mail communication can be outlined, rehearsed, and reviewed (see Robinson, 2004).

Oral presentations, using presentation (e.g., PowerPoint) technology, have become a primary communication mode for students engaging in open-inquiry. The opportunity to regularly present their work to teachers and classmates builds spoken communication skills, and assists students in polishing and strengthening their thoughts and findings before formal presentations at science fairs and symposia. Teachers and students alike can use well-designed formative evaluation rubrics to provide meaningful feedback to presenters. The rubrics might contain indicators that include: organization of the presentation, clarity of subject knowledge, quality of graphics, grammar mechanics, eye contact with the audience, and elocution.

Thoughtful teachers seek to find a balance between being a didactic knowledge deliverer and a mentor-facilitator. There are times when a teacher may need to model effective presentation techniques, and there are times when the teacher may need to take a more Socratic approach and work in conjunction with other students to provide the student investigator with helpful feedback in the form of thought-provoking questions and constructive criticism. Questions and feedback that encourage self-evaluation and introspection can play a pivotal role. Students surely “learn by doing” but they may learn even more when a teacher helps them to “reflect on the doing.”

Awareness of the dynamic nature of scientific research. Science is a dynamic self-correcting enterprise subject to change without notice. This means, of course, that there is no standing still in science. Teachers need to be life-long learners in order to keep their science courses timely, contemporary, and up to date. Incorporating current advances in science can also serve another purpose; namely, it can introduce self-motivated students to new and interesting developments at the cutting edge of scientific research. Virtually all of the students in the present study began their work because something in science engaged their attention, interest, and imagination.

Quo vadis? Students and mentors in this study view science and scientific research as a creative, idiosyncratic, nonlinear, situated process. This conception of the nature of science is in alignment with strikingly similar views in the National Science Education Standards (NRC, 1996; NRC, 2000). One final suggestion offered here, then, is for teachers to strive to help all of their students acquire such understanding and appreciation of the pursuit of science. The findings of this dissertation suggest that one of the most effective ways to accomplish this goal is to engage students in authentic scientific research.

Suggestions for additional research

Because problem finding is not extensively studied, and studies of students participating in high-level science fairs is relatively nonexistent, additional studies are warranted to confirm and expand the results and conclusions of this study. Direction for future studies might include varying the research design, using other samples, or examining the open-inquiry process as a longitudinal ethnographic case study. Studies into the types of instructional programs that facilitate open inquiry might also be examined.

Findings from this study might be operationalized for a quantitative study. For example, types of projects can be classified by the schema developed here and compared with the community of practice (judges) project rating scores, including subscales of creativity. Problem finding could be correlated to other factors found in this study such as communication ability, parental involvement, student self-regulation, or perhaps teacher or student perceptions of the nature of science or inquiry.

Conclusion

Problem finding in science is a uniquely creative process that can inspire and direct open-inquiry research. Students who problem find well, do so by utilizing a situated cognition learning framework. Their problems, and subsequent projects, have value to a greater community outside of the scope of the classroom, and often have a novel approach. Students commonly and effectively find their problems using resources from previous, specialized experiences. They have a positive self-concept and a temperament towards creative, logical, and analytical perspectives of science research. Good problem finding is derived from an idiosyncratic, nonlinear, and flexible use and understanding of inquiry. Finally, problem finding is influenced and assisted by the community of practice, to whom the students have an exceptional ability to communicate with effectively. These students and their problem finding strategies can serve as models for other neophyte researchers who wish to successfully pursue an open inquiry project.