

CHAPTER 1: INTRODUCTION TO THE STUDY

Introduction to the topic area

Secondary school teachers have long valued developing student problem solving skills. Indeed, problem solving has become an integral part of instruction across curriculum areas. Students are challenged to use a variety of strategies to identify problems and their implications, develop action plans, utilize a variety of relevant sources, information, and data to address the problems, and formulate solutions (NHS, 2003; OHS, 2007). Problem solving techniques can be highly idiosyncratic. However, in perhaps too many educational settings involving problem solving, teachers provide students with the problem or question, and sometimes even the methodology for determining the solution. This approach may be due to curricular requirements, time factors, or the limited scope and goals of particular learning modules or the inability of teachers to effectively employ inquiry-oriented instructional techniques.

What, therefore, seems lacking are opportunities for students to problem find: to develop their own unique ideas for study. While problem solving requires primarily logical/analytical thought processes, problem finding is a creative process (Dillon, 1982). Student success in science can often be attributed to motivation and an understanding of what science is (Simpkins, Davis-Kean, & Eccles, 2006). Thus, students might benefit greatly from a more holistic instructional approach to the nature of science, which includes experiences in both problem finding and problem solving. When these opportunities become authentic, there is potential for great gains in student learning (Aulls, Shore, & Delcourt, 2007).

Rationale

Problem finding has been primarily studied in the arts. Getzels and Csikszentmihalyi (1976) conducted one of the initial problem finding studies: longitudinal research of artists. Few

studies of problem finding in science students exist (Hoover, 1994; Hoover & Feldhusen, 1994; Roth & Bowen, 1993; Roth & Roychoudhury, 1993; Shepardon, 1997; Subotnik, 1988). Only a limited number of studies have been conducted and most of these are over 10 years old. Even a leading psychology of learning text only dedicates one page to problem finding, while expounding on problem solving for over 22 pages (Driscoll, 2005, p. 472). Problem finding exists more often as a theoretical construct, rather than an empirically studied concept and is infrequently associated with science education.

Problem finding and open inquiry have, on a limited basis, been examined in the classroom setting (Aulls, Shore, & Delcourt, 2007). Surprisingly, there appears to be almost nonexistent published research of open inquiry, in terms of science fairs, and problem finding. Reports of students at science fairs are primarily descriptive in nature, (e.g. Bellipanni, 1994; Colwell, 2003; Pyle, 1996; Shore, Delcourt, Syer, & Shapiro, 2007). Therefore, the population of students in this study, those from the 2007 Connecticut Science Fair and the 2007 International Science and Engineering Fair, represent an untapped resource of valuable information and insight regarding problem finding abilities, strategies, and dispositions. Indeed, these student-scientists are innovators, novel thinkers, and model learners that can provide meaningful insight for science teachers looking to promote creative endeavors for students in their classes.

Problem Statement

The aim of this research is to seek and analyze data that may lead to a better understanding of problem finding in authentic open inquiry science environments. The present study is designed to provide guidance for instructional strategies to promote creativity, in terms of problem finding.

Benefits of the research

This study is qualitative in nature and is focused on identifying characteristics and behaviors of students who complete open inquiry research projects. The transferability of key findings should provide teachers with insights and techniques for helping their students create and conduct exemplary open inquiry research projects.

Definition of key terms

1. A *problem* is a question to be investigated by a researcher; the aim of the study. The problem may be described in terms of the effects of (an) independent variable(s) upon (a) dependent variable(s), engineering goals, or a generalized purpose (Fraenkel & Wallen, 2002; SS, 2006a).
2. *Applied Research* is an original scientific investigation or engineering project undertaken to acquire new knowledge, seek to solve practical problems, or develop new products.
3. *Authentic Research* is scientific research conducted by students with existent, emergent, or potential problems (Dillon, 1982). Existent problems are evident – a problem exists and research is conducted to solve and/or explain it. An emergent problem is implicit. The problem must be developed, formulated, or found before it can be studied. A potential problem is one that does not yet exist: it is uncovered, discovered, or invented. Results of the study are unknown before research is undertaken.
4. *Inquiry* is the “diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (NRC, 1996, p. 23).

- Inquiry can also refer to activities of students in which they develop knowledge and understanding of scientific concepts, and methods to study the natural world.
5. *Open* refers to any activity that takes place that is not bound by specific rules, structures, or confines. Open implies that choice is available and expected.
 6. *Open Inquiry* is a student-centered instructional approach for learning that begins with a student's question, followed by research, design, experimentation, and communication of results. Open inquiry requires higher order thinking and direct, practical work with concepts. A key feature of open inquiry is having students ask their own questions (Martin-Hansen, 2002).
 7. *Problem finding* is a science student's ability to define or identify a problem (Kay, 1994). The process involves consideration of alternative views or definitions of a problem that are generated and selected for further consideration (Fontenot, 1993). Problem finding requires students to set objectives, define purposes, decide what is interesting, and ultimately decide what they want to study (Leavitt, 1976).
 8. An *ill-defined problem*, in learning psychology, is one in which either the starting position, the allowable operations, or the goal is not clearly specified, or a single solution may not exist (Colman, 2001).
 9. A *well-defined problem*, in learning psychology, is a problem in which the initial state or starting position, the allowable operations, and the goal are clearly specified, and a single solution exists (Colman, 2001).
 10. A *Science Fair/Symposium* is a high school event for students to present the results of their inquiry projects via scientific posters for fairs. Local school districts may provide fairs, which feed to regional fairs. The State of Connecticut conducts the

Connecticut Science Fair (CSF) in March at Quinnipiac University. This regional fair sends its four best projects and students to the Intel International Science and Engineering Fair (ISEF) in May to compete with approximately 1,500 students. The State of Connecticut also hosts a regional Junior Science and Humanities Symposium (JSHS) at the University of Connecticut in March. Students present the results of their research in oral presentations. Top presenters attend and compete in the national JSHS in May. Scientists often present the findings of their research at non-competitive symposia as well. Schools follow this practice and offer students non-competitive opportunities to present research, as well

11. A *Type I Activity*, defined by Renzulli (1977), is an enrichment activity where students are exposed to a wide variety of experiences that may not be available in the essential curriculum. Guest speakers, demonstrations, field trips, documentaries and other resources are provided to expose students to a wide variety of disciplines, topics, and occupations. The goal of Type I activities is to stimulate new interests and understandings that students may choose to pursue through intensive study.
12. A *Type II Activity*, defined by Renzulli (1977), is an enrichment experience where students develop advanced research and thinking such as problem solving and creative thinking. These learning activities encourage high-level thinking and reasoning skills in order to prepare students to conduct advanced, independent, Type III activities.
13. A *Type III Activity*, defined by Renzulli (1977), is an enrichment activity involving students who become interested in pursuing a self-selected area of study (Renzulli & Reis, 2001). Students must be willing to commit the time necessary for advanced

- content acquisition and process training in which they assume the role of a first-hand inquirer. Type III activities, in the context of this study, refer to open inquiry activities that may or may not be for the purpose of educational enrichment.
14. *Reverse engineering* is the process of discovering the functional principles and processes of a device, object, or system through analysis of its structure, function, or operation. It often involves taking the device apart and analyzing its workings in detail for the purpose of making a new device or program that does the same thing without copying anything from the original (Rekoff, 1985).
 15. The *community of practice* is a process of social learning that occurs when individuals and practicing scientists and engineers collaborate over an extended period of time to share ideas, find solutions, and innovate (Wenger, 1998).
 16. *Peripheral trajectory* is outside or unstructured participation in a community of practice. Based on situated cognition learning theory (Brown, Duguid, & Collins, 1989), it describes students who did not engage in meaningful brokering of relations with scientists or engineers, but may have participated in the science fair process.
 17. *Inbound trajectory* describes a neophyte who invested in the community of practice and was heading towards full participation. These students gained experiences and expertise that often led to the development of a meaningful project.
 18. *Insider trajectory* occurs when an individual is no longer a neophyte, but still engages in continuous self improvement
 19. *Boundary trajectory* describes a full member of the community of practice who brokers relations and expertise with other individuals in the community. Some students in this study achieved boundary trajectory.

20. *Outbound trajectory* occurs when a member leaves the community of practice. From a student perspective, this may arise due to the completion of a project, change in interest, graduation, or new opportunities.

Related Literature

To meet the needs of diverse student learners, non-traditional, research-focused courses in science have recently appeared in high school programs (Atkin & Atkin, 1989; DeBruin & Schaff, 1982; Murphy & Cappola, 1997; Ngoi, 2004; Pavlica, 2004; Robinson, 2004). These courses are designed to allow students to learn science through authentic, situated experiences. The development of open inquiry-based science research programs addresses these needs by allowing students to conduct yearlong and multiyear research projects on topics of individual student interests. Although these programs are developed and implemented in a great variety of formats, they have some commonality that allows students to excel and succeed at very high levels (Rosvally, 2002). Students' scientific success is often measured externally at local, regional, state, national, and international science fairs and symposia. Students may also demonstrate their success through a scientific community's peer-reviewed publication.

From a teaching and learning perspective, the major pedagogical goals of high-quality extended scientific open inquiry are to provide students with the opportunity to assume more and more responsibility for their own intellectual development by becoming independent learners (inquirers) who: (a) interact with practicing scientists; (b) participate in a significant research experience; (c) select, develop and conduct an independent research project; and (d) develop the skills of reporting, presenting, and sharing research results.

Inquiry and its application in science education

Inquiry learning has long been the gold standard for quality science education (Biological Science Curriculum Study, 2007; LaBanca, 2007; Yulo, 1967). Inquiry, as described by the National Research Council (1996), encompasses “diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (p. 23). Inquiry also refers to activities of students in which they acquire knowledge and understanding of scientific concepts, as well as problem-solving skills.

Research has demonstrated that students who engage in inquiry learning perform significantly better on higher thought assessments and as well on traditional fact-oriented cognitive assessments as students who did not experience inquiry-oriented instruction (Costenson & Lawson, 1986). In order to implement inquiry learning successfully, teachers must understand what inquiry is, understand the structure of their scientific disciplines, and be skilled in inquiry-teaching. Since it can take many forms, it is critical that educators understand different forms of inquiry, and the value of implementing each.

Herron (1971) established a hierarchy of cognitive expectations associated with different types of hands-on laboratory activities and created a rating scale from zero to three (see Table 1). Teachers of inquiry would likely group Herron’s 0 and 1 levels together and refer to them as *cookbook* activities – those requiring the student to, in essence, follow a recipe to gather prescribed results. Inquirists term cookbook laboratory activities as *structured inquiry* (Martin-Hansen, 2002). Level 2 on Herron’s scale is termed *guided inquiry*: students are given a problem, often curricular in nature, and asked to develop an appropriate strategy for solving the problem.

Table 1

Herron scale of cognitive expectations for inquiry

Score	Description
0	Problems presented, methods, and correct interpretations are obvious. Observation labs, experience labs, labs that teach new techniques
1	A problem and method are posed. Students are expected to find new relationships
2	Problems are posed, methods and answers are open for student interpretation
3	Problems, answers, and methods are open. Students are confronted with raw phenomena

Very rarely are students, in a traditional science academic setting, able to engage in Level 3, or *open inquiry* activities. Although the National Science Education Standards and professional organizations encourage open inquiry, the practicality of meeting curricular demands coupled with teachers' lack of research experience often makes the feasibility low. Teachers often use a hybrid of guided and open inquiry, termed *coupled inquiry* (Martin-Hansen, 2002). Teachers will present a guided inquiry activity and then allow students to follow up the experience with a related open inquiry activity. The experience is not truly open, because students are basing their raw phenomena on a very specific related topic.

Open inquiry opportunities vary from school to school, but all potentially have a common experience for students to present their research for professional evaluation or review: science fairs and symposia. Students have the opportunity to select topics of personal interest, to develop them, and then execute the project, often working in conjunction with field mentors. But students

can gain more: they have the opportunity to be creative and autonomous by choosing research projects on their own rather than projects given to them or predetermined by a teacher.

Creativity and Problem Finding

In the gifted education literature, the Enrichment Triad Model (Renzulli, 1977), although not science-domain specific, parallels the Herron (1971) and Martin-Hansen (2002) models. Consisting of three levels of activities, Type I activities are general interest, though not typically found in the regular curriculum, and Type II are categorized as *how-to activities*. Open inquiry science research falls under the general domain of Type III. The model suggests that students assume the role of first-hand inquirer, create original authentic products (in this case, authentic scientific research) and share it with an appropriate audience. Renzulli's (1986) three-ring conception of giftedness suggests the student exhibiting gifted behaviors will possess above average, though not necessarily superior ability, high motivation, and creativity.

Creative/productive behaviors are critical characteristics of a student researcher. There must be an interest and proficiency in science concept attainment, proficiency in the laboratory, a high rate of science knowledge acquisition, and high retention of knowledge (Pizzini, 1982). Such students are independent, confident, and curious.

Creativity and self-actualization are critical behaviors for students engaging in Type III scientific endeavors (Innamorato, 1998; Pizzini, 1982; Renzulli & Reis, 2001; Romey, 1980). Innamorato (1998) defines authentic scientific creativity as “a meshing of artistic and scientific abilities” (p. 58). When surveying the components of scientific ability, he states “science has less to do with rules and formulae and more with imagination” (Innamorato, 1998, p.55). The very nature of inquiry is a creative process. Students may follow a seemingly logical sequence when identifying a problem and designing methodology, but the actual research almost always requires

flexible and innovative strategies. Practicing scientists often work in idiosyncratic ways and the creative processes of students should parallel these behaviors (Metz, 2006).

Creativity and scientific inquiry merge at the concept of problem finding. Einstein and Infeld (1938) state “The formulation of a problem is often more important than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires imagination and marks real advance in science” (p.83).

Problem finding, therefore, may be defined as science students’ ability to define or identify a problem (Kay, 1994). The process involves consideration of alternative views or definitions of a problem that are generated and selected for further consideration (Fontenot, 1993). Problem finding requires students to set objectives, define purposes, decide what is interesting, and ultimately decide what they want (Leavitt, 1976). Roth and Bowen (1993) indicate that good scientific problem finding (framing) occurs when students are in a situated setting, collaboration occurs with peers and experts, the environment contains the necessary tools and/or expertise, and students possess appropriate content background knowledge. When students problem find, they develop more in-depth sophisticated methodologies for solving problems (Shepardson, 1997).

The unique aspect of open inquiry is the opportunity to problem find, which is rarely taught during the process of problem solving (Siu, 2001; Washton, 1967). Having the opportunity to problem find often increases students’ motivation and provides a sense of ownership of a problem (Czarnik & Hickey, 1997).

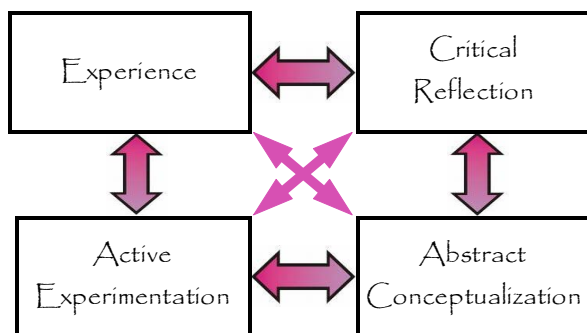
The nature of science in context: situated cognition

Open inquiry science research enables students to learn in context. Brown et. al. (1989) suggest that activities in context are integral to learning. The main tenet of the theory is that learning knowledge and skills occurs best when they are in a context that reflects the way they will be used in real life (Collins, 1988). The situated cognition model states that knowledge is conceived as lived practice (Driscoll, 2005). In essence, the sociocultural setting and activities of individuals drives the acquisition of knowledge. Learning for students occurs as they participate in a community of practice.

An active, student-centered, hands-on, minds-on approach promotes student understanding and, more importantly, student ownership. Learning, therefore, is not only internal to the student, but there is a social component too. Interactions are critical and occur reciprocally. Students learn from teachers and experts, and the experts learn from students. Learning becomes a co-constitutive process in which all participants change through their actions and relations to others (Driscoll, 2005).

The goal of situated cognition is to have students become part of a community of learners and members of a “culture of practice” (Brown, Collins, & Duguid, 2001, p. 39). Students enter such programs in the role of a newcomer, observing the scientific community from the outside, but gradually become full-fledged participating inquirers. The goal is to help students move from novice scientists to more capable and independent researchers experts, who learn to use their expertise, intuition, and deep understanding of science to solve problems of their choosing. Students need appropriate experiences with opportunities to examine their ideas, develop underlying concepts, and conduct experiments to successfully complete an open inquiry experience. Figure 1 represents this iterative progression.

Figure 1. Iterative process of situated cognition learning theory



Note. From A case study in situated cognition. In M. Orey (Ed.) Emerging perspectives on learning, teaching, and technology, by F. LaBanca, Retrieved January 20, 2008 from: http://projects.coe.uga.edu/epltt/index.php?title=A_case_study_in_situated_cognition.

Reproduced in accordance with the Creative Commons License.

Following this situated cognition model, Roth and Roychoudhury (1993) were able to generate findings to show student growth in science knowledge, skills, and dispositions via extended open inquiry. Their qualitative data indicated that student interpretation of results evolved from simplistic formulations to being able to identify complex relationships using multiple representations and analyses of experimental data. Following their own interests was motivating, and students were able to generate new ideas from previous results. In addition, students became more adept at planning experiments when given the freedom to choose topics.

Perhaps one of the most significant results of the Roth and Roychoudhury study was that students were able to define concepts, events, and actions to design their experiments and communicate the results. In other words, content acquisition occurred in situ: as students needed to understand scientific concepts to further their experimentation, they used the necessary and

varied resources to achieve that goal. Students were able to develop highly competent integrated science process skills in a situated cognitive context. Tytler (1992) demonstrated the importance of the development of student autonomy when working in an open inquiry environment.

There seems little doubt that students learn well when they participate in educational experiences, which allow them to focus on their own individual interests. The concept of students learning science through projects is well documented in educational research (AAAS, 1993; Buldyrev, 1994; NRC, 1996; Roth & Roychoudhury, 1993). Surely it is unfortunate that formal opportunities to pursue extended open inquiry are not common in secondary science education despite the findings that they can be so effective and productive.

Methodology

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?

Population

Students participating in the study have completed a research project and presented their results at either the 2007 Connecticut Science Fair (CSF) or the 2007 Intel International Science and Engineering Fair (ISEF). Each event evaluates students using a panel of professionals. The scoring rubric is developed and utilized for evaluation by the sponsoring organizations. CSF and ISEF provided student scores to select a range of quality in projects for this study. Selection included projects that were judged to include both high and low quality. A sample of 12 students from approximately 500 were purposefully selected from the 2007 Connecticut Science Fair (CSF) held March 13-17, 2007 at Quinnipiac University in Hamden, Connecticut. These students

were in grades 11-12, approximately 16-18 years of age, and attended a Connecticut or New York High School. A sample of 8 students were purposefully selected from the 2007 Intel International Science and Engineering Fair (ISEF) held May 13-19, 2007 in Albuquerque, New Mexico. These students were in grades 11-12 or international equivalent. ISEF subjects were all major category winners (see Appendix A), which were the top 17 projects out of approximately 1500 (SS, 2006a). Three teachers, three university mentors, and two fair directors from both CSF and ISEF student projects were purposefully selected in order to find out their explicit role in the problem finding and problem solving processes.

Research design

The qualitative paradigm was used to conduct this study. This involved a multicase study using a descriptive strategy to explain, identify, and document the phenomenological role of problem finding in open inquiry. The study was conducted utilizing in-depth, opportunistically-developed, semi-structured interviews, document analysis, demographic survey, and an affective instrument. Data from multiple sources was categorized and triangulated. Triangulation of data was achieved through methods (interviews, document analysis, surveys) and sources (students, teachers, mentors, fair directors, documents).

Instruments

Semi-structured interviews of student-scientists, parents, and mentors. Semi-structured interviews (Appendix B) were digitally recorded, transcribed, and analyzed using *The Ethnograph*, computer software designed to make qualitative data analysis research easier, more efficient, and more effective (QRA, 2006). Each record of interview data underwent content analysis in a search for patterns and categorical themes (Spradley, 1979). Consistency of responses from multiple sources were analyzed by triangulation. A cross-validation technique

was used to verify data coding, conclusions, and recommendations. Multiple student cases, from both CSF and ISEF, were used to generate comparison groups to provide a replication strategy for single-case findings (Huberman & Miles, 1994).

The Updated Science Research Temperament Scale (USRT). The USRT is an updated version of the Science Research Temperament (SRT) Scale (Kosinar, 1955). The SRT Scale was developed in the 1950s. It was intended to aid in the identification of personality traits that are associated with research productivity. This 42-item instrument has a reliability of .71. USRT data were used descriptively in this study.

Data collection procedures

Selection of student-subjects. Judging at the CSF and ISEF was conducted by science professionals in industry, academia, and service organizations using fair-developed standards. These professionals judged each project using an analytical scoring system and then caucused to determine a rank order and/or quartile level rank for the projects. CSF and ISEF provided their scoring data of potential subjects so a variety of projects could be identified. The purpose of using the CSF and ISEF scores was to allow a group of professionals, independent of this research, to identify and determine the quality of the projects.

Student-subject procedures. Both CSF and ISEF informed all participating students of this study via email. Initial face-to-face contact with potential subjects was made at the CSF and ISEF. Students received an invitation to participate in the study, informed consent, and other pertinent information. Follow-up phone calls were made to all potential subjects. Once consent was received, student-subjects were asked to complete the demographic survey and the USRT, online. Finally, subjects were interviewed either by phone or in person at their respective schools.

Teacher-mentor procedures. Students provided teacher and mentor contact information in their demographic survey. A group of parents and mentors was purposefully selected, from a subset of the student-subjects, and informed consent was provided. Adult subjects from CSF students were interviewed in person or by telephone and ISEF adult subjects were interviewed by telephone.

Documents. The Lexis-Nexis databases were searched using a guided news search and “International Science and Engineering Fair” and “ISEF” as keywords. A previous five-year search parameter was used. Articles were open coded and subsequently axial coded to observe trends in data.

Reflexivity Journal and Peer/Mentor Evaluation. An on-line reflexivity journal (LaBanca, 2008a; LaBanca, 2008b) was maintained throughout the study to provide an audit trail. Peers and mentors were utilized for evaluation of research techniques and data.

Limitations

The study had a limited number of subjects (n=20). Students in this study were from the state of Connecticut to examine regional fair practices and triangulated against ISEF. Other states (e.g. New York) have better established and entrenched statewide research programs than

Connecticut, which includes teacher training, as well as access to facilities. Therefore, diverse subject populations may be underrepresented.

In order to increase the trustworthiness of the study, the following research strategies were employed. To improve credibility, students were sampled at both the state (CSF) and international (ISEF) level to attempt to access a wide variety of student backgrounds. A blog was used for a reflexivity journal. Data were triangulated between and among student researchers, teachers and mentors as well as document analysis. The investigator utilized both peer and mentor examination to evaluate research data and techniques.

Although there was not prolonged engagement with the subjects directly, the investigator has prolonged engagement in the science fair process. He has been involved with the cooperating organizations for many years: the investigator sits on the advisory board of the Connecticut Science Fair and has had more than 40 students participate over the past seven years. In addition, the investigator has attended the International Science and Engineering Fair three times, both as a CSF representative and twice as mentor of a competing student.

Transferability of the study seems promising because the sample was representative of a range of quality projects from two sites. It will ultimately be up to the reader to determine the transferability of the findings of this study to his or her own unique situation.

Dependability of the study was supported by all data undergoing a code-recode process as well as peer and mentor examination to ensure accuracy of technique and findings. As previously described, data were triangulated. To ensure credibility an audit trail was maintained.