IMPACT OF PROBLEM FINDING ON THE QUALITY OF AUTHENTIC OPEN INQUIRY SCIENCE RESEARCH PROJECTS

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IMPACT OF PROBLEM FINDING ON THE QUALITY OF AUTHENTIC
OPEN INQUIRY SCIENCE RESEARCH PROJECTS

Frank LaBanca

B.S., University of Connecticut, 1994
M.S., University of Bridgeport, 1995

A Dissertation
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Education in Instructional Leadership
in the
Department of Education and Educational Psychology
at
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IMPACT OF PROBLEM FINDING ON THE QUALITY OF AUTHENTIC OPEN INQUIRY SCIENCE RESEARCH PROJECTS

Frank LaBanca, Ed.D.

Western Connecticut State University

ABSTRACT

Problem finding is a creative process whereby individuals develop original ideas for study. Secondary science students who successfully participate in authentic, novel, open inquiry studies must engage in problem finding to determine viable and suitable topics. This study examined problem finding strategies employed by students who successfully completed and presented the results of their open inquiry research at the 2007 Connecticut Science Fair and the 2007 International Science and Engineering Fair. A multicase qualitative study was framed through the lenses of creativity, inquiry strategies, and situated cognition learning theory. Data were triangulated by methods (interviews, document analysis, surveys) and sources (students, teachers, mentors, fair directors, documents). The data demonstrated that the quality of student projects was directly impacted by the quality of their problem finding. Effective problem finding was a result of students using resources from previous, specialized experiences. They had a positive self-concept and a temperament for both the creative and logical perspectives of science research. Successful problem finding was derived from an idiosyncratic, nonlinear, and flexible use and understanding of inquiry. Finally, problem finding was influenced and assisted by the community of practicing scientists, with whom the students had an exceptional ability to communicate effectively. As a result, there appears to be a juxtaposition of creative and
logical/analytical thought for open inquiry that may not be present in other forms of inquiry.
Instructional strategies are suggested for teachers of science research students to improve the quality of problem finding for their students and their subsequent research projects.
Doctor of Education Dissertation

*Impact of Problem Finding on the Quality of Authentic Open Inquiry Science Research Projects*

Presented by

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2008
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DEDICATION

This work is dedicated to:

Ann M. Dougherty
Biology Teacher, New Fairfield High School

and the memory of
Claire M. Berg
Professor of Molecular and Cell Biology, University of Connecticut

Remarkable women of science who most significantly influenced and shaped my professional path and taught me about the beauty and grandeur of the nature of science and the personal reward of conducting authentic research
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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. 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.

9. 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.

10. 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.

11. 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.

12. 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).

13. 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).

14. *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.

15. *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.

16. *Insider trajectory* occurs when an individual is no longer a neophyte, but still engages in continuous self improvement.

17. *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.

18. *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_

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

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.
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.
CHAPTER 2: REVIEW OF THE LITERATURE

Since the launch of the Soviet spacecraft, *Sputnik*, fifty years ago, there has been a movement in science education to focus more on inquiry learning.

Inquiry refers to the work scientists do when they study the natural world, proposing explanations that include evidence gathered from the world around them. The term also includes the activities of students -- such as posing questions, planning investigations, and reviewing what is already known in light of experimental evidence – that mirror what scientists do (Martin-Hansen, 2002, p. 35).

The US government has long been concerned about high school-aged students falling behind the sciences and engineering fields compared with their counterparts from other countries. To that end, many funding opportunities have been created to revitalize and modernize science teaching and learning in secondary education.

Today, a few organizations still stand strong as a testament to the vision of students learning science in a conceptual inquiry-based context instead of an isolated, fact-based pedagogy. For example, Biological Sciences Curriculum Study still produces high quality inquiry-based textbook programs for the biological sciences as well as free curriculum supplements that are all field tested (BSCS, 2007). The Junior Science and Humanities Symposium (JSHS), a program developed in 1962 in cooperation with the National Academy of Applied Sciences in cooperation with the military, gives students the opportunity to present the results of original research they conduct. Students have the opportunity to present their research at a regional event, with the possibility of presenting at a national event (JSHS, 2007). Regional
science fairs and their national counterpart, which had seen their advent, about ten years previous to JSHS, began to blossom as well.

Advent of Science Fairs

In the 1920s, Science Service (SS), a nonprofit organization, was established to combat much published pseudoscience (SS, 2006b). The organization was formed to generate a short, weekly publication based on current science advances that was easily accessible to the public. In essence, they were charged with popularizing public interest in science. The bulletin was primarily circulated to news organizations that might use the information to generate news stories. In the mid 1960s, this news bulletin eventually developed into the weekly Science News.

In the early 1940s, Watson Davis, the editor of Science News, envisioned reaching a wider audience to expose mainstream America to science. In cooperation with the American Institute of the City of New York, Science Service established the Science Clubs of America, a group of over 800 science clubs. Science News reported on September 17, 1941, “In developing this broad science clubs movement, there will be enlisted the enthusiasm, support, and participation of newspapers, museums, schools, and other scientific and educational institutions, including professional scientific societies, and industrial organizations” (p. 20).

In order to promote research being conducted by students in these clubs as well as careers in the sciences and engineering, Science Service partnered with Westinghouse in 1942 to establish the Science Talent Search (STS), a contest for high school seniors to present the results of their original research in writing. The STS, now sponsored by Intel, has alumni who include three National Medal of Science winners, nine MacArthur Foundation Fellows, two Fields Medalists, and six Nobel Laureates (SS, 2006b). Students of the top 40 projects annually
convene in Washington, D.C. at the National Academy of Sciences where they present their research to distinguished scientists and engineers to compete for scholarships (Intel Corp, 2006).

Many of the science clubs began to provide opportunities for a wider range of students to submit and present their research in the form of science fairs. Connecticut established its fair in 1949 under the auspices of the now-defunct newspaper, the *Hartford Times*, spearheaded by its education editor Albert Prince (LaBanca, 2007).

Simultaneously, these regional fairs wanted to showcase their top projects, and in 1950 the first National Science Fair was held in Philadelphia at the Franklin Institute. Connecticut sent its two top students who joined 28 others in the first-ever pre-college national science fair (LaBanca, 2007). The National Academy of Sciences in cooperation with the Army established the Junior Science and Humanities Symposium, another program with opportunities for high school students to present their research, while the National Science Fair continued to grow. An uproar for science excellence and improvement was truly evident in 1957 with the Soviet launch of Sputnik. The National Fair was held in Hartford in 1959, and for the first time, included international competitors from Canada, Germany, and Japan (Intel Corp, 2006; LaBanca, 2007).

In 1960, the National Science Fair’s name was changed to the International Science and Engineering Fair (ISEF), to better reflect the new international component. The Connecticut Fair also continued to grow, holding its annual March event at various colleges and universities around the State, generally with preference towards the central and eastern parts. Connecticut was granted title sponsorship by United Technologies Corporation (UTC) when 1950s student standout, George “Bob” Wisner, an engineer with the UTC Research Group, became the CSF’s chairman of the board. UTC still sponsors the annual event with other major Connecticut corporations. Wisner has been active as a student, professional, and volunteer with CSF for
almost 50 years. He has regularly been called upon by students and teachers alike to assist in the development of high quality student projects. His guidance, along with outstanding research programs from across the state, led to an unprecedented four top projects at ISEF within five years from 1999-2004.

ISEF, currently title-sponsored by Intel, is held in May each year in various major US cities, and occasionally Canada. The fair boasts over 550 affiliated fairs from all 50 states and 40 nations. In 2007, a record 1511 students presented their research at ISEF, 57% male and 43% female (SS, 2007). It is the largest and most prestigious pre-college science fair.

Research on science fair learning

Limited studies have been conducted to evaluate characteristics of students via their science fair projects. In fact, only three studies exist to examine the US top science students who have conducted extended open inquiry research and presented at the national or international level (Bellipanni, 1994; Pyle, 1996; Subotnik, 1988). Bellipanni studied predictors for success of students at the 1993 ISEF, Pyle examined research strategies of students at the 1993 ISEF, and Subotnik studied problem finding behaviors of students who competed in the 1983 Science Talent Search. All other studies have examined the science fair process through a local or regional lens.

Grobman (1993), a long time science fair judge, callously identified numerous problems with science fairs and suggested they should not take place outside of the classroom. He exposed that science fair projects too often reflect the work of parents, not students. Shore, Delcourt, Syre, and Shapiro (2007) confirm that cheating occurs in the science fair setting, often when a student is under pressure to complete a task without the proper infrastructure that would lead to
independent success. When this is the case, the science fair paradigm does not provide students with the authentic opportunity to conduct meaningful studies.

On the opposite end of the spectrum, Olsen (1985) reported that students participating in a regional science fair in a Midwestern state overwhelmingly (>96%) rated the value of doing a science project as high, compared to medium (3.8%) and low (0%). Most students (>73%) indicated that the science fair experience had some influence on their career path, with 51% selecting a career in the sciences.

Gifford and Wiygul (1987) examined factors that led to success for participants in a regional science fair in a southern state. They reported several factors that influenced success: (a) the use of college and university resources, (b) the costs and funding available for developing a project, (c) the hours spent in the high school laboratory, and (d) the hours spent in a public library. Factors that did not influence success included: (a) the use of the school library, (b) the use of school shops, (c) the use of farms, (d) the use of medical schools, and (e) consultation with professionals at medical schools, research universities, or research facilities.

Using the Gifford and Wiygul instrument, the Science Fair Survey (SFS), Bellipanni (1994) conducted a study at the 1993 ISEF to examine if there was a significant relationship between receiving an award and predictors of resources and facilities, resource personnel, personal costs, time, and personal characteristics. Bellipanni’s analysis indicated that an aggregated factor of resources and facilities was significantly (p<.05) related to winning an award. Interestingly, ability or achievement in the traditional school setting did not have statistical significance. Bellipanni results were not in total alignment with the Wiygul and Gifford study, indicating that winners made significantly more use of parents or friends’ businesses or farms and research facilities, while non-winners made more significant use of
school labs and parents or friends’ personal shops. Use of libraries, public or school, had no significant relationship to students’ success. Bellipanni, while demonstrating significance, reported low magnitude in his results and suggested that further study would be necessary to confirm the results.

Pyle’s (1996) study examined strategies employed by students as they engaged in the research process. Pyle used an interpretive methodology, studying 22 subjects via questionnaire and scrutinizing a large pool of artifacts collected from the students and Science Service. He determined that the selection of research design (e.g. experimental, descriptive, comparative analysis) was unimportant. However, he noted that the majority of ISEF projects were experimental in nature and questioned factors such as a regional fair that might eliminate non-experimental projects from reaching ISEF. His descriptions of the types of projects were broad and lacked clear definition. He also indicated that mentors and parents allowed students to take ownership of projects and offered suggestions to further define the roles of parents and mentors. Finally, Pyle noted that students conducting research were intrinsically motivated and suggested that parents and mentors should facilitate a positive experience for children.

Subotnik (1988) studied subjects (n=146) participating in the 1983 Science Talent Search, the nation’s oldest continuous competition for original science research. She examined problem finding ability of subjects who were dubbed “independent problem finders” (p. 46). These students developed their problems independent of assistance of a teacher, parent, or mentor. They were also not assigned the problem. Of the sample, this represented 39%. Subotnik attempted to align problem finding characteristics with the Guilford’s (1967) structure of intellect model. She concluded that good problem finders manifested and described their application of creativity best in terms of intelligence as convergent production of semantic
implications. In more general terms, this means that convergent problem solving, utilizing logical deductive reasoning, was facilitated by communicating with others (Meeker & Meeker, 1986). The second highest rating was assigned by the problem finding students was evaluation of semantic implications, better coined as making decisions or judgments using logical deductive reasoning that is facilitated by communication with others (Meeker & Meeker, 1986).

In other words, scientific creativity appeared to imply stronger ties to convergent thinking rather than divergent thinking. Subotnik suggests that divergent thinking is not the key factor associated with scientific creativity as there was a much stronger tendency for preference of convergent production. This study aligned scientific creative strategies used by talented teens with previous studies of practicing scientists (Allen, Guilford, & Merrifield, 1960).

Subotnik followed many of her subjects (n=50) longitudinally to track their development as potentially creative problem finding researchers (Subotnik & Steiner, 1994). Students who were pursuing advanced scientific careers were generally doctoral students at this point. A percentage of students did not pursue careers as scientists. Of those who were initially problem finders, 45% remained problem finders, while 15% were presented with the problems they studied, and 35% became non-researchers. Of the initial non-problem finders, 30% became problem finders, 13% were presented with the problems they studied, and 57% were not involved in research.

The data also demonstrated that mentors played a key role in the development of the students’ research abilities. All of the subjects identified as problem finders had a mentor relationship, with 72% classifying the relationship as intense with active participation where the mentee received regular guidance and feedback. Therefore, an important finding of the
longitudinal study was that mentors played a critical role in developing and encouraging future scientists.

*Inquiry in education*

Inquiry in its most simple and perhaps elegant definition is investigation by questioning. Inquiry, as an instructional strategy, has long suffered from various interpretations or misunderstandings of definition by teachers (Hammer & Schifter, 2001; Roehring & Luft, 2004; Wallace & Kang, 2004; Windschitl, 2004). The National Research Council (NRC) published a manuscript, *Inquiry and the National Science Education Standards*, specifically intended to address inquiry and the National Science Education Standards (NRC, 2000). The manuscript addressed a definition of inquiry, from both an aesthetic perspective and a teaching-learning perspective:

First [inquiry] refers to the abilities students should develop to be able to design and conduct scientific investigations and to the understandings they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. In this way, the *Standards* draw connections between learning to do science, and learning about science. (p. xv)

Inquiry, therefore, is more of a philosophy of teaching rather than a way to conduct laboratory activities. Following that assumption, it would be reasonable to conclude that inquiry need not only take place in a laboratory-experimental setting, but could be used as a foundation for various types of instructional strategies, including, information-processing models such as
direct instruction, inductive thinking, synectics, and memorization (Joyce, Weil, & Calhoun, 2004).

Inquiry learning has the instructional goals of teaching scientific knowledge and processes of research, while nurturing a commitment to scientific inquiry, promoting open-mindedness with an ability to balance alternative perspectives, and a cooperative spirit and skill (Joyce, Weil, & Calhoun, 2004). Research has demonstrated that teachers who subscribe to a sustained philosophy of inquiry teaching engaged in intensive study of the academic substance of inquiry, and models of inquiry teaching (Joyce, Weil, & Calhoun, 2004; Manconi, Aulls, & Shore, 2007). In essence, they were metacognitive about inquiry education.

Manconi, Aulls, and Shore (2007) qualitatively studied eight experienced teachers, six of whom were inquiry teachers and two non-inquiry teachers, to determine their use of inquiry strategies and their understandings of inquiry. The study demonstrated that teachers not using inquiry in their classrooms did not possess a clear understanding of it, opted to use a more traditional teacher-centered approach to instruction. Teachers who possessed a clear conceptualization of an inquiry teaching approach were able to transfer their expertise and enthusiasm to their students.

Inquiry models, especially when teachers have implemented the process effectively and have a solid understanding of content, have consistently demonstrated strong gains in student learning (Bredderman, 1981; Costenson & Lawson, 1986; El-Nemr, 1979; Prince, 2004; Shymansky, Hedges, & Woodworth, 1990). Costenson and Lawson (1986) demonstrated that high school students engaging in inquiry learning were able to make significant growth in higher order conceptual thinking. At the same time, they were able to demonstrate that students maintained equal retention of fact-based comprehension-type knowledge, thus demonstrating
that student learning in an inquiry setting facilitates more overall growth. In his review, Prince (2004) summarizes the many benefits of inquiry learning at the university level: (a) a positive student attitude, (b) long-term retention of knowledge, (c) improved student performance, and (d) studying which focused on meaning over recall.

Shymansky evaluated inquiry programs compared to traditional textbook programs in a meta analysis of 81 studies (Shymansky, et al., 1990). Shymansky demonstrated four of seven clusters with significant effect sizes in the comparison of inquiry instruction across science curricular areas (see Table 2). He further examined effect size of inquiry versus traditional instruction with other factors such as grade level, subject area, gender, and school type. Specifically, the overarching four categories with significant effect sizes were: the composite, achievement, perceptions, and process. The analytic, related skills, and other clusters did not show a significant effect size.

It is interesting to note that applied knowledge skills including critical and creative thinking show no significant effect size. Problematic to studies of inquiry programs are the types of inquiry that take place in such programs. Rarely are open inquiry programs part of school curricula, rather guided and structured inquiry opportunities would more likely be present. Without an open focus, students will bypass the creative problem finding steps and be presented with a problem from a teacher, thus only engaging in logical/analytical problem solving.
Table 2

*Cognitive and affective learning clusters from Shymansky et al. (1990) meta analysis*

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Criteria</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>Total of all clusters</td>
<td>0.26&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Achievement</td>
<td>Fact/recall items</td>
<td>0.30&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Synthesis/analysis/evaluation items</td>
<td></td>
</tr>
<tr>
<td></td>
<td>General achievement items</td>
<td></td>
</tr>
<tr>
<td>Perceptions</td>
<td>Affective attitudes towards subject, science, teaching techniques, and self</td>
<td>0.19&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Process skills</td>
<td>Process measures, lab skills, techniques, methods of science</td>
<td>0.33&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Analytic skills</td>
<td>Critical thinking</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Problem solving</td>
<td></td>
</tr>
<tr>
<td>Related skills</td>
<td>Reading comprehension and readiness, Mathematics concepts, skills, and applications</td>
<td>-0.10</td>
</tr>
<tr>
<td></td>
<td>Communication skills, writing, speaking</td>
<td></td>
</tr>
<tr>
<td>Other areas</td>
<td>Creativity, logical thinking&lt;sup&gt;b&lt;/sup&gt;, spatial relations&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.10</td>
</tr>
</tbody>
</table>


<sup>a</sup>significant at p<.05

<sup>b</sup>Piagetian tasks
Smith (1996) also conducting meta analysis and Mao and Chang (1998) conducting a large-scale study of earth science students using inquiry versus traditional instructional strategies, demonstrated that inquiry methods improved content mastery and retention, and increased positive perceptions of science. Contrary to the Shymansky studies, Smith demonstrated improved critical thinking skills, but no significant difference in process skills. Mao and Chang specifically recognized significance in higher order critical thinking but did not measure process skills.

In summary, inquiry is most frequently defined and studied in terms of a specific content-oriented traditional class setting for practical reasons: most educational learning takes place with teachers and students in the classroom. However, in an individualized, student-centered research project-based learning environment, roles of teachers and students sometimes change. Nonetheless, good questions are the hallmark to good inquiry. However, there are a range of types of questions that are posed.

**Definitions for inquiry activities**

*Levels of inquiry.* Following the definition of inquiry as investigation by questioning, there are various continua of the nature of questioning that have been developed (Herron, 1971; Martin-Hansen, 2002; Renzulli, 1977). Martin-Hansen (2002) described a continuum of inquiry-type laboratory activities that might take place in the science classroom and published it in a widely distributed science teaching journal. The type of inquiry activity is often dictated by the type of lesson or specific instructional needs of the classroom. The inquiry continuum is described in Figure 2.
Structured inquiry is a guided form of inquiry, generally directed by a teacher (Martin-Hansen, 2002). This is typically exemplified by a hands-on learning experience where students follow the step-by-step directions provided by the teacher. Students are provided with a problem, a procedure, sometimes the data analysis procedure, but they are not informed of the predetermined results. Student behavior is focused on following teacher-derived instructions. Structured inquiry activities are predictable: students are studying a well-known question with a well-known outcome using a reliable and reproducible method. Practitioner vernacular sometimes refers to structured inquiry activities as “cookbook.”

When students engage in guided inquiry they have more responsibility and independence than when using structured inquiry. A teacher poses a question, often curricular in nature, and students work to develop a solution by designing their own methods and data analysis procedures. In guided inquiry, more problem solving responsibilities are given to students. However, students do not determine the question for study; they do not problem find.

At the far end of the inquiry spectrum is open inquiry. In open inquiry, students become responsible for asking their own questions, designing and conducting experiments, then analyzing and reporting the results. In essence, a creative element is added because students must problem find before they can problem solve. Students are challenged to observe raw phenomena, identify a problem, and determine a solution. Students conducting an extended open inquiry project, often with an opportunity to present at a science fair or symposium, are challenged to do
more: they are given autonomy and often engage in more higher-order thinking (Aulls, Shore, & Delcourt, 2007; Buldyrev, 1994; Shepardon, 1997; Tytler, 1992).

*Herron’s hierarchy.* Herron (1971) established a taxonomy of cognitive expectations for different types of hands-on laboratory activities. The activities were rated from zero to three, based on the learning expectations for the students. Skill-based activities that teach techniques or expertise, for example learning to use a microscope or perhaps a triple-beam balance, would be labeled zero. Observation labs would also fall into this category.

Level 1 activities pose a problem with a prescriptive method. Level 1 activities differ from Level 0, because students are actually finding relationships between an independent and dependent variable. Therefore, data analysis procedures are necessary to interpret information for the purpose of drawing conclusions.

Like Level 1, Level 2 activities pose the question for study, however methods and answers are not provided, allowing student design and interpretation. There is more student autonomy in Level 2, but similar to guided inquiry, students are only problem solving; there is no opportunity for problem finding.

At the top of Herron’s hierarchy is a Level 3 activity. In Level 3, problems, answers, and methods are all open. Students become independent, self-directed learners, who have to make their own decisions for area of study. The creative process of problem finding merges with the logical/analytical processes of problem solving.

*Enrichment triad.* Renzulli’s (1977) enrichment triad model, one of the most widely used instructional strategies for gifted education was originally developed for primary schools (Renzulli & Reis, 1985). However the model was transferrable and adapted for the secondary
school setting (Renzulli & Reis, 1986). The model suggests that students participate in three
types of interrelated enrichment activities.

Type I activities are general exploratory activities. The purpose of the activity is to move
students beyond the scope of the regular curriculum to potentially expose them to new areas of
interest. Type I activities can be facilitated through a number of outlets including printed
materials, field trips, guest speakers, or perhaps targeted Internet activities.

Type II enrichment activities are sometimes thought of as “how to do it.” The activity is
designed to give students the opportunity to develop technical and cognitive skills, so they can
carry out investigations. Renzulli and Reis (1986) suggested that the activities include creative
thinking and problem solving, critical thinking, decision making, affective processes, research
and communication skills, as well as learning how-to-learn skills.

Type III enrichment allows students to investigate real self-selected problems as
individuals or in small groups. Students change their traditional role of being knowledge
consumers to having a more authentic role of being knowledge producers. These
creative/productive behaviors are realized by problem finding, problem solving, and presentation
of their product. Renzulli and Reis (1986) suggested that students should emulate professional
investigators and prepare their products for an authentic audience. Type III investigations have
their genesis from the influence of Type I and Type II activities, as well as the regular curriculum
and other external influences (see Figure 3).
Figure 3. Enrichment triad model

**Synthesis of inquiry models.** Although the enrichment triad instructional strategy was originally designed as a model for gifted education and was not developed solely for an open inquiry science learning experience, there is a clear connection between this model, which focuses on links between task commitment, creativity, and above average ability (Renzulli, 1977) and the inquiry continuum (Martin-Hansen, 2002). In addition, Herron’s scale also aligns with both models. Although the initial levels do not align exactly, it is interesting to note that the highest student-centered, independent, open inquiry level parallels across all three models (see Table 3).
A comparison of learning models applicable to science education.

<table>
<thead>
<tr>
<th>Herron Scale</th>
<th>Levels of Inquiry</th>
<th>Enrichment Triad</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>Non-inquiry learning activity</td>
<td>Type I</td>
</tr>
<tr>
<td>0</td>
<td>Structured Inquiry</td>
<td>Type II</td>
</tr>
<tr>
<td>1</td>
<td>Structured Inquiry</td>
<td>Type II</td>
</tr>
<tr>
<td>2</td>
<td>Guided Inquiry</td>
<td>Type II</td>
</tr>
<tr>
<td>3</td>
<td>Open Inquiry</td>
<td>Type III</td>
</tr>
</tbody>
</table>

(Herron, 1971; Martin-Hansen, 2002; Renzulli, 1977)

*Open Inquiry.* Scientific investigations that allow students to ask their own questions and conduct their own experiments allow for the greatest freedom to develop inquiry. The opportunity for students to learn scientific concepts well in an open inquiry environment exists because of the situated nature of learning. Students have a unique stake in the work because it is personally meaningful to them and their experiences.

Roth and Bowen (1993) qualitatively studied eighth grade students examining their problem finding (framing) and solving abilities as the students worked with pre-constructed contextual word problems versus student-designed contextual word problems. Students worked for 10 weeks studying various environmental zones on the school property and developed word problems based on their data collected as a product. Students were not directed to the types of experiments to conduct, but rather were given weekly experiences to develop laboratory skills or techniques that might potentially be useful. The rest of the instructional time, as well as non-scheduled time was allocated for student-directed study.
Roth and Bowen concluded that the open inquiry approach was better suited for learning authentic science than a traditional classroom setting because it recognized that problem solving was a tentative process and did not always lead to a prescribed result. It also allowed for improved social construction of knowledge. They also demonstrated that student learning was conceptually focused, resulting in more abstract understanding of scientific concepts.

Although Roth and Bowen were able to observe the problem-finding phenomenon in an open inquiry environment, students were limited by the constraints of a 10-week time period. Also, they were assigned a specific region of the school grounds to study; they did not make this choice themselves. The weekly instruction focused on specific skills and techniques that the teacher thought would be valuable to the student, thus interjecting leading instruction which might significantly impact student choice, problem finding, and problem solving.

Roth and Roychoudhury (1993) qualitatively examined the development of process skills during open inquiry lab investigations conducted by two teachers with male students in high school physics (n=77) and male students in eighth grade general science (n=60). Data consisted of videotaped laboratory sessions, laboratory reports of students, and reflexivity journals of teachers. Students worked in collaborative groups, and analysis of the data indicated that when students worked in this non-traditional setting, they more effectively developed higher-order inquiry process skills by (a) better identification and definition of variables, (b) improved interpretation and analysis of data, (c) enhanced planning and designing of an experiment, and (d) proper formulation of hypotheses.

Quantitative results mirror the qualitative results of the Roth studies (Brown & Campione, 1994; Metz, 1995; Schneider, Krajcik, Marx, & Soloway, 2002). Schneider, et al. (2002) report on the effects of an open project-based science program at an alternative high
school and its impact on the National Assessment of Educational Progress (NAEP) science test. The NAEP test utilizes multiple choice, short constructed response, and extended construction response across content of earth science, physical science, and life science and process areas of conceptual understanding, scientific investigation, and practical reasoning. Students ($n=142$) in this study participated in the school’s project-based science curriculum. The structure of instruction was for students to study integrated scientific subject matter by investigating open questions and creating artifacts. Typical projects lasted from 7 to 16 weeks. Broad multidisciplinary essential questions were provided, and groups of students worked to solve them.

Results on the NAEP test were compared between the students and the national averages. Analysis indicated a statistically reliable difference between the scores of students at the school and those of the national average ($p<.001$). Individual item analysis demonstrated that the school average was at the seventieth percentile of the national sample. Similar results were generated via gender and socioeconomic status. Although there was limited generalizability in this study due to the unique curricular and instructional strategies employed at this school, those who conducted open inquiry projects generally represent a small microcosm of science education. Open inquiry science programs generally do not have typical standardized curricular standards, thus a transferability strategy from data generated about the process would be more user-friendly than a generalizability strategy. In other words, this data should be used to suggest teaching and strategy options that might be considered, rather than suggesting changing program implementation due to the narrow scope of research.

From a practical standpoint, the literature suggests strategies for teachers wishing to engage in open inquiry studies with their students. Educators should be sensitive to the
development of the creative talents of students engaging in open inquiry learning. Student learning should focus on concrete reasoning, science concept attainment, as well as other realms, that demonstrate student innovation (Innamorato, 1998). Students who develop authentic projects, scientifically-based or not, make gains in the quality of their investigative skills, enhance personal characteristics, and are likely to engage in these types of activities in the future (Delcourt, 1993; Delcourt, 2007). Therefore, priority should be to develop the student’s creative abilities while studying the domains of science.

In an extended open inquiry environment, student autonomy is significant (Tytler, 1992). Students spend an extraordinary amount of time and effort working on their projects. In addition, they displayed independence in their pursuit of background knowledge and the development of their experimental designs and protocols. All of the students in the Tytler qualitative multi-case study displayed characteristics of independence, drive, curiosity, and a desire for new knowledge acquisition. This autonomy went beyond the normal expectations of a traditional science classroom. A few displayed an awareness of the difference between themselves and other students (Tytler, 1992). The Tytler study did not indicate that students needed to be academically elite. Rather the key factors for success were interest and motivation. There was a wide range of dispositions and abilities of students.

In summary, of the various forms of inquiry, open inquiry allows for the most independence for students. They are involved in a greater continuum of study, because they have the ability to seek out their own questions or problem find. This problem finding strategy is a creative process.
**Problem finding**

The ability to ask questions may be an indicator of creativity in science. Creativity, from a general perspective, is the ability of an individual to transcend traditional ideas, rules, patterns or relationships (Lexico Publishing Group, 2007). Torrance (1965) classified four measurable behaviors to indicate creativity: fluency, flexibility, elaboration, and originality. Fluency referred to the total number of interpretable, meaningful, and relevant ideas that an individual generated. Flexibility referred to the number of different categories of responses. Originality tracked the rarity of responses compared to those of others. Finally, elaboration indicated the amount of detail in a response. Torrance factors primarily tested divergent thinking and problem solving skills.

Indeed the type of question posed can dictate the level of creativity associated with it. Washton (1967) proposed a taxonomy of student questions based on qualitative data he collected with teachers of middle and high school students from metropolitan New York. He suggested that the higher up in the taxonomy a student question appears, the more creative the question is. His taxonomy lists the following order for questions: (a) factual questions, (b) questions related to scientific principles that are answerable using a scientific concept, (c) questions related to the ability to transfer or make applications that are potentially experimental, (d) spontaneous questions of curiosity that are experimentable, and (e) questions that are genuine problems that need to be solved. Although Washton did not propose a systematic method for classifying or evaluating questions, he notes that the ability to identify and formulate a problem, or problem find, is rarely taught during the process of problem solving.

*Defining problem finding*. Problem finding has long been deemed a creative process (Dillon, 1982; Einstein & Infeld, 1938; Feldhusen & Kennedy, 1988; Getzels, 1979; Getzels &
Csikszentmihalyi, 1976). Problem finding, operationalized for the purpose of this study, is defined as 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 investigate (Leavitt, 1976).

Problem finding is often considered a distinctively different process than problem solving (Dillon, 1982; Getzels & Csikszentmihalyi, 1976). Problem finding is considered a creative process, while problem solving is considered an analytical cognitive process. One of the great limits in the literature has been the operationalization of problem finding. It has been studied sparsely from an empirical perspective. Dillon (1982) proposed an ordering of problem finding definitions in an attempt to conceptualize a framework that could be used for study (see Table 4).

Table 4

*Dillon’s (1982) conceptualization of the problem finding schema*

<table>
<thead>
<tr>
<th>Level</th>
<th>Type</th>
<th>Activity</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Existent</td>
<td>Recognize problem</td>
<td>Perceiving a situation as problematic; recognizing the existence of an evident problem</td>
</tr>
<tr>
<td>II</td>
<td>Emergent</td>
<td>Discover problem</td>
<td>Probing data for hidden, unclear, or incipient problem</td>
</tr>
<tr>
<td>III</td>
<td>Potential</td>
<td>Invent problem</td>
<td>Producing a problem or solution out of elements of a situation but not portending a problem event</td>
</tr>
</tbody>
</table>
Problem finding in science and creativity. Unfortunately, many studies correlate problem finding with divergent thinking (Runco & Nemiro, 1994; Runco & Okuda, 1988; Runco & Okuda, 1991; Wakefield, 1985). Hoover and Feldhusen specifically examined so-called scientific problem finding by analyzing ninth grade and fifth grade students’ abilities to generate hypotheses from ill-defined natural science problems (Hoover & Feldhusen, 1990; Hoover & Feldhusen, 1994). They demonstrated that intelligence and aptitude did not relate to scientific problem finding. They were not able to make a link to creativity, which in the case of the study, was measured by divergent thinking. So they postulated that scientific problem finding (i.e. formulating hypotheses) was independent of creativity.

Their narrow definition and measurement of scientific problem finding, as well as their conception of the nature of science almost certainly hampered their ability to develop a meaningful relationship between scientific problem finding and creativity. As previously mentioned, students engaging in scientific problem finding appeared to be using convergent thinking by bringing ideas together to develop their inquiry rather than using divergent thinking skills (Allen, Guilford, & Merrifield, 1960; Subotnik, 1988). Interestingly, Firestien and Treffinger’s (1989) Creative Problem Solving instructional model, used in many gifted and talented school programs to promote open inquiry, provides strategies for each of their six approaches (mess-finding, data-finding, problem-finding, idea-finding, solution-finding, and acceptance-finding) and suggests that students initially start off each strategic phase with divergent thinking; as ideas or concepts crystallize, student thinking becomes more convergent.

Smilansky (1984) quantified that problem finding was a different process from problem solving and created a method for measuring problem finding quality. Using the Raven Progressive Matrices Test (Raven, 1958), Smilansky measured non-language, non-mathematical
problem solving of 296 tenth and eleventh grade private school students in Israel. The test provided a series of patterned images, and the subject was asked to predict the final one. The test was ordered from simplest to most difficult. To measure problem finding, after administering the test, a blank matrix was provided, and the subject was asked to invent a new challenging matrix problem that could be used on a future test. The invented item was scored based on a criterion that aligned with the difficulty of the items on the test. The more difficult the item was, the higher the problem finding score.

The problem solving scores were correlated with the problem finding scores to a low correlation coefficient (r=.18). Although this value was statistically significant, it indicates low to no positive correlation. Smilansky concluded that the ability to solve problems was very different from inventing them, because less than four percent of the variance in one was explained by the other. Unfortunately, the nature of this problem finding exercise was very limited to scope and degree of difficulty of the problem, and does not thoroughly test the subject’s use of fluency or flexibility.

*Instructional approaches to problem finding.* Because problem finding suffers from being defined by varied constructs, there are multiple descriptions of how it functions from a cognitive perspective (Dillon, 1982; Hoover & Feldhusen, 1990; Runco & Chand, 1994). However, a lack of consensus on the cognitive process of problem finding does not negate the practical applications of teaching effective problem finding in schools. In fact, Robinson (2006) boldly stated during a platform presentation at the prestigious TED (Technology, Entertainment, Design): Ideas worth spreading conference, “My contention is that creativity now is as important in education as literacy, and we should treat it with the same status” (transcribed from flash video).
Starko (2007), working with a teacher with seven years of experience, personally planned and executed a problem finding curriculum for third through fifth grade students over six weeks. In case-study format, she described the 10-lesson unit and a qualitative collaborative data collection strategy. She made the following observations: (a) a classroom environment promotes risk taking and respects the diverse cognitive abilities of students, because older, experienced students more effectively develop problems, (b) teachers must have strategies to deal with the variety of prerequisite knowledge and skills of students, (c) the content of inquiry lessons should be selected carefully, and (d) a philosophy of inquiry promotes student independence.

Kay (1994b) was able to qualitatively demonstrate that introducing problem finding strategies was curricularly appropriate for elementary students in grades 3-6 participating in a discovery unit. Moreover, students who completed the learning unit for a second time produced higher quality products and better ideas because of their previous experience. The study was particularly valuable because it mapped out instructional strategies for approaching an open project. Suggestions for introducing the unit, problem finding, peer and mentor review workshops, and presentation preparation and execution are provided. Although the unit design was for elementary students, there was strong potential for transferability to a high school science setting.

Yoshioka, Suganuma, Tang, Matsushita, Manno, and Kozu (2005) used strategic interventions to improve problem finding of first-year college (freshmen) female medical students (n=207) conducting problem-based learning case studies. Their task was to take a prompt and extract problems in a given amount of time. The treatment group was given three interventions: (a) lectures on self-directed learning with repeated briefings, (b) encouragement to
identify problems in various fields, and (c) self-evaluation forms geared at assisting in problem finding and utilizing different resources.

The study had the potential to suggest some important strategies to help teachers increase problem finding with students in a situated learning setting. Unfortunately, the group used multiple unpaired t-tests to evaluate their data, where a two-way analysis of covariance would have been more appropriate. In addition, the treatment group received training one year after the control group. No attempt was made to covary the data or to consider differences in teaching from one year to the next. Although the study produced significant results (p<.05), they should be viewed with skepticism.

Fontenot (1993) examined the effects of creativity and problem finding on business people (n=62) provided with appropriate training. Fontenot defined problem finding in terms of Dillon’s (1982) existent definition (see Table 4, above). Fontenot contended that problem finding and solving skills were underdeveloped for many business people and could be improved through training using practice techniques and exercises as well as developing appropriate dispositions towards creativity. The experimental procedure utilized a post-test only control-treatment group design.

Those in the treatment group received an 8-hour experiential training program based on the Osborne-Parnes creative problem solving model (Daupert, 2002). Similar to the Firestien and Treffinger’s (1989) *Creative Problem Solving* instructional model, the six stages include (a) mess or objective-finding, (b) fact-finding, (c) problem-finding, (d) idea-finding, (e) solution finding or idea evaluation, and (f) acceptance-finding or idea implementation. This study’s definition of problem finding would include all of the stages listed above. The study concluded
that the creativity training improved fluency in both data finding and problem finding, increased flexibility in problem finding, and increased the quality of generated problem statements.

An underlying problem with the Osborne-Parnes and Firestien and Treffinger creative problem solving models is the assumed linearity. Although Firestien and Treffinger do not support linearity of their model, it is presented that way, and the flexibility of the model is therefore often obscured in classroom application. Similar to the so-called scientific method taught irresponsibly in many science classrooms, these models purport a starting and endpoint with a clear step-by-step progression. However, the idiosyncratic nature of science and creativity suggest that such a methodology might only serve the misplaced pedagogical needs of a teacher, and not be truly representative of the actual asynchronous routes that individuals traverse during the problem finding process.

The creative process is viewed as a critical behavior for students engaging in open inquiry or Renzulli Type III scientific endeavors (Innamorato, 1998; Pizzini, 1982; Renzulli & Reis, 2001; Romey, 1980). Therefore, it is important to consider instructional strategies to improve this process. It appears that problem finding training most often is aligned with inquiry learning.

*Factors influencing problem finding.* Kay (1994a) defined problem finding in terms of an individual finding, defining, or discovering an idea or problem “not predetermined by the situation” (p. 117). This definition is problematic because it assumes there are no underlying or situated factors that might influence decision making factors. There are boundaries and parameters that are required for students engaging in creative problem finding behaviors that are established by the field of study and the domain-culture (Csikszentmihalyi, 1990). These
predetermined factors must surely influence the nature of the problems individuals choose to study.

Runco (1994) suggested that all problems have an affective component, meaning they must be perceived as problematic. An individual’s bias, influenced by situated domain factors, therefore, will predispose certain choices in problem generation. Treffinger, Tallman, and Isaksen (1994) implied that social influence greatly affected creativity and problem finding. Smilansky (1984) proposed that individuals cannot effectively problem find unless they have the skills to solve their problem. This is echoed by Getzels (1976), who suggested that problem finding not only involved determining a problem, but must be formulated in a way that a solution can be generated.

Suwa (2003) demonstrated that architecture students use their preconceived perceptions to reorganize information and then conceptually generate problems. Not only were students using situational information to determine problems, but the perceptual reorganization and conceptual generation was deemed a skillful act. Furthermore, they were able to demonstrate that experienced individuals were more skilled at coordinating perceptual reorganization and conceptual generation than neophytes. In other words, there was a level of expertise.

**Expertise**

Experts of a domain structure their knowledge differently from novices (Chase & Simon, 1973; Chi, Glaser, & Rees, 1982; Feldhusen, 2005; Larken, McDermott, Simon, & Simon, 1980; Sternberg, 2001). Expert knowledge is centered on conceptual understanding, with the use of specific domain-based strategies (Driscoll, 2005). Expert problem finding and solving, therefore, is a utilization of pattern recognition based on previous experience and matching those patterns to corresponding aspects of a problem. Novices generally do not possess the same understanding,
and, in turn, utilize more general, non-domain specific, problem finding and solving strategies (Driscoll, 2005). Glaser’s (1984) research determined that expert knowledge is organized around principles and abstractions of concepts while novice comprehension is organized around literal, direct understanding of information given in a problem.

Glaser defined the knowledge of novices as “organized around the literal objects explicitly given in a problem statement” (p. 98). Experts’ knowledge is organized around the principles and abstractions that hierarchically include these objects. The abstractions and principles employed by the experts are often not apparent in the problem, but are derived from subject matter knowledge and compose a tight schema. When problem finding, the challenge for novices might include the limitation in their knowledge and experience base. Although novices may have a general understanding of a problem’s situation, they may not have the understanding of related principles and their application.

Ericsson and Lehmann (1996) examined expertise in multiple disciplines and found that (a) measures of general basic abilities do not predict success in a domain, (b) the superior performance of experts is often very domain-specific and rarely transfer outside of an area of expertise, and (c) differences between experts and novices are often attributed to the experts’ extensive training. Experts select relevant information and encode it in representations that allow planning, evaluation, and reasoning about alternative courses of action when examining a problem. Expert success is most often derived from extended, intense practice.

In one of the original expertise studies, Chase and Simon (1973) examined the differences in expert chess players compared to intermediates and novices when examining and replicating a chessboard. The subjects were asked to view a chessboard arranged in specific
configurations congruent to specific patterns that would often be found in a chess match. The players then had to reconstruct the board on an adjacent one.

They were able to demonstrate that expert players chunk information together in abstract relations. The experts encoded positions of pieces based on their relationships with others found in a likely match configuration. The data also suggested that an expert might hierarchically organize the chunks. The novices did not show this abstract level of sophistication, but rather found more simple, concrete patterns when reconstructing the board. The thought processes were statistically different (p<.05) between groups.

Chi, Glaser, and Rees (1982) examined differences in novice and expert physicists’ ability to solve problems. They demonstrated that experts could solve problems four to five times faster than novices and the methodology choice was different as well. Experts tended to group equations in chunks: they selected one equation that led to another. In essence, one principle led to the next, and the principles tended to be chunks of related configurations. Experts were inclined to construct a physical representation of the problem in terms of real-world mechanisms. This physical representation permitted direct inferences to be drawn about relations that might not be explicit in the problem, but could be deduced once the representation was constructed.

When Chi, Glaser, and Rees asked subjects to describe their problem solving process in situ, experts made, on average, one statement, while novices made five. They rationalized that experts were generally (a) better at recognizing the correctness of a solution and need not voice uncertainties, (b) might have multiple ways to solve a problem so they could double check their work, and (c) might have a well-structured representation of the problem to compare his or her results.
Expert and novice solution paths were also different. The experts would work from the variables given in the problem, generating equations successively, while the novices selected the equation containing the unknown variable and used a trial and error heuristic to verify their methodology. The experts brought procedural knowledge with an understanding of how knowledge structure could be manipulated to effectively solve a problem. Novice learners, on the other hand, brought factual and declarative knowledge, while lacking procedural knowledge and skill as well as conditional knowledge for application.

In an instructional setting, some teaching practices lead to the conveying of decontextualized information, whereby students are unable to transfer what they have learned to relevant situations (Brown, Collins, and Duguid, 1989). Students, as novices, have difficulty solving complex, authentic problems because they “tend to memorize rules and algorithms” (Driscoll, 2005, p. 161). Experts would tend to use situational cues to solve problems. Because they have greater domain-specific content knowledge, experts approach finding and solving problems by recognizing and applying previously experienced patterns.

Sternberg (2001) suggested that gifted students can more rapidly acquire expertise than non-gifted individuals, and thus proposed a model for giftedness based on developing expertise within a domain. The model had five interactive elements: metacognitive skills, learning skills, thinking skills, knowledge, and motivation.

Learning skills referred to knowledge acquisition components, while thinking skills encompassed critical or analytical thinking, creative thinking, and practical thinking. Sternberg classified the knowledge skills as declarative (facts, concepts, principles) and procedural (procedures, strategies). Finally, motivation is described in two classes: achievement motivation and competence or self-efficacy motivation. Achievement motivation referred to individuals who
seek moderate challenges or risks, so they can improve themselves by accomplishments.

Competence motivation referred to an individual’s belief in his or her own ability to solve a problem.

Sternberg also noted that expertise acquirement happens best in context, which echoes Brown, et al. (1989). Although Sternberg appeared most concerned with the traditional educational environment as opposed to alternate learning pathways, like an open inquiry research experience with external opportunities for interaction with professionals, he created a structural framework for describing expertise.

The literature description of expertise resides almost solely with the concept of problem solving, not problem finding. Although inferences can be made to this alternate, creative process, it does not appear to be directly studied within the scope of expertise. Rosten (1994) studied professional scientists and artists and noted that those who were critically acclaimed producers devoted a larger time to problem finding than their counterparts who were only technically competent. This suggested that the quality of problem finding might relate to expertise.

Situated cognition

Theory and instructional application. When students participate in extended open inquiry learning experiences, they assume the role of the scientist and become practicing members of the scientific community, often in a situated setting. Brown, et al. (1989) described the learning theory of situated cognition. They emphasized that students will not learn effectively in a decontextualized setting, and imply that conceptual learning takes place best when students have the opportunity to learn from an authentic perspective.

The learning theory suggested that knowledge is conceived by learned practice. In other words, learning of abstract concepts occurs best when an authentic situation puts them in context.
Understanding is developed through continued situated use. In terms of instructional implications, learning in a situated cognitive setting exploits the use of cognitive apprenticeship, learning communities, and assessment in situ (see Figure 4). This is sometimes phrased “lived practice,” meaning that knowledge must be understood both in relation to social aspect as well as individual perspective (Driscoll, 2005).

![Figure 4. Summary of the situated cognition learning theory](image)

An individual engaging in an open inquiry science research project must enter the community of practice. The community of practice provides a setting for a process of social learning that occurs when individuals with a common interest in some subject or problem, in the case of this study, science or engineering, collaborate over an extended period to share ideas, find solutions, and innovate (Wenger, 1998). Considering the instructional implications, and
therefore applications, a situated cognitive model parallels well with an inquiry approach. The main tenet of the model suggests that students should engage in cognitive apprenticeships: “Cognitive apprenticeship methods try to enculturate students into authentic practices through activity and social interaction in a way similar to that evident – and evidently successful – in craft apprenticeship” (Brown, et al., 1989, p. 37). In an open inquiry setting, the student assumes the role of the scientist, both in thought and action.

The learning community establishes an authentic environment for students to gain knowledge and experience where teachers and students work collaboratively to achieve important goals. Learning communities emphasize distributed expertise which suggests that students come to a learning task with different ideas and experiences which provides the community with the opportunity to learn diverse concepts (Pea, 1993). The idea of learning communities fits well with both an open inquiry science research classroom setting, as well as the experiences at a science fair or symposium.

By virtue of students participating in a situated setting, the rules of assessment must change. Tangible products or portfolios should be at the heart of a situated learning environment. In an open inquiry setting, students conduct research, and therefore report the results of their findings in an appropriate way. The scientific community would accept a lab report, a platform presentation, or perhaps a scientific poster. All products allow for peer review and interaction with practicing professionals.

Depending on the involvement of apprenticeship, the student (or even a professional) will develop different levels of participation in the community of practice. The learning trajectory might include (a) peripheral trajectory where the student never fully engages in participation with the community, (b) inbound trajectory, where an individual is a neophyte, acclimating him
or herself to the community and beginning to participate more fully, (c) insider trajectory, where an individual is no longer a neophyte, but still engages in continuous self improvement, (d) boundary trajectory, where the individual is a full member and brokers relations and expertise with other individuals in the community, and finally (e) outbound trajectory, where a member is leaving the community of practice (Wenger, 1998). Outbound trajectory, from a student perspective, may be the result of the completion of a project, a change in interest, graduation, or new opportunities. Practicing scientists may experience outbound trajectory for similar reasons, perhaps even including retirement. Outbound trajectory would often be initiated by the needs of the individual member.

*Self regulation in a situated setting.* Students who are challenged to work independently on authentic problems often develop their own controls and regulatory mechanisms to achieve success. Learners who self regulate “set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features of the environment” (Pintrich, 2000, p. 453). Bandura (1997) suggests that self-regulation occurs in a three-phase cycle: forethought, self-reflection, and performance (see Figure 5).

![Figure 5. Bandura’s cyclical nature of self-regulation](image)
In the forethought phase, an individual sets goals, chooses learning and motivational strategies, decides to participate, and arranges the environmental conditions necessary for success. As an individual works toward the goals, the self-reflection phase takes place, where judgments about learning performance are assessed, and the evaluation of goal attainment for self-improvement takes place. The performance phase employs strategies to focus and execute a task while tracking and adjusting performance and judging progress toward the goal. These phases are non-consecutive, non-linear, and can be recursive.

Motivation appears to be enhanced for students when they attribute their success to their effort and effective learning strategies (Driscoll, 2005). To that end, students conducting open inquiry should be provided with opportunities to set their own goals and manage the ways to attain them (Pavlica, 2004). Dweck (1986) suggested that learning goals are more likely to produce self-efficacy than performance goals. In other words, when students set learning goals they seek to increase their competence for the purpose of better understanding concepts. Contrarily, a performance goal is generally set to gain favorable judgment of competence, such as a good grade on a test.

Therefore, teachers might do well by providing assistance for students to effectively choose strategies for learning, time management, and controlling the context surrounding their learning. Students should also be provided with opportunities to self-appraise by analyzing their learning style and to self-monitor their progress on a learning task. Finally students should become reflective, because the more opportunities an individual has to reflect on his or her own learning and that of others, the greater the habit of self-regulation (Driscoll, 2005).

*Empirical evidence.* Conducting open inquiry often results in solving ill-structured problems. Ill-structured problems have vaguely defined, unclear goals, and unstated constraints.
They often possess multiple solutions with no consensual agreement on the appropriate solution path. In addition, there are often relationships to be found between concepts and principles that might not be consistent from case to case (Jonassen, 1997). The ill-structured problem is typical of an open inquiry science project that is thoughtfully conceived and executed.

Unlike ill-structured problems, well-structured problems require the application of a finite number of concepts and principles applied to a constrained problem situation. Well-defined problems possess correct, convergent answers, while ill-structured problems are far more divergent. Jonassen (1997) suggests that well-structured problem solving relied on information processing theories of learning based on the work of Bransford and Stein (1984), Gick (1986), Greeno (1978), and Newell and Simon, (1972). Ill-structured problem solving, on the other hand, relied on a situated cognitive approach to learning.

He proposed a 7-step instructional process for solving ill-structured problems: (a) the articulation of problem space and contextual constraints, (b) the identification and clarification of alternative options or perspectives, (c) the generation of possible problem solutions, (d) the assessment of the viability of alternative solutions, (e) the monitoring of problem space and solution options, (f) the implementation and monitoring of the solution, and (g) the adaptation of the solution. It is an ironic conclusion to try to linearize and formalize an instructional process which purportedly should be open and without constraints.

Roth and McGinn (1997) also indicated differences in learning between information processing learning schema and situated cognition. They suggested that traditional science education is taught using an information processing format even though practicing and apprenticing scientists work in a situated cognition format. Utilizing case studies of both a high school student and professionals (n=4), they synthesized various qualitative data sets combined
with a couple of quantitative studies (Roth, 1993; Roth 1998) to demonstrate that students learned well in a situated setting and had better dispositions toward science compared to students in an information processing setting. They concluded that a situated approach to science instruction would better serve students regardless of their career aspirations.

Evensen, Salisbury-Glennon, and Glenn (2001) qualitatively studied six first-year medical students participating in a problem-based curriculum. They were able to demonstrate that successful students display an evolving, interactive-transitive stance towards learning. The students were assigned a faculty facilitator and were challenged to determine their own topics of study and learning objectives. The module was intended to be peripheral (e.g. Wenger, 1998). The learners, learning, and learning context all appeared to be integrated, which matches the construct of situated cognition. In fact, when certain learners (n=2 of 6) attempted to retain a traditional schema to learning (i.e. dictates of a prescribed curriculum) they remained outside of the peripheral trajectory. Although they may have learned content, they did not develop attitudes, dispositions, or epistemological identifications with the community of practice.

Bleicher (1995) provided evidence that a high school student-university professor internship experience could increase students’ conceptual understanding of science as well as understanding about the nature of scientific research. Thirty-two students participated in a 6-week summer internship for three consecutive summers. Students engaged in cognitive apprenticeship by participating in project-based laboratory experiences, seminars, field trips to research facilities, as well as making their own presentations.

Bleicher used multiple forms of triangulated qualitative data including video tapes of all aforementioned experiences, focus groups and individual interviews with mentors and students, and document analysis of student reflexive journals. The data indicated that student conceptual
understanding of scientific concepts was high and this understanding transferred back to their traditional high school courses. Students identified the types of experiences they had in terms of the open inquiry/Type III definition. They also had improved attitudes towards science, written and oral communication skills, motivation, and self-confidence.

A similar qualitative interpretive case study examined two high school students who worked in a university chemical engineering laboratory under the mentorship of a professor (Ritchie & Rigano, 1996). As the students progressed through the experience, the data indicated that they were empowered and more likely to seek empirically based evidence when evaluating knowledge claims.

Also examining an intensive molecular genetics summer institute at a major university, Charney, Hmelo-Silver, Sofer, Neigeborn, Coletta, and Nemeroff (2007) examined students apprenticing with expert scientists. They verified an increased understanding of molecular genetics concepts and a less rigid and stringent view of the nature of science. Qualitative student journal writing demonstrated an increased ability to generate and consider alternate hypotheses, implement models and logical argumentation in explanations, connect ideas and concepts, and ask relevant questions.

It is interesting to note that the Bleicher (1995) study, Ritchie and Rigano (1996) study, and the Charney, et al. (2007) study all examined learning and attitudes during an apprenticeship period with a specific time limit, that of a scheduled summer apprenticeship. While these studies are important to understand how a situated learning, open-inquiry environment functions for students, many meaningful experiences may take students longer to complete than a period predetermined by a professional or a program. A true open-inquiry experience is not confined by a set schedule. Considering a situated, authentic, learning framework must not limit the
timeframe for participation for students, which is often quite extensive, lasting many months to years.

Promoting higher order thinking skills and conceptual understanding using a situated framework, regardless of student ability, has consistently demonstrated improved student learning and positive attitudes towards science. (Gersten & Baker, 1998; Girill, 2006; Rojewski & Schell, 1994; Zohar & Dori, 2003). Therefore situated, cognitive apprenticeship-type experiences combined with self-efficacy, appear to be better predictors of success than ability, in open inquiry experiences.

Summary

Open inquiry learning environments appear to intersect concepts of inquiry, creativity, and situated cognition (see Figure 6). A student who has the opportunity to both find and solve authentic problems participates in a more holistic approach to science education and, as a result, often demonstrates strong gains in higher order thinking and positive self-efficacy.

Figure 6. The relation between inquiry, creativity, and situated cognition.
Because of the limited studies of open inquiry as a lens to understanding problem finding, an investigation was warranted. Assuming a conceptual framework focused around the three main themes of inquiry, the creative process of problem finding, and situated cognition learning theory, student perceptions, understandings, and uses of problem finding in an authentic open inquiry environment were examined. Since a situated cognition approach was utilized, the social effects and influence of others (e.g. mentors, teachers, parents) were also examined.

The research was framed around the following two 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?
CHAPTER 3: METHODOLOGY

Research Design

The following questions were addressed in this study:

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?

A qualitative paradigm was used to conduct this study. A multicase study using a descriptive strategy to explain, identify, and document the phenomenological role of problem finding in open inquiry, was used. The focus was on the essence or basic structure of the problem finding experience. The process of phenomenological study first requires an intuitive understanding of the problem finding and open inquiry phenomenon while simultaneously holding personal beliefs tentative (Merriam, 1998). This is followed by investigations of examples of the processes “to gain a sense of its general essence” (p. 16). Relationships are then sought to interpret the problem finding phenomenon.

Phenomenological study might best be described by Moustakas (1994):

The challenge facing the … researcher is to describe things in themselves, to permit what is before one to enter consciousness and be understood in its meanings and essences in the light of intuition and self-reflection. The process involves a blending of what is really present with what is imagined as present from the vantage point of possible meanings; thus a unity of the real and the ideal. (p. 27)
The study was conducted utilizing in-depth, opportunistically-developed, semi-structured interviews in conjunction with document analysis, demographic survey, and an affective instrument. In order to compensate for the limitations of a single-method research design, this study included triangulation of data sources and methods (Merriam, 1998). Triangulation of data was achieved through methods (interviews, document analysis, surveys) and sources (students, teachers, mentors, fair directors, documents).

Member checks with the subjects and peer and mentor examination of unprocessed and processed data were also utilized to verify the plausibility of the findings and interpretations as they emerged. In the development of the interview schedules, a participatory/collaborative strategy was used with high school research students to conceptualize and align questions within the study (Merriam, 1998). Multiple student cases, from both CSF and ISEF, were used to generate comparison groups to provide a replication strategy of single-case findings (Huberman & Miles, 1994).

**Affiliations**

The investigator began his career in teaching in 1995. After serendipitously attending the Connecticut Junior Science and Humanities Symposium (CT-JSHS) in 1998, he began working with students to conduct authentic independent research projects. So began the prolonged involvement in the authentic extended research process complemented with opportunities for students to publicly present their work.

He has had approximately 25 students present their work at the CT-JSHS from 1999 to the present. Three of his students have placed in the top five for platform presentations, earning a spot on the National delegation, to the National JSHS. One of the three earned top honors at the CT-JSHS and earned a bid for national presentation. He has also had five students finish in first
place for the poster presentations. He has served as an active member of the executive committee of the CT-JSHS since 2000.

After receiving advice from a colleague, in March of 2000, he took students to the Connecticut Science Fair, held at Quinnipiac University. The students’ work was recognized, and approximately 50 of his students have attended the CSF from 2000-2008.

Appreciating the volunteer efforts of the CSF, he offered his services, and in 2003, was asked to attend the ISEF, that year held in Cleveland, Ohio, as a teacher representative for the state of Connecticut and the CSF. In 2005, he was asked to participate as a member of the Advisory Committee of the CSF. In 2006 he also became a member of the executive committee of the CSF, primarily involved in publicity and scientific review of projects.

He attended the ISEF in 2006 in Indianapolis, Indiana as a teacher-mentor, having his first student reach the pinnacle of state competition. In 2007, he also attended the ISEF, in Albuquerque, New Mexico, both as a principal investigator for Western Connecticut State University, under the auspices of this study, and again as a teacher-mentor, having his second student, finish top at the CSF. This student successfully placed third in the Environmental Sciences Category at the ISEF.

**Target Student-Subjects**

Students who participated in the study had completed their research projects and presented their results at either the 2007 CSF or the 2007 ISEF. Therefore, a completed, presented project was a mandatory factor for consideration of recruitment of subjects. Gender was not a limiting factor, because previous research indicated few identifiable sex differences in creative performance (Richardson, 1986). In order to participate in the CSF, a student’s school must register by October of the previous year. The CSF region includes all Connecticut public
and private schools, schools from Brewster, NY, North Salem, NY and Fishers Island, NY, as
well as any student whose permanent address is in Connecticut. Each school is permitted to
submit a maximum of eight projects to the CSF directly. There are numerous regional fairs,
which also submit projects to the CSF including Danbury’s Science Horizons, the Bridgeport
City Science Fair, and the New Haven City Science Fair. If a student does not have school
sponsorship or is home schooled, but does meet the location guidelines, he or she may enter as
an independent.

In order to participate in the CSF, students completed an application, which included
demographic information. They also submitted a research plan, which was approved by the CSF
Scientific Review Committee. All students had an adult sponsor and a parent or guardian sign for
the project. In some cases, students had additional professional mentorship if their project fell
within the scope of several potentially dangerous or ethical categories (i.e., recombinant DNA,
human subjects, vertebrate animals, potential pathogens, restricted substances or chemicals).

The CSF is an affiliated regional fair of the ISEF. In order for a student to participate in
ISEF, he or she must earn a top spot from his or her regional fair, such as the CSF. There is no
alternative method of entry to ISEF. Each regional fair holds a charter, or multiple charters
which gives students entry to ISEF. The CSF holds two charters to the ISEF, thus allowing them
to send four individual projects and two team projects. Based on financial constraints and
program philosophy, CSF sends only four individual projects to the ISEF.

CSF and ISEF provided student scores to help target a variety of quality projects for this
study. A sample of 12 students were purposefully selected from approximately 500 students at
the 2007 CSF held March 13-17, 2007 at Quinnipiac University in Hamden, Connecticut. They
were selected based on CSF documents, including judging sheets, entry paperwork, and student
abstracts. Four students were 16 years old, 7 were 17 years old, and 1 was 18 years old. Eight were in eleventh grade and four were in twelfth grade. Nine attended a public high school, and three attended a private high school. Six were male; six were female.

A sample of 8 students were purposefully selected from the 2007 ISEF, held May 13-19, 2007 in Albuquerque, New Mexico. These students were in grades 11-12 or the international equivalent. Five students were American, and three students were international. Five students were male and three students were female. ISEF subjects were all major category winners (see Appendix A), which were the top 17 projects out of approximately 1,500 (SS, 2006).

The sample size of 20 individuals is in alignment with a target population for a multi-case phenomenological study (Sandelowski, 1995; Van Kaam, 1959).

Permissions

Permission for conducting the study was acquired from both the CSF and the ISEF. Each organization had its own requirements for accepting the study, interaction with students, and the transfer of secured data.

Connecticut Science Fair. Both the Chairman of the Board and the President of CSF were contacted by electronic mail and telephone to discuss the feasibility of the proposed study. The Chairman requested a copy of the proposal. After reviewing the proposal, the Chairman requested a presentation be made to the CSF Board of Directors so they could vote to approve the study.

In January of 2007, at the Mother House of the Daughters of Mary of the Immaculate Conception in New Britain, Connecticut, said presentation was completed at the CSF annual meeting. The president moved to accept the proposal as read and provided the necessary support for the study. Several additional questions were posed during discussion, and the motion passed.
unanimously. The major concerns were ensuring that the CSF process was not interrupted in any way by this study. The CSF agreed to provide working space during the event as well as any requested data from the database. A written letter of approval was provided by the Chairman and was included in the institutional review board (IRB) application (see Appendix C). IRB documentation was provided to CSF subsequent to its receipt.

The CSF takes place annually at Quinnipiac University during the university’s spring break. The 2007 fair took place March 13-17. The CSF receives, free of charge, annual use of the athletic facility during the fair week. The fair sets up its exhibition hall in the gymnasium, which has the capacity for holding up to 500 projects. Students arrived between noon and eight o’clock to set up their projects on the Tuesday of fair week (March 13). During the setup students checked in, were assigned a spot and project number in the exhibition hall, and then had their project approved by a member of the Rules and Safety committee. Upon successful completion, they checked out and received a t-shirt.

The investigator offered to take digital pictures of all students and their posters for CSF during project setup. CSF, in turn, provided a printed list of all eleventh and twelfth grade students, ordered by project number, and included fair category, project title, student’s name, student’s school, student’s adult sponsor, student’s address, student’s telephone number, and student’s electronic mail address. During the setup, the investigator asked the grade level of the high school students to see if they fell within the parameters of the study sample (i.e., grades 11-12). If they did, the students were told about the study and were provided with some literature about the study, which included a card-stock page overview, a copy of the informed consent, and a newspaper article highlighting the study (see Appendix D). This was the initial stage of recruitment.
Preliminary judging took place without students on Wednesday. Approximately 200 industry and academic professionals volunteered to judge. They were charged with scoring each project, based on a CSF judging rubric and placing it in a quartile. The top quartile of students’ project numbers were posted on the CSF website and were required to attend finalist judging on Thursday (March 15). The finalist list was cross referenced to the eleventh and twelfth grade list, previously provided, to target specific students for recruitment.

Finalist judging began with student check-in at the entrance to the exhibition hall. Each student received a nametag, pin, and bottle of water. Students entered the exhibition hall alone. Parents, teachers, and mentors were not permitted in the exhibition hall at any time during judging. In fact, once the judging period began, parents, teachers, and mentors were not permitted in the athletic facility. CSF provided a hospitality suite on the other side of campus for those wishing to stay. CSF graciously allowed the investigator to enter the exhibition hall during judging to identify and speak with potential subjects. In return, the investigator again took pictures of all finalists for CSF.

During the judging period, the investigator identified himself as “not a judge,” and would speak to target students about the study. Students were provided with two copies of the informed consent, a pre-stamped, preaddressed envelope, a copy of the newspaper article, and instructions for completing online surveys. Students were also asked to verify their electronic mail address and phone number from the database. Approximately 20 students were approached and asked to participate based on sample size suggestions of Sandelowski (1995). Follow-up telephone calls were made to those students who did not mail back informed consent, but expressed an interest in participating in the study.
An additional group of students from the lower quartile who did not make finals were also targeted for participation by telephone call. When the student’s adult sponsor was also a teacher, that educator was also contacted to request student participation in the study. Rate of participation for non-finalists was far lower than that of finalists, 71% and 33%, respectively.

Those students who agreed to participate and submitted an informed consent were contacted by electronic mail and asked to complete online study documentation. Interviews were requested to take place at the student’s school, and this was generally coordinated through both the student and the adult sponsor. Interviews generally took place in the early afternoon while the student was still in school, so the investigator could optimize the use of release time since the employing school district allows half-day personal days.

*International Science and Engineering Fair.* The CSF Chairman of the Board, on behalf of this study, made initial contact via electronic mail with Science Service, the sponsor and coordinator of ISEF. The CSF Chairman recommended working through Science Service’s Director of Science Education Programs. The Director was amenable to having research conducted at ISEF as limited studies have previously been completed using ISEF populations (Walker, 1979; Bellipanni, 1994; Pyle, 1996). Discussions were held by telephone and electronic mail to map a strategy that would allow for successful recruitment of subjects without interference with the ISEF experience for the students.

The following conditions were placed on the study: (a) the study’s proposal and Institutional Review Board approval was reviewed and approved by the ISEF Scientific Review Committee, (b) a confidentiality statement was signed to ensure that any student results given by Science Service were safeguarded (see Appendix E), (c) information from the Environmental Sciences Category was excluded, since the investigator had a student competing in that category,
(d) Science Service would provide special credentials to identify the investigator at the fair (see Appendix F), (e) recruitment of subjects would take place during public viewing, not judging, (f) Science Service would provide judging results, but would not provide contact information for students, (g) all interviews would take place after the completion of the ISEF, and (h) Science Service would provide a follow-up electronic mail message to encourage participation of the target student participation.

The 2007 ISEF took place at the Albuquerque Convention Center in Albuquerque, New Mexico from May 13-19. The fair took place on the convention center floor, hosting approximately 1,500 students. The volunteer host committee provided a range of both academic and social experiences for the students and adults attending throughout the city. Participants generally arrived on Sunday or Monday, set up their projects and had them cleared by a member of the Rules and Safety committee. Opening ceremonies took place Monday evening in the Tingley Coliseum. The ceremony was professionally staged and directed, complete with a 200-foot video display screen (see Iwahedi, 2007). Social events, workshops, and a session with Nobel Prize winners took place on Tuesday. Wednesday was dedicated to judging. Students reported to the exhibition hall at nine in the morning and were judged until half past six in the evening. The students were given an hour lunch break and a half hour snack break. All results were tabulated late into Wednesday evening to determine fair winners. Many presentations and sessions were observed for this study and detailed field notes were generated.

Judging results were provided for this study on Thursday at seven in the morning. The Education Director for Science Service provided 16 abstracts of the category winners, which listed the title of the project, the student’s name, the student’s school, city, and country, as well
as an abstract of the student’s research. Information was rapidly organized, but more importantly, evaluated and assimilated so a credible conversation with the student was possible.

Public viewing was scheduled from 10 in the morning until 2 in the afternoon that same day. Students were required to be stationed at their projects to discuss their studies with the public. School visits are common during this session. During the public viewing session, students were recruited for the study in a similar fashion to CSF. Students were provided with two copies of the informed consent, a pre-stamped, preaddressed envelope, a copy of the newspaper article, and instructions for completing online surveys. Students were also asked to provide their electronic mail address and phone number from the database. Since recruitment took place during public viewing, unlike the CSF, which was during judging, and since all interviews would be scheduled by phone, instead of face to face, the investigator spent more time with each potential subject to increase rapport. The ISEF week ended with three awards ceremonies, where over five million dollars of prizes and scholarships were awarded.

Fifteen students were approached and asked to participate during the public viewing session. Follow-up telephone calls were made to those students who did not mail back informed consent, but expressed an interest in participating in the study. Interviews were requested at the convenience of the student after online instruments were completed. Interviews generally took place in the evening or on a weekend.

Survey Instrumentation

*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. There are 42 items on the instrument. For each item, the
subject is asked to select between two adjectives which best describe him or her. If neither word describes the individual, the subject is asked to select the nearest description. The pairs are based on 32 different words. Content was based on Cattell’s (1943) list of traits. Standardization was based on 310 research scientists from 12 locations around the Chicago area. Correlation to productivity was based on a weighted rating system of published articles and patents. Reliability of this affective instrument is .76. An affective instrument has adequate reliability at .70 or above (Gable, 1986). Factor analysis was not computed for the original instruments, thus no subscales are currently available.

Since the instrument is over 50 years old, wording vernacular was updated with permission for several items and the item was reformatted (LaBanca, 2006). The USRT underwent updated validity and reliability testing in the fall of 2007 under a separate study with first semester introductory chemistry students (Chem 127Q) at the University of Connecticut. The new reliability of the instrument is .71. USRT data were used descriptively in this study.

The USRT was XML coded with php scripts for use as an online scale (see Appendix G). The webpage was designed using Dreamweaver MX version 6.0 (Macromedia, Inc, 2002). The php scripting was hand-coded based on the Level Ten FormMail template (Lorentz Consulting, 2003). Students were given the web address to complete the instrument. Upon clicking of the submit button, the data were mailed to an electronic mail address, then imported to a Microsoft Excel (Microsoft, 1999) spreadsheet for automatic tabulation.

Demographics Survey. A survey was developed to capture demographic information about individual student-subjects (see Appendix H). Categories on the survey included (a) personal information, including name, address, telephone number, electronic mail address, age and grade, (b) school information, including name, address, telephone number, principal name,
guidance counselor name, and currently enrolled courses, (c) most helpful teacher information, including contact information, area of expertise, and help provided, (d) parent information, including contact information and help provided for the research project, (e) mentor information, including contact and affiliation information, area of expertise, and help provided, and (f) other relevant information. The demographics survey was coded for online use, similar to the USRT Scale. Data were archived in a Microsoft Excel spreadsheet.

Semi-structured student interviews

**Question development.** Questions were initially developed as part of a pilot study conducted with CSF top finishers during the 2006 ISEF in Indianapolis, Indiana. Questions fell into three general categories: (a) the nature of problem finding, (b) the creative processes of science, and (c) the role of the scientist and the student-scientist as a creative individual. Questions were developed considering the taxonomy of ethnographic questions (Spradley, 1979). During the debriefing that followed each interview, subjects provided feedback on the quality and nature of questions as well as suggested new and alternative questions. The CSF president audited these interviews, and her suggestions were also considered in question modification.

In the fall of 2006, a high school applied research class of 15 students worked with the interview schedule and posted alternative interview questions on their class blog (LaBanca, 2008d). Focus grouping was conducted with the students to optimize and improve the question battery. Mock trials of questions were also conducted. Questions were then peer audited by four other science research teachers in Connecticut. The interview schedule was opportunistically modified based on field notes and respondent answers. Major revisions of the interview schedule are depicted in Appendix B.
Connecticut Science Fair student interview procedures. After informed consent was received and students completed the online versions of the demographic survey and USRT Scale, an appointment was made to conduct the interview. The interviews were conducted at the students’ schools. Appointments were coordinated with the student as well as the teacher who acted as the adult sponsor for the project. Teachers followed their appropriate individual school procedures for having a guest in the building. Interviews were scheduled either during a student’s unassigned period or during the mentor-teacher’s class period. Informed consent, the objectives of the study, interview procedures and recording methods were reviewed with the student before the interview was conducted.

The subject first trained the Dragon Naturally Speaking 9.0 Preferred voice recognition software (Nuance Communications, 2007) using the Dragon headset and a laptop computer. The subject read a script for approximately six minutes to train the software to his or her voice. After training, the interview was conducted with the use of the voice recognition software in tandem with a Sony ICD-MX20 digital recorder with a SanDisk 512 MB Memory Stick Pro Duo and handwritten notes. The voice recognition software converted the speaker’s words to text in a Microsoft Word file (Microsoft, 1999). An audio file was not generated with the voice recognition software, thus the redundant use of the digital recorder. The interview schedule was followed as opportunistically-modified from previous interviews. When clarification or more details were required, follow-up questions were utilized to encourage the student to elaborate.

Post interview, detailed field notes were generated. Digital recorder files were archived to the hard drive of a computer. Transcription began with the previously generated Microsoft Word file. The digital audio file was played through the digital recorder using headphones. Errors in the text file were corrected and edited to match the audio file. Completed text files were saved in
‘track changes while editing’ mode to clearly delineate any future changes made. Each file was electronically mailed to the subject for member checking verification and correction.

*International Science and Engineering Fair student interview procedures.* Based on question development and opportunitistic changes that occurred during the CSF interviews, a stable interview schedule was used for all ISEF interviews (see Appendix B). Follow up questions were often used to clarify or further develop student responses.

All ISEF interviews were conducted by telephone, since subjects were spread across the United States and the world. Telephone interviews allowed for efficient, yet reliable, collection of data (Ibsen & Ballweg, 1974). Special consideration was given to style and technique using the telephone to ensure complementary results were comparable to the face-to-face CSF interviews. The only face-to-face rapport for ISEF subjects was developed during a short (15-30 minute) discussion during the public viewing session. Rapport can potentially develop effectively during a telephone conversation, since it is an interactive process (Lawler, 1994). It is assumed that the trustworthiness of experiences and beliefs provided during phone conversations is comparable to that obtained during an in-person interview. Indeed, research supports the contention that qualitative data are generally equally accurate by telephone and face-to-face interviews (Baxter, et al., 2003; Midanik, et al., 1999; Ibsen & Ballweg, 1974; Korner-Bitensky, Wood-Dauphinee, Shapiro, & Becker 1993).

Special questioning and speaking strategies were used to enhance data collection based on suggestions derived from the research literature. For example, when the goals, objectives, and nature of the study were explained to subjects, they were more likely to provide valid information (Singer & Frankel, 1982). Subjects who received assurance of confidentiality were more likely to answer sensitive items than those to whom confidentiality was not mentioned.
An interviewer can be perceived as more empathetic, warm, and genuine when lengthy pauses on the telephone are avoided (Natale, 1978). However, short pauses or short interjections were important to cue the subject to take command of the conversation and provide detailed information. Affirmation of responses also improves telephone rapport (Natale, 1978).

Midanik, Hines, Greenfield, & Rogers (1999) report that telephone subjects use a very similar strategy for retrieval of information compared to face-to-face subjects. The most common similarity tends to be subjects anchoring and restating their information. A response is made immediately, followed by a reasonableness assessment, further recall, and a restatement of the original response. It is much rarer for a subject to anchor and then adjust. Context was also commonly used in both mediums. Subjects used anecdotal stories to explain their ideas. Subjects also often tended to define concepts to clarify what they were attempting to explain. Very rarely would subjects decompose information (i.e., explaining a general idea or concept then breaking down the concept into parts). The interview, therefore, used follow-up questions systematically to clarify and delve deeper into student responses.

Interviews were conducted as close to the ISEF as possible to reduce amount of error in the information recalled (Baxter, Thompson, Litaker, Guinn, Frye, Baglio, & Shaffer, 2003). A corded telephone handset was equipped with a RadioShack Mini Recorder Control #43-1237. The control attached to the telecom port and converted the audio signal through a 1/8” minijack. The minijack was plugged into a Sony ICD-MX20 digital recorder with a SanDisk 512 MB Memory Stick Pro Duo. Several interviews took place on a cellular telephone. In this case, the hands-free module of the cellular phone was equipped with a RadioShack Wireless Phone Recording Controller #17-855. The Controller had a port for a wired hands-free headset and an
output 1/8” minijack, which was connected to the digital recorder. This system required use of the wired hands-free earpiece/microphone. This system did not work with a wireless headset (e.g. Bluetooth). Both the corded landline and cellular systems exported sound in mono (left ear) only as a restriction and function of the RadioShack controllers. After the interview, field notes were generated. Audio files were archived to the hard drive of a computer.

Manual transcription of the audio file was generated via the recorder with headphones. An alternate strategy for transcription was developed for files with lower quality audio. Files were uploaded to the computer, and replayed through high-quality speakers. Digital voice editor (Sony, 2005) was used for listening. The software automatically equalized the sound file to compensate for background noise. The following user modifications were made to the software to aid in transcription in the Tools/Options window/Transcribing Key tab: (a) the start button was assigned to F10; (b) the stop button was assigned to F11; (c) the easy search forward button was assigned to F9 with a timeframe of 10 seconds; and (d) the easy search reverse button was assigned to F8 with an initial timeframe of 10 seconds, but was modified to 5 seconds to better access the files. Digital voice editor does work with foot control pedals, part #foot control unit FS-85USB, but they were not used in this application.

Completed text files were saved in ‘track changes while editing’ mode to clearly delineate any future changes made. Each file was electronically mailed to the subject for member checking verification and correction.

Semi-structured teacher and mentor interviews. CSF teacher interviews took place in person at the teacher’s respective school. CSF mentor and ISEF mentor interviews took place by telephone. Informed consent and interview protocols were similar to those of the student
interviews. An interview schedule was developed to elucidate information for triangulation with the student interviews (see Appendix B).

*Semi-structured fair director interviews.* Fair director interviews took place by telephone. Informed consent and interview protocols were similar to those of the student interviews. An interview schedule was developed to elucidate information for triangulation with the student interviews.

*Newspaper and popular press document analysis*

A five-year guided news search of the Lexis-Nexis database was conducted to collect newspaper artifacts regarding the ISEF. The following search parameters were used:

1. Search terms: International Science and Engineering Fair, ISEF
2. Sources: all news, all newspapers, US newspapers and wire, all magazines
3. Date: previous five years (October, 2002-October, 2007)

The article title, source, and body text of each article was retrieved, copied, and converted into a Microsoft Word file.

A similar procedure was used to search the Education Resources Information Center (ERIC) database for ISEF artifacts.

*Reflexivity journal*

An online reflexivity journal blog (LaBanca, 2008b) was developed to maintain an audit trail and document tentative interpretations of the data (Merriam, 1998). A blog, or weblog, is an online journal: a personal chronological log of thoughts published on a web page using a user-friendly, word processor-based interface. Posts are displayed in reverse chronological order and each post has a link to allow comments and responses to the author. Blogs are simple to construct and use, because complex understanding of programming languages is not necessary. They are
free, and only a rudimentary understanding of a web browser and word processing program are necessary.

Because there were a large number of posts, the blog automatically archived data, making access more cumbersome. A chronological index of the blog with links to each post was created on a wiki (LaBanca, 2008c). A wiki is a collaborative website that users can easily modify via the web, again, using a user-friendly, word processor-based interface. Each post on the blog was identified on the wiki with a date, the title of the post, a priority level (no, low, medium, high), and a brief description.

Peer and mentor audits of the reflexivity blog were conducted periodically during the study. Auditors were given the wiki address and asked to post comments. An audit took place between the CSF and ISEF data collection, at the conclusion of data collection, before coding of data, and after coding of data.

In summary, there were many advantage to using the blog and wiki as a reflexivity journal. Data were always available asynchronously online. Data were easily accessible and well organized. Blogs and wikis are easy to set up and do not require advanced computer programming skills. Auditors provided comments easily without receiving cumbersome files either by electronic mail or paper. Auditors had access to other auditors’ comments making their posts richer and more varied. Peer and mentor audit comments were effectively made, listed, shared, and compared both by the investigator and the auditors.

Analysis of data

A phenomenological multicase study must be sensitive to assumptions that might bias the study. Prejudices of the process or of the investigator must be considered through multiple, varied lenses. Metacognitive techniques, such as epoche, bracketing, and imaginative variation
can be used while analyzing the data. Epoche is the process of becoming aware of the self-prejudices and viewpoints of, in this case, the problem finding process (Merriam, 1998). Bracketing, the process of setting aside what is known about a phenomenon, can be achieved by explaining the basis for the study, identifying presumptions based on the researcher’s experiences, and disclosing assumptions about the methodology (Pitney & Parker, 2002). Finally, imaginative variation challenges the researcher to view the problem finding phenomenon from multiple, divergent perspectives (Moustakas, 1990).

Qualitative analysis of the data occurred during and after collection. Emergent categorical themes were directly interpreted as interviews were conducted. Subsequent analysis was subject to an organized categorical aggregation (Stake, 1995). Data were preliminarily organized into case records (Patton, 1980). Content analysis of interview data were generated to search for patterns and categories (Spradley, 1979). Units of data were categorized and met the Lincoln and Guba (1985) criteria. First, a unit of data was heuristic, serving to indicate or point out revealing information relative to the study. Second, the unit of data was interpretable independent of other information, meaning the category was clearly delineated (Lincoln and Guba, 1985). The codes were organized to combine recurring regularities in the data to construct categories (Merriam, 1998).

Category construction was generated by analyzing an interview, related field notes, and documents. Each interview was cross-referenced with previously analyzed interviews to search for patterns. Categories were designed to reflect the nature of the research questions. The following criteria were used when generating categories: (a) categories were exhaustive allowing the placement of all data units, (b) categories were mutually exclusive, (c) categories were as sensitive as possible to best explain data, and (d) categories were conceptually congruent.
meaning “the same level of abstraction should characterize all categories at the same level” (Merriam, 1998, p. 184).

All data were coded and categorized using *The Ethnograph*, computer software designed to make qualitative data analysis research easier, more efficient, and more effective (QRA, 2006). Entire case records were imported into the program. Each case was treated as an individual file within a project. Three projects were generated for this study: (a) student interviews, (b) adult interviews, and (c) popular press documents. A coding summary is provided in Table 5.

Table 5

*Summary of categories generated in each project*

<table>
<thead>
<tr>
<th>Project</th>
<th>Number of cases</th>
<th>Number of categories</th>
<th>Number of coded segments</th>
<th>Average number of coded segments per case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students</td>
<td>20</td>
<td>48</td>
<td>1426</td>
<td>71.30</td>
</tr>
<tr>
<td>Adults</td>
<td>6</td>
<td>31</td>
<td>294</td>
<td>49.00</td>
</tr>
<tr>
<td>Documents</td>
<td>98</td>
<td>4</td>
<td>100</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Each file was independently coded, saved, and printed. Category segments were identified by highlighting. Each question was assigned a category to facilitate later sorting. After each project was completely categorized, cases were collectively compiled and sorted by category for cross-case analysis. Each category was assigned to a category cluster.

Categorized data was further analyzed by triangulation of both data sources and data methods. Patterns and categories of data records were compared and contrasted between cases.
Spradley, 1979; Miles & Huberman, 1984; Stake, 1995). Data that were critical to an assertion or a key interpretation were confirmed and validated by identifying that data across cases as well as confirming by peer and mentor audit (Stake, 1995). Several sections of significant data were verified by a panel of science content experts (n=6). All had graduate degrees in a natural science or engineering field.

Figure 7. Triangulation strategy for methods

Multiple triangulation strategies were utilized to compare data sources and methods (see Figure 7). Data source triangulation observed if a phenomenon or finding remained the same for other individuals, times, or places in an attempt to see if what is observed carries the same meaning in different circumstances. Although investigator triangulation, using several different researchers for the study (Janesick, 1994), was not utilized, data were validated with a panel of
science research teacher-experts. Theory triangulation, using multiple theoretical perspectives as well as reviewers from alternative theoretical viewpoints was utilized to coordinate findings (Janesick, 1994; Stake, 1995). Theoretical triangulation was primarily achieved through peer and mentor review of the reflexivity journal. Methodological triangulation, using multiple sources, including interviews, documents, and surveys further validated the findings. Finally, interdisciplinary triangulation, utilizing multiple education disciplines during the research process, helped to broaden the understandings in the study (Janesick, 1994). The triangulation strategies provided checks for both credibility and dependability of collected data (Isaac & Michael, 1997).

A confirmability audit, utilizing a cross-validation technique was used to verify data coding, conclusions, and recommendations. An independent evaluator, knowledgeable in the precollege science research process and qualitative analysis reviewed and critiqued the findings. The expert concurred with 93% of the categories generated.

This study’s design accounts for reduced sample size by allowing for an in-depth view of the problem finding phenomenon utilizing multiple sources and methods. Multiple strategies, therefore, were utilized to improve trustworthiness and transferability of the study (see Table 6) (Krefting, 1991).
Table 6

Summary of methodological strategies to improve trustworthiness

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Criteria</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credibility</td>
<td>Prolonged involvement</td>
<td>The researcher has been a teacher-participant in the open inquiry science research process and local, regional, statewide and international science fairs and symposia for eight years.</td>
</tr>
<tr>
<td>Pilot interviews</td>
<td>Pilot interviews</td>
<td>Pilot interviews were conducted to frame the scope of the research questions and direct the focus of the research.</td>
</tr>
<tr>
<td>Reflexivity</td>
<td>An online reflexivity journal was maintained throughout the study.</td>
<td></td>
</tr>
<tr>
<td>Triangulation</td>
<td>Triangulation</td>
<td>Triangulation of data sources and methods was utilized in data analysis.</td>
</tr>
<tr>
<td>Member checking</td>
<td>All interview transcripts were reviewed by their respective subjects.</td>
<td></td>
</tr>
<tr>
<td>Peer/mentor examination</td>
<td>Doctoral cohorts, science research teachers, and mentors reviewed the reflexivity journal.</td>
<td></td>
</tr>
<tr>
<td>Interview technique</td>
<td>Opportunistic questioning was utilized. Questions were removed or expanded based on previous responses.</td>
<td></td>
</tr>
<tr>
<td>Structural coherence</td>
<td>Inconsistencies in the data were interpreted and explained.</td>
<td></td>
</tr>
</tbody>
</table>
Table 6 (continued)

*Summary of methodological strategies to improve trustworthiness*

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Criteria</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transferability</strong></td>
<td>Nominated sample</td>
<td>CSF and ISEF judging scores were utilized to identify potential subjects.</td>
</tr>
<tr>
<td></td>
<td>Thick description</td>
<td>A complete description of the methodology was described including verbatim</td>
</tr>
<tr>
<td></td>
<td></td>
<td>transcription of the interviews.</td>
</tr>
<tr>
<td><strong>Dependability</strong></td>
<td>Question development checking</td>
<td>Questions for interviews were developed in conjunction with research student</td>
</tr>
<tr>
<td></td>
<td></td>
<td>participants.</td>
</tr>
<tr>
<td></td>
<td>Triangulation</td>
<td>As described above.</td>
</tr>
<tr>
<td></td>
<td>Cross validation</td>
<td>Coding consensus was achieved with the researcher and an independent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>evaluator.</td>
</tr>
<tr>
<td><strong>Confirmability</strong></td>
<td>Confirmability audit</td>
<td>Cross validation and peer and mentor audits were utilized.</td>
</tr>
<tr>
<td></td>
<td>Triangulation</td>
<td>As described above.</td>
</tr>
<tr>
<td></td>
<td>Reflexivity</td>
<td>As described above.</td>
</tr>
</tbody>
</table>
CHAPTER 4: RESULTS AND DISCUSSION

Research Design

The following questions were addressed in this study:

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?

The questions are answered through analyses of individual cases then a synthesis of all cases. Data has been triangulated between student cases as well as using teacher and mentor interview cases, surveys, and documents. Multicase data analysis was focused around the following three themes: (a) problem finding and inquiry, (b) problem finding and creativity, and (c) problem finding and situated cognitive learning.

An overview of each student is provided, focusing on student demographics, student project problem finding, and student successes at science fairs. Pseudonyms have been assigned to each student and are positioned in alphabetical order. Students in this study participated in either the Connecticut Science Fair (CSF) or the International Science and Engineering Fair (ISEF). Summary tables for students, their project fields, and their fair results are found at the end of the CSF student profile and ISEF student profile sections. Entrance to the Connecticut Science Fair (CSF) and ultimately the International Science and Engineering Fair is by a systematic process as described in Figure 8. Non-Connecticut ISEF students who participated in this study followed a similar path as CSF students to gain ISEF admittance.
Direct Entry

Each Connecticut High School can enter up to 8 projects directly into the CSF

Independent Entry

Direct entry is granted to individual students who are home schooled or attend a non-participating school.

City Fairs

Two Connecticut cities sponsor their own fair and then submit top projects to the CSF

Regional Fair

Two fair categories: Biological Sciences, Physical Sciences
- 20% of participants categorized as finalists
- Top 6 from each category plus overall winner advance to CSF (13 total)
- Overall winner advances to ISEF

State Fair

Two fair categories: Biological Sciences, Physical Sciences
- Top 25% of projects termed Finalists, Middle 40% termed Second Honors, Bottom 35% termed Third Honors
- Top 2 from each category advance to ISEF (4 total)

International Fair

17 fair categories
- Each category awards first through fourth awards and a category winner.
- 3 overall winners “Intel Young Scientist”

Other ISEF-Affiliated

There are approximately 550 fairs held worldwide that submit projects to ISEF

Figure 8. Student pathways for participating in science fairs.
Connecticut Science Fair student profiles

Andrew

Andrew is a 17-year-old senior, attending a public high school in an affluent coastal Connecticut town. He has participated in his school’s formal science research program for three years, always focusing his research on his primary passion: computer science. He also has an interest in languages and has worked to integrate both in his research. In addition to taking his science research course, Andrew is enrolled in four Advanced Placement courses, including AP Calculus BC, AP Physics C, AP US Government, and AP Spanish Literature. He is also taking Middle East Studies and Contemporary American Literature.

While working on computer science-type projects, Andrew discovered an article on a computer news site that discussed a new algorithm that could analyze bodies of text. Recognizing the value of this algorithm, Andrew contacted the author and diligently persuaded the author to provide him with the source code. Andrew recognized the limitations to this algorithmic method and developed his own heuristic method. This heuristic method is a trial-and-error method of problem solving, used when an algorithmic approach is impractical (LPG, 2008). He used his experiences from science research, as well as AP Statistics, and an online linguistics course he had taken, to develop his problem and strategy.

Andrew presented the results of his computer science research for three consecutive years at the Connecticut Science Fair (CSF). Each year, he was a fair finalist, garnering awards tailored for the computer science subcategory. This year his project entitled, *A novel heuristic search method using inferential statistics*, finished fifth place in the physical sciences category, which is one of the two general fair categories. There are typically well over 100 entries in this category. He won first place in the math subcategory, third place in the computer science subcategory, and
three special awards. Andrew’s project was the design and implementation of a method for analyzing speech patterns, a sophisticated grammar checker. He used a unique algorithm to do the searching. He regards the projects he produced over the three years as one continuous process.

Andrew worked independently under the auspices of the school’s science research program. His school’s program director is a Ph.D. neurobiologist. Andrew utilized support, primarily via email with professors and researchers, but does not identify any one person as his mentor.

Andrew was also a national semifinalist in the Intel Science Talent Search, the country’s oldest and most highly regarded pre-college science contest, designed specifically for seniors who have conducted independent research. Andrew plans on majoring in computer science in college. His experience in the science research program has focused and strengthened his interest for this field of study.

Bobby

Bobby is an 18-year-old junior, attending a private high school in an upper-middle-class rural community in northwestern Connecticut. An exchange student from China, Bobby is boarding at the school and was also assigned a host family in the community. He regularly spends time with his supportive second family, but will be returning to China at the end of the academic year. Bobby’s interests are in Chemistry: the focus of his project. Bobby is enrolled in AP Calculus BC, AP Chemistry, AP Music Theory, English, and United States History.

Bobby’s project entailed the development of coating for paper that would allow it to be reused. The pen used water as ink; and the paper had a chemical coating that would react with the water to produce an image. After time, the watermarks would fade and disappear so the paper
could be reused. The basis of Bobby’s project derived from his native land. He is a young man who is gravely concerned about the amount of forestry being cleared in China.

Bobby strived to develop a new type of paper, as no one had undertaken anything like this before. He did extensive research both online and in person. Visiting stores in China, he saw what kinds of products were already in existence. Bobby conducted almost all of his research and experimentation in China. Once Bobby had conceived of his general idea, he worked with his teacher and made contact with university professors to troubleshoot ideas for possible solutions. His main challenge was devising a strategy to utilize materials that would work in a very practical way. He was concerned with the seemingly endless approaches to the problem, and tried multiple strategies before finding a successful combination of chemicals to achieve his goal.

Once in the United States, Bobby elicited the help of teachers and fellow students to examine and evaluate his work. He evaluated their suggestions and incorporated those he felt would benefit the ultimate presentation of his work. His project, *The preparation of an environmentally friendly “novel paper” for painting and calligraphy exercises*, was presented both at the CSF and the Connecticut Junior Science and Humanities Symposium (CT-JSHS). His enthusiasm and excitement at both venues was contagious and he quickly surrounded himself with many new friends who were interested in both him and his project.

Bobby placed third in the physical sciences category in the fair, and won third place in the applied technology subcategory. After completing his senior year in China, Bobby hopes to pursue a college degree in chemistry. He has a deep appreciation for his experience in the United States.
Caitlin

Caitlin is a 16-year-old junior attending a technology-based magnet school in a central Connecticut urban center. She was recruited to participate in her school’s newly formed science research class. The research class was developed in conjunction with a regional educational resource center (RESC) using interdistrict funding, which seeks to develop interactions and collaborations with suburban and urban students. Besides her science research class, Caitlin is enrolled in SAT preparation class, A+ advance, and honors American literature.

Caitlin struggled immensely in the development of a project idea. Her teacher allowed her to go through the struggle independently, to Caitlin’s regular frustration. She eventually developed a project related to tsunamis. However, because of the limitations associated with her ideas, she lacked a tangible original concept. Her project, therefore, was mainly based on preexisting data. She recognized that the project did not merit significant external recognition, but nonetheless identified her unwavering dedication to its completion.

Caitlin worked under the careful guiding mentorship of her teacher. Her project, *Designing future tsunami protection in the eyes of the coast lines*, was awarded third honors in the physical science category at the fair. That award placed her in the bottom third triad. She considers the award an honor because it represents her successful completion of a body of work. Having completed the science fair experience, Caitlin admits to valuing the frustrations associated with her project and its development, because she now knows she is able to accomplish a large meaningful task on her own, regardless of the challenges. Caitlin is considering attending college and would be the first member of her family to accomplish such a goal.
Dana

Dana is a 16-year-old junior also attending a technology-based magnet school in a central Connecticut urban center. Dana was recommended for her school’s science research class. In addition to science research, she is enrolled in SAT prep, pre-calculus, and honors English.

Dana decided that she really wanted to conduct a project that she perceived to be very practical. Observing that she was often tired during the school day, she decided to see if there was a solution to her exhaustion. Dana worked with her science research teacher and her gym teacher to conduct a study about the effects of a yoga program on students’ alertness during the school day. Working with her fellow classmates as subjects, she coordinated a 1-week study with a control and treatment group, where each participant would self-report his or her alertness at various times during the school day. She clearly understood the limitations to her project and the inability to control confounding variables that might be present. She also generally used techniques of convenience while conducting the study.

Dana reports that the selection of her topic came easily – she did not spend much time thinking about it. She had some initial interest in sleep and noticed that there were quite a number of websites that mentioned yoga. When her gym teacher informed her that he was going to try a yoga program, she jumped at the idea.

The study, entitled Does yoga influence a student’s alertness during the school day? was awarded third honors in the life sciences category of the CSF.

Eric

Eric is a loquacious 17-year-old senior, attending a private academy in an affluent coastal Connecticut town. Eric’s school does not have a formal research program, although his
chemistry teacher is interested in launching one. Eric’s project was completed under the auspices of an independent study. Eric gave up taking a fourth year of language to take independent study in conjunction with another science class. Rejecting the counsel of others, he was advised against this path by a counselor and peers. They felt colleges would be more interested in a student taking four years of language over conducting an independent, student-driven, self-directed experience. Eric notes that the prestigious Midwest college that he will attend, was thought to be out of his reach for admittance. He, however, notes the application asked for a description and an abstract, if available, of the independent work he had conducted.

With his strong quantitative-analytical interests, Eric is enrolled in AP Physics, AP Calculus AB, Independent Science study, as well as AP English, and a history elective. He is most interested in science and notes that he perceives himself as different from his classmates, who do not share this same intrinsic interest.

Eric conducted a serious organic/physical chemistry project. He made very small batches of bio-diesel using different conditions and tested his fuel to see how effective it was. He looked at a number of physical properties in the collection. Eric has conducted his project in a fume hood located in a teacher preparatory room. His teacher/mentor, a Ph.D. physical chemist, allowed him to work almost exclusively without direct supervision.

Eric was very passionate about chemistry and knew he wanted to conduct a project looking at a chemical reaction, but was not sure what reaction to examine. He had a good friend who was an avid environmentalist and they began to talk about alternative fuels, specifically bio-diesel. Eric did additional research on the chemistry of bio-diesel production and determined that it was a feasible process that would allow him to learn new techniques in analytical chemistry.
He knew, with such national political interests in alternative energy, that a bio-diesel study would be worthwhile and potentially produce novel, innovative results.

Eric’s project, entitled *Cleaner air, better fuel, a solution: refined bio-diesel*, placed fourth overall in the physical sciences category at the CSF. He was first place in environmental science subcategory and first place in the energy subcategory. He was also awarded common stock from the title sponsor of the fair, and two other special industry awards. Eric’s project has reaffirmed his passion for science as he plans to major in chemistry in college. He was impressed by the powerful, positive reaction he received for his research and recognizes that it was due to the relevance of the topic on a national scale.

*Felipe*

Felipe is a 17-year-old junior, attending a public regional high school in a middle class rural town. The town hosts the state’s largest public university and the school is located adjacent to the university campus. Many students at the high school, like Felipe, have parents who are professors.

His school does not have a formal research program, but has a culture for students conducting research across diverse fields of study, many of whom work at the University. This is not the case for Felipe; he has conducted all of his research at the high school under the mentorship of his teacher. His teacher was recently awarded a prestigious science education grant and converted the school’s petite, ground-level, attached greenhouse into an aquaculture center, specifically for propagating corals. Felipe has aquaria in his home and, based on his positive experience with the coral, has converted all of his tanks to salt water.

As a junior, Felipe is registered in college calculus, college physics, Latin IV, world civilizations, English, and independent study. Felipe has a strong interest in marine ecology and
the accompanying outdoor sports: kayaking, snorkeling, and scuba diving. He believes the idea of developing better propagation strategies in aquaculture is important because it will give hobby aquarists a better source of corals for their tanks, without disrupting the fragile, natural coral reef environments. After developing a functional coral system by plumbing the flow system, Felipe carefully crafted environmental studies to optimize the growth rates of a certain species of coral.

Felipe presented the results of his research entitled *Effects of lighting intensity on aquacultured zoanthid colonies*, at both the CSF and CT-JSHS. In the CSF’s biological sciences category, Felipe placed fifth overall. He was also a finalist in the environmental sciences category and won four special awards.

Felipe’s father is a professor of ecology and evolutionary biology at the university. Ironically, Felipe only utilized his father to dissect his paper and listen to his lecture. The experimentation, and project development was fully under the guidance of his teacher. Felipe describes his project as an offshoot of his interests in developing the aquaculture system with his teacher. He developed significant expertise during the design and construction phase and would have been satisfied just working on the system. He did, however, take the advice of his teachers to develop and present a project based on his work. He plans on continuing his work into his senior year.

*Gabrielle*

Gabrielle is a 16-year-old junior, attending a public high school in a diverse coastal Connecticut city. Although the school has a diverse population both ethnically and socio-economically, there is a significant professional population. With a 30-mile proximity to New York City, students, like Gabrielle, have opportunities to access academic institutes and professors who often aid in the success of their projects. This is Gabrielle’s second year
participating in the school’s formal science research program. The school has a long, rich history with its program, being the first research class offered in a high school in the state during the academic day.

Gabrielle’s project was a method development. She was seeking a strategy to grow worms in the lab, but in natural conditions. She tested different environmental and nutrient conditions extensively to see what would allow the best survival rate for the worms. Gabrielle’s project origin was rooted in her strong interest in the environment. She did some preliminary work using earthworms and soil.

Her teacher recognized the project was more of a sophisticated technical project, and encouraged her to seek a project that would involve more novel work. He provided her with an article about a different species of worm and a regulatory system within the worm. The research paper was written by one of the teacher’s former research students who had become a professional scientist. After examining some viability options, Gabrielle consulted with a professor in New York City who helped her focus her ideas, loaned her some equipment, and provided regular guidance, primarily by email, but once a month, in person at his institution.

Gabrielle worked primarily in her school’s science research laboratory. The lab is very atypical for a high school science classroom, holding hundreds of thousands of dollars of analytical instrumentation that has been either purchased or acquired by donation. The science research teacher is a former trainer and technical support representative for a major international company that manufactures analytical scientific instruments.

Gabrielle was a CSF fair finalist and won one special award for her project *Long-term survival of “C. elegans”-lacking CED-3 in a soil-type environment*. She also placed second at the CT-JSHS. The second place award for the CT-JSHS won her a bid to present her research at
the National JSHS. Gabrielle’s mentor in New York was amazed by her dedication and commitment to her work and offered her an internship for the summer. Desiring a career in research, Gabrielle has excitedly jumped at the opportunity.

**Hannah**

Hannah is a 17-year-old senior attending a rural regional public high school in northeastern Connecticut. Hannah completed her project under the auspices of her school’s senior project program. The school requires that students complete a project in any field, in order to graduate. In addition to her senior project, Hannah was enrolled in computer science, anatomy, college multivariable calculus, AP English, AP Latin V, and world civilizations.

Hannah has a strong interest in science. Working at a middle school enrichment summer science camp at a local university, she had the opportunity to speak extensively with the program facilitator, who also happens to be the co-director of the CT-JSHS. She also met with the chair of the science department during the summer to speak about possibilities. As her ideas and interests began to focus, she spoke extensively with numerous doctors and individuals about the gastrointestinal system. She worked under the mentorship of another teacher in the school’s science department who earned a Ph.D. in molecular biology. Hannah commented frequently about the positive experiences she had working with and gathering information from professionals in the field. Her father, a math teacher in the school, provided Hannah with support, but fostered her independence as a self-directed learner by allowing her to seek out her own resources.

Her project, *The effect of probiotics on gastrointestinal symptoms*, was a finalist in the biological sciences category at the CSF. Hannah’s project also won a governmental special award.
Igor

Igor is a 17-year-old senior attending a private academy in an affluent coastal Connecticut town. Igor’s chemistry teacher is running a research program with Igor and two other classmates under the cloak of an independent study. Igor is a strong political environmentalist. He is passionate about the environmental movement and in mobilizing people by informing and educating. Aside from his independent study, Igor is enrolled in AP environmental science, AP calculus, AP French, video production, as well as history and English electives.

Igor was first excited by the prospects of learning more about renewable energy resources while taking an environmental science class during his junior year. He had previously spent a semester away from home, by choice, in a southwest experiential learning institute, where he developed his deep and meaningful appreciation for the environment. He was motivated to participate in this program by a distinguished speaker who had come to his academy for a presentation. Politically savvy, Igor recognized that his passion in the environment could be tied in with a project about alternative fuels, specifically bio-diesel.

Spurred by the controversy about the minimal net energy gain from the use of ethanol, Igor developed a project to examine the lifecycle of bio-diesel, in hopes of determining that the fuel had the potential to be more energy viable. His project developed into a scaled compilation of online data. Igor was disappointed in the overall quality of his work, noting that his lack of experimentally-based data was a detriment. He gave praise to the model his friend Eric had taken for his project, who was also simultaneously working on an experimentally-driven bio-diesel project.
The two, along with a third peer, had conceived a plan where Eric would be the chemical engineer, Igor took the role of the environmentalist, and the third friend took the role of the mechanical engineer to attempt to scale up Eric’s methods. Although appealing for a school-based project, when the projects needed to be targeted for the CSF judging audience, the nature of Igor’s work did not optimally match the CSF format.

Igor’s project, *Bio-diesel: an honest environmental assessment*, was awarded third honors in the physical sciences category of the CSF.

Jessica

Jessica is a sixteen-year-old junior attending a public high school in a middle class suburban town in eastern New York, proximate to western Connecticut. Jessica has participated in her school’s formal science research program all three years of her high school career. In addition to taking her school’s after school research class, Jessica is enrolled in AP biology, AP calculus, AP English, AP US History, and Spanish.

Jessica has been participating in the science fair process since middle school when she studied mudslides. Each year of experience has improved the quality of her research efforts. She had read an article about mudslides and their effects on the chaparral ecosystem plant growth. She found the ecosystem fascinating and wanted to learn more about it. Her current interests are focused on chaparral plant germination cues that occur after destruction by wildfires. She found this both interesting and exciting, because there was an apparent paradox in the lifecycles of these plants: wildfires promoted their growth.

Jessica’s project, entitled, *Analyzing heat shock germination cues: how environmental alterations can send a wake-up call*, placed fourth in the life science category of the CSF. She also won a special award. Her project gained admittance to the CSF fair through a regional fair.
hosted in northern Fairfield County that includes neighboring New York towns. In this regional fair, she placed first in one of the life sciences category.

Jessica utilized many mentors, primarily via email. Her science research teacher, a former physical chemist researcher, assisted in the facilitation of initially contacting these individuals, as well as providing her with lab space to conduct her experiments.

Kyle

Kyle is a 16-year-old junior attending a public high school in a culturally and socio-economically diverse, coastal Connecticut city, proximate to New York. Kyle has always wanted to participate in his school’s formal science research program, but due to prior scheduling conflicts, he elected to take other classes, until this year. In addition to taking his school’s science research seminar course, Kyle is enrolled in AP physics C, honors engineering, honors advanced multivariate calculus, AP government, honors Latin seminar, and honors British literature. A true analytical whiz, Kyle completed AP calculus his sophomore year of high school.

Kyle has always been a garage engineer, tinkering and building devices at home. He wanted to assemble a carbon dioxide laser in his basement to cut wood. This idea was vetoed by Kyle’s parents. Three of his four grandparents and both of his parents are engineers. Though he has a family with a strong technical background, they allow him to be independent and self-directed in his own work. When considering what he wanted to do for his project, Kyle realized, from a practicality standpoint, that his school had a lot of optics equipment. He had a strong interest in optics and lasers and wanted to combine this interest with his desire to build something.
While rummaging through one of the storage rooms at the school, Kyle came across a sophisticated light microscope. He decided that it would be interesting to take it apart to learn more about it. During the process he thought it might be interesting to reconfigure the microscope to include a laser fluorescence system. He was unsure of what the benefit would be, but still decided to pursue it.

His teacher arranged a trip to a major cancer hospital and research center in New York City, with the goal of discussing laser-induced fluorescence microscopy. They also sought out a purpose for this sophisticated instrument he had built. Kyle ultimately decided to demonstrate the use the microscope by measuring fluorescence in vivo in single-celled, chlorophyll-rich *Euglena* organisms.

Kyle’s project, entitled *New techniques in fluorescent microscopy*, placed first overall in the physical sciences category. He also won two special awards. By virtue of his first place win, Kyle’s project was awarded a trip to compete at the International Science and Engineering Fair (ISEF). Admittance to ISEF is only through a regional fair. Students attending ISEF have the option of competing in 1 of 17 categories (see Appendix A). Kyle chose to participate in the Physics category where he received a Third Award. CSF and ISEF participation have reaffirmed Kyle’s engineering passion, as he plans to pursue it as a career.

*Laura*

Laura is a 17-year-old junior attending a public high school in a middle class suburban town in eastern New York, proximate to western Connecticut. Laura has participated in her school’s formal science research program for her three years of high school. Laura’s science research class meets one night a week. Students pursue the content of their projects on their own time, often after school or during an unassigned time during the school day. In addition to taking
Laura has a passion for horses. She has been riding most of her life and works at several barns in the area. Laura also has a strong interest in learning about things that are interesting to her, although not necessarily taught in school. When Laura was a freshman, she completed a project about nutrition and degenerative bone navicular disease in horses. This work won her regional fair and earned her a trip to ISEF. As a sophomore, she continued working on navicular disease. This topic eventually bridged into her junior-year project.

In her junior year, her equine studies became more focused. Her grandmother had read an article about reattachment surgery and was surprised to see that leeches were still used (Shin, 2006). This discussion with her grandmother regarding this method reinvigorated Laura and she realized that there was a potential anticoagulant medication that could be used on horses—thus the nature of her project. She developed a novel protocol to isolate and purify the anticoagulative agent from leeches.

Her project, *Integrating hirudin from “Hirudo medicinalis” into an anticoagulative medicine for “Equus caballus”*, again won the western Connecticut regional fair and a bid to ISEF. She competed in the CSF and was a finalist, winning an additional special award. At ISEF, Laura competed in the animal sciences category, earning a Fourth Award. Just as passionate about music, Laura is contemplating a double major in science and music at college.

*Summary.* Twelve students participating in the 2007 CSF participated in this study. Their projects covered a broad spectrum of topics, each suited to the individual interests of the respective student (see Table 7). The twelve students represent both urban and suburban high schools, public and private schools, as well as various socioeconomic backgrounds.
Table 7

Summary of CSF results for subjects

<table>
<thead>
<tr>
<th>Name</th>
<th>Project field</th>
<th>Category</th>
<th>Placement</th>
<th>Subcategory</th>
<th>Placement</th>
<th>Special Awards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>Algorithm development</td>
<td>Physical Science</td>
<td>Finalist: 5th place</td>
<td>Mathematics</td>
<td>1st place</td>
<td>G (1); S (2)</td>
</tr>
<tr>
<td>Bobby</td>
<td>Applied chemistry</td>
<td>Physical Science</td>
<td>Finalist: 3rd place</td>
<td>Applied Technology</td>
<td>3rd place</td>
<td>None</td>
</tr>
<tr>
<td>Caitlin</td>
<td>Meteorology</td>
<td>Physical Science</td>
<td>Third Honors</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Dana</td>
<td>Human behavior</td>
<td>Biological Science</td>
<td>Third Honors</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Eric</td>
<td>Alternative energy</td>
<td>Physical Science</td>
<td>Finalist: 4th place</td>
<td>Environmental Science</td>
<td>1st place</td>
<td>G (1); I (2)</td>
</tr>
<tr>
<td>Felipe</td>
<td>Marine biology</td>
<td>Biological Science</td>
<td>Finalist: 5th place</td>
<td>Environmental Science</td>
<td>Finalist</td>
<td>S (2); I (2)</td>
</tr>
<tr>
<td>Gabrielle</td>
<td>Cell/organism culturing</td>
<td>Biological Science</td>
<td>Finalist</td>
<td>none</td>
<td>None</td>
<td>S (1)</td>
</tr>
<tr>
<td>Hannah</td>
<td>Genetics/human systems</td>
<td>Biological Science</td>
<td>Finalist</td>
<td>none</td>
<td>None</td>
<td>G (1)</td>
</tr>
</tbody>
</table>
### Table 7 (continued)

**Summary of CSF results for subjects**

<table>
<thead>
<tr>
<th>Name</th>
<th>Project field</th>
<th>Category</th>
<th>Placement</th>
<th>Subcategory</th>
<th>Placement</th>
<th>Special Awards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Igor</td>
<td>Alternative energy</td>
<td>Physical Science</td>
<td>Third Honors</td>
<td>none</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
| Jessica
d | Ecosystem maintenance | Biological Science      | Finalist: 4th place | none        | None      | S (1)          |
| Kyle
e   | Engineering           | Physical Science        | Finalist: 1st place | none        | None      | I (2)          |
| Laura
c, f | Chromatography        | Biological Science      | Finalist      | none        | None      | S (1)          |

*a* Pseudonym used

*b* Special awards are given from governmental agencies (G), professional societies (S), or industry (I); awards are reported by type followed by the number of awards given by that type in parenthesis

*c* Gabrielle placed second at the CT JSHS and presented her work at the National JSHS

*d* Jessica placed first in her category at a regional science fair of the CSF

*e* Kyle and Laura both attended the International Science and Engineering Fair and are also profiled in Table 8

*f* Laura placed first overall at a regional science fair of the CSF and earned her bid to ISEF through that fair
International Science and Engineering Fair category winner student profiles

Over 1,500 students, representing over 550 regional fairs from around the world participated in the 2007 ISEF. These students, representing 46 states and 50 countries, presented their research to academic and industry professionals, as well as the general public in a gala event, taking place over the course of a week in May. The students, divided into 17 categories, based on their project content, collectively compete for over five million dollars in scholarships and prizes.

Each category awards the top projects with a first through fourth award, and a category winner. Of the category winners, three are selected as the overall fair winners and are dubbed Intel Young Scientists, receiving a $50,000 scholarship. Of those category winners, 13 were from the United States, three were from South Africa, and one was from Hong Kong. Of the three fair winners, all were United States citizens: two were immigrants, and one was a home-schooled student. Five United States citizens, including the home-schooled fair winner, and all three South Africans participated in this study.

Maggie

Maggie is a senior attending a suburban public high school near a major metropolis in a mid-Atlantic state. She has participated in her school’s formal science research program for all four years of her high school career. Maggie has a spatial learning disability and has often been discouraged from taking advanced science courses.

She did not meet the eligibility requirements for admittance to AP chemistry this past year. Nonetheless, she has pursued her science research projects with fervor and has achieved great success. Maggie’s science research teacher has her serving as his teaching assistant for his
freshmen classes. In addition to science research, Maggie takes calculus, AP English literature, AP US government, AP macroeconomics, and Latin.

Maggie has, as a result of her processing disability, had an interest in memory and the brain. Several years ago, she was fascinated by a PBS *Scientific American Frontiers* special that featured Alan Alda interviewing a researcher about memory in fruit flies (Chedd, 2004). She began conducting her own research about fruit flies, working with a partner. In her junior year, she and her partner won their regional fair as a team, and advanced to ISEF taking best team project in the 2006 fair. This year, her partner wanted to pursue a different course of study, but Maggie wanted to follow her interests in fruit flies and memory.

She forwarded her 2006 research paper to multiple high caliber laboratories around the US and received three offers to conduct research during the summer. She chose to work in a Midwest university laboratory and her supportive parents allowed her to move to that city for an extended summer internship. While working on her initial project, Maggie generated startling data relating to a common genetic marker, often studied during the Medelian genetics unit of a typical high school biology class. Meticulous in data collection and analysis, Maggie was constantly reviewing her data and redoing experiments to verify and validate her results. Skeptical at first, her supervisor, who gave Maggie the ability to work very independently, also recognized that Maggie’s results would invalidate almost thirty years of studies conducted using this marker.

Maggie identifies this project as an accident. She was conducting other research, but the expertise she had developed over the past three years performing fruit fly studies allowed her to quickly identify the irregularity of her data and, in turn, the significance of the results she was generating.
Maggie competed in the Behavioral and Social Sciences category at ISEF. She was the category winner, thus having one of the top 17 projects at a fair that had over 1,500 projects from all over the world. Maggie would ideally like to pursue a career in medicine, but feels this is an unachievable goal based on her processing disability. She instead is debating between economics and her science fair interest: neuroscience and behavior.

Nathan

Nathan is an 18-year-old senior attending an arts and science magnet school in the Midwest. He initially had a concentration in the arts, but transferred his concentration to the science portion of the school. As a requirement, students in the science academy must annually complete a research project. They are not under any obligation to present the results of their research outside of the school, and as a result, the projects are not always of high quality. Nathan had a desire to produce a very high quality project based on his personal hobby interests and what he considered a light senior year schedule. He was enrolled in AP biology, AP environmental science, college calculus III, government and economics, world literature, band, and tech corps.

Nathan is extremely interested in computers and computer science. For the past five years, he has regularly met with his friends for computer parties. During the parties they discuss new technology and also enjoy the latest gaming software. They also design and build new computers. A reoccurring problem that Nathan and his friends have encountered is the ability to cool processors so they operate efficiently.

Circuitry can generate a great deal of heat and it is critical to be able to dissipate the heat quickly and effectively so the computer chips do not burn out. Water cooling is the typical strategy used, but Nathan felt that it was not an effective system. At one of their computer
parties, one of Nathan’s friends talked about a paper that about liquid metal pumping. Nathan then spent a prolonged period at a local college library where he conducted extensive research to see if using liquid metal pumping might be an effective cooling system strategy, since it had never been attempted. After evaluating multiple liquid metal strategies, Nathan chose one that he thought would be most effective and then designed and built a closed-system circulator.

Nathan worked independently at home for the majority of his novel project. He utilized his former physics teacher as a mentor, primarily to assist him with questions about physical concepts. He was able to enlist the help of technical support experts at the industries that supplied him with his materials via telephone. In the past, Nathan had often wasted his money on materials because he did not design a good engineering plan. He wanted to avoid this pitfall with his new project.

Nathan’s project won his regional fair and he competed in the Engineering: bioengineering and materials category at ISEF. At ISEF, his project was awarded best in category.

Oliver

Oliver is a 16-year-old senior attending a private boys preparatory school in South Africa. He comes from a fairly affluent family and speaks both Afrikaans and English at home. He lives near the coast proximate to a major city. In school he takes advanced mathematics and science classes, computer science, Latin and history.

He notes that he comes from a developing country where all students are not afforded equal opportunity, especially in education. Socially aware of his country’s and continent’s limited resources, Oliver comments that science classes in many high schools do not offer any hands-on opportunities because there are no materials available. Technology has only recently
begun to permeate schools in South Africa, thus Oliver thought an alternative option to help with lack of laboratory resources might be to create a virtual lab system.

Unlike much educational software available, Oliver built his software system as a gaming platform. In his design, he thought it would be valuable to have a system that was modular and based on virtual reality. His experience as a computer user heavily influenced his design considerations. He also wanted educators to have the flexibility to add specific learning units with ease. Therefore, Oliver coded the system platform framework. This was the basis for the virtual reality platform.

In order to attend the ISEF in the United States, Oliver took his first international plane flight. He was amazed at the scope and magnitude of such an event, and commented about the availability of resources, especially technological ones, available to the participants.

Oliver’s project, *Computer-aided instruction in the modern classroom*, competed in the Computer Science category with 64 other projects. His project was recognized as best in category.

*Paige*

Paige is an 18-year-old senior attending a university school in South Africa. She grew up on a working livestock farm. She boards at school and returns home on the weekends. Her education path is that of a natural sciences program. She takes courses in chemistry, physics, biology, and math.

Paige was assigned an independent project as part of her school’s curriculum. She had the freedom to choose her topic. So, she began a conversation with a great number of people, but ultimately deferred to her mother who suggested she do something with her farm animals. Browsing through a local farming magazine, listened to a radio program in which a farmer asked
a veterinarian about the possibility of using aloe vera as a potential tick-pest control in animals. The responding veterinarian rejected the idea citing a study conducted at a university. In her usual skeptical attitude, Paige thought this might not be true, because she had heard otherwise from other farmers.

Livestock diseases caused by ticks are fairly widespread in South Africa, and there is a need for a practical, inexpensive solution to address this problem. There are current pesticide/chemical solutions available, however they are very expensive, not environmentally friendly, and the ticks typically build up immunity to the treatment usually on an annual basis.

Before pursuing aloe vera as a potential medicinal solution, Paige made extensive contacts with the local aloe factory, and interviewed the chemists as well as a large number of farmers who were interested in aloe vera as a potential treatment. Once she had collected enough information, she was able to design a study to test the effects of aloe vera on her sheep, both during the dry and rainy season. Because aloe vera has poor solubility in water, she also tested the delivery system to the sheep – both using water and paraffin as the delivery agent.

Paige won her regional fair, which is one of three in South Africa. Her success earned her a trip to the ISEF. Paige’s project, *Aloe: a bitter pill for ticks to swallow*, competed in the plant sciences category. She was the category winner.

Paige received varying reactions for her project’s success. Farmers were thrilled and very interested in her results, while veterinarians were quite skeptical. Paige thinks this skepticism might be biased, since many veterinarians are funded by the chemical manufacturers. Her success at ISEF led to many newspaper articles and radio show appearances. Paige was initially not planning on attending a university, but based on her science fair success and fame, she was
offered a full scholarship with a bursary to a University in South Africa. She will be the first member of her family to receive a post secondary education.

Quincy

Quincy is an 18-year-old senior attending a private academy near a major city in South Africa. He lives at home with his family and is interested in pursuing a career in the sciences. He is particularly passionate about Chemistry. At school, Quincy is enrolled in all advanced courses: two math classes, science, Zulu, English, Latin and history.

Like his other South African compatriots at ISEF, Quincy is very aware and sensitive to his country’s and continent’s needs as a developing region. Although he does not come from an impoverished background, he recognizes the lack of resources available to his people.

Quincy has always been interested in rocketry and space. One of the problems that he has encountered while trying to pursue his rocketry interests is the availability of a suitable fuel to launch the rockets that he builds by hand. This led him to think about different possibilities for developing a working fuel formula. He found limited expertise and mentorship available in his own country and eventually made contact with a scientist in Canada, who served as his mentor. The mentor quickly pointed Quincy towards a novel strategy of utilizing epoxy for a fuel source.

After much deliberation, Quincy determined a possible, suitable formula which he synthesized and field tested, much to the chagrin on his mother, in his kitchen and on the adjacent patio. Still, his parents supported him, by funding the project and giving him space to work. He modified and adapted the formula many times to eventually generate a successful fuel mix. He then constructed a rocket, complete with a sensor system that he designed and programmed to collect data during the launch and subsequent parachute return.
Quincy’s project won his regional fair and earned a bid to the ISEF. Quincy’s project, titled, *African space: fueling Africa’s quest to space*, competed in the energy and transportation category. His project was dubbed category winner.

Ryan

Ryan is a 17-year-old senior attending a science magnet high school in a mid-Atlantic state. Ryan is enrolled in advanced biology and mathematics, takes literature, Spanish cinema, and Russian history. His school encourages science research and apprenticeships, having in-house laboratories for electronics and stem cell research to name a few as well as providing all senior students with an internship experience. Although the school philosophy reeks of authentic experience, few students have been successful at pre-college science fairs.

Ryan, however, has been the exception. His senior-year ISEF experience is his third. Ryan’s passion is electrical engineering, software-based projects, often at the sacrifice of his traditional schoolwork. His ideas are often inspired by inadequacies he observes in consumer electronics products and possibilities suggested by science fiction television dramas. His projects are often massive in scope, eclipsing even the most talented of his peers. He tends to work late into the evening or early morning.

For his senior year project, Ryan wanted to create a three-dimensional holographic generator. He had numerous ideas for completing this project, but wound up having extensive conversations with the electrical engineer-inventor who he was assigned for his internship. This dialogue helped him focus his design. His mentor repeatedly suggested that Ryan pare down his project: this idea was dismissed. Ryan needed to reverse engineer the projection chip that he obtained from a used projector, design circuitry and software to run it, as well as build a mechanical table that would spin the device to generate the 3-D image.
Ryan spoke with his father to brainstorm ideas. Although his dad does not have an engineering background, Ryan feels that he is an excellent soundboard to share his ideas. His dad is good at asking questions that focus and challenge Ryan’s thoughts, which, in turn, helps him to develop a solid project idea. Sometime, after conversations with his father and mentor about his big idea of a 3-D holographic generator, Ryan was travelling and stopped at a fast food restaurant, where he finally figured out how he was going to make his project work. Grabbing napkins from the metal dispenser, he quickly scribbled and scribed his design model. He noted that once he had figured out the strategy, the rest was going to be easy; it was just a matter of engineering it.

And engineer it, he did. His project, *I want a holodeck*, referencing to a science fiction television series, was in the Engineering: electrical and mechanical category. The project was the overall category winner, and Ryan also received several special awards. One award of note, identified his project as one of the top three in the fair, conducted by seniors. The award is an all expense paid invitation to attend the Nobel Prize ceremony in Stockholm for the International Youth Science Seminar.

Ryan achieved significant fame during the summer after the fair for unlocking and decoding a hyped and recently released proprietary communications device. He was interviewed extensively for local and national news broadcasts. Ryan traded a second version of the device, something he considered a piece of electronics history, to the president of a communications company in exchange for an expensive sports car and a summer internship. He was simultaneously offered summer internships and work at several major Internet search engine companies.
Although Ryan has demonstrated superior ability and creativity in electrical engineering, he feels he needs to pursue a different path for his higher education. He believes he has become a good ‘hacker’ of electronics, so now he wants to focus on ‘hacking the brain,’ thus his desire to study neuroscience.

Scott

Scott is a 16-year-old home-schooled junior from the Midwest. He lives on a farm. Officially, his mother is his teacher. Scott actually takes the majority of his classes at the local branch of the state university system or via distance learning with other universities. At the college, he is enrolled locally in genetics, intermediate German, world civilizations. By distance education, he is taking physics: optics and thermodynamics, AP language and composition. Under the guidance of his mother, he is independently taking differential equations and reading.

As a high school freshman, Scott was taking college chemistry at the university with college freshmen. His professor noticed that he was completing his coursework and assessments with ease and offered him an additional opportunity to conduct research in his laboratory. Scott excitedly accepted and began to complete some technical work focused around optimizing a potting soil mixture. Scott was initially excited by the experience because he was getting the opportunity to conduct authentic research, but he soon tired of it, because he ultimately found it to be lacking a challenging theoretical base without much ingenuity or creativity involved.

He met another professor whose expertise was in chemical physics. The professor was originally working on a novel polymer that could effectively clean optical surfaces. When Scott began working in the lab, the professor visited other professors abroad who were at the forefront of nanotechnology development. They were hoping to effectively quantify the solubility of the nanoparticles they were creating. Scott and the professor headed to the main campus of the
university system to use some of the advanced instrumentation and generated poor, inconclusive results.

Scott was frustrated with the data and poured over it, with no avail, for several weeks. His mentor provided him with some background literature that he thought might help try to explain the phenomena they had collected. After reading a classic paper from the 1940s, Scott realized that the strategy they were implementing was totally wrong and would never result in quantitative, conclusive results.

Based on the information, both theoretical and technical, that Scott had gathered, he devised a possible theoretical solution. Upon discussion with his mentor, the two agreed that the measurement strategy had very solid potential. Unfortunately, there was not an instrument sensitive enough to gather the data. Scott thought it might be possible to build the device. His mentor agreed and provided him with salvaged parts from throughout his department. Scott built the instrument and found that it worked beyond his expectations. This solution was truly a breakthrough in the nanotechnology field.

Scott presented his project, *Determining carbon nanotubes’ thermodynamic solubility*, at the ISEF in the chemistry category. Scott was the category winner and also was recognized by many corporate and governmental groups, winning numerous special awards. Scott achieved the pinnacle of success at ISEF, having his project named one of the top three of the fair, and earning the distinguished title, Intel Young Scientist. Scott was humbled and amazed by his success, but admits it is such a pleasure to be rewarded for doing something that he absolutely loves: authentic research.
Tami is a junior attending a large urban public school in a mid-Atlantic state. Tami is taking a traditional honors curriculum at school. She is enrolled in trigonometry and analytical geometry, Spanish IV, physics, chemistry, English, and AP world history. Honors science students complete research projects annually as part of their coursework.

As a freshman, Tami had a very positive experience in a semester earth science class. Having participated in the science fair process in middle school, she approached her teacher and inquired if there were any other opportunities. Recognizing Tami’s talents in high school, her teacher paired Tami up with a friend at a local university. Tami was able to immerse herself into the lab’s geologic study and was asked to participate in an extensive summer field excursion with a research team in Utah. Excited at the prospect of becoming a field hand and having the opportunity to learn more, Tami traveled with the team. Her job, initially, was to lug materials, help process samples, and enter data. Having gained field expertise during the excursion, Tami was allowed to work independently and started observing geological phenomena. She noticed some unique features, and with the help of the senior scientists, actually conducted a project during her field internship. This was originally not part of the plan.

Tami was able to determine a unique understanding and explanation of these geological features that had not been previously reported in the geologic literature. Returning to school her sophomore year, she prepared the data from this summer project, presented it, and, after winning her regional fair, went to the ISEF. At ISEF, she won her category and was named one of the three overall winners, the Intel Young Scientist.

Tami continued her research in Utah during the summer between her sophomore and junior year, developing a more sophisticated understanding of the features. Her project, On shaky
Tami continued her work the summer of her junior-senior year and plans to present these results this coming year. Tami is now regularly invited to participate in numerous professional meetings and present the results of her research. She feels her science research experience has opened the door to opportunities that she would have never conceived and looks forward to a career in the sciences.

Summary. Eight students participating in the 2007 ISEF participated in this study. Their projects covered a broad spectrum of very sophisticated, in-depth topics, each suited to the individual interests of the respective student (see Table 8).
Table 8

*Summary of ISEF results for subjects*

<table>
<thead>
<tr>
<th>Name</th>
<th>Regional Fair origin</th>
<th>Category</th>
<th>Placement</th>
<th>Special Awards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyle*a,b</td>
<td>Connecticut</td>
<td>Physics</td>
<td>Third Award</td>
<td>None</td>
</tr>
<tr>
<td>Laura*b</td>
<td>New York</td>
<td>Animal Sciences</td>
<td>Fourth Award</td>
<td>None</td>
</tr>
<tr>
<td>Maggie</td>
<td>Mid Atlantic</td>
<td>Behavioral and Social Sciences</td>
<td>Category winner</td>
<td>None</td>
</tr>
<tr>
<td>Nathan</td>
<td>Midwest</td>
<td>Engineering: materials and bioengineering</td>
<td>Category winner</td>
<td>None</td>
</tr>
<tr>
<td>Oliver</td>
<td>South Africa</td>
<td>Computer science</td>
<td>Category winner</td>
<td>None</td>
</tr>
<tr>
<td>Paige</td>
<td>South Africa</td>
<td>Plant science</td>
<td>Category winner</td>
<td>None</td>
</tr>
<tr>
<td>Quincy</td>
<td>South Africa</td>
<td>Energy and transportation</td>
<td>Category winner</td>
<td>None</td>
</tr>
<tr>
<td>Ryan</td>
<td>Mid-Atlantic</td>
<td>Engineering: electrical and mechanical</td>
<td>Category winner</td>
<td>IEEE Foundation, United Technologies Corporation, Seaborg SIYSS Award</td>
</tr>
</tbody>
</table>

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*a
d""
Table 8 (continued)

Summary of ISEF results for subjects

<table>
<thead>
<tr>
<th>Name</th>
<th>Regional Fair origin</th>
<th>Category</th>
<th>Placement</th>
<th>Special Awards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scott</td>
<td>Midwest</td>
<td>Chemistry</td>
<td>Overall fair winner(^d)</td>
<td>American Chemical Society</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>China Association for Science and Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>National Taiwan Science Education Center</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>United Technologies Corporation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Office of Naval Research</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>United States Army</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sandia National Laboratories</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AVS Science and Technology Society</td>
</tr>
<tr>
<td>Tami</td>
<td>Mid-Atlantic</td>
<td>Earth Science</td>
<td>Category winner(^c)</td>
<td>Geological Society of America</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Society of Exploration Geophysics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New Mexico Institute of Mining and Technology</td>
</tr>
</tbody>
</table>

\(^a\)Pseudonym used  
\(^b\)CSF winner attending ISEF  
\(^c\)Seaborg Stockholm International Youth Science Seminar during the Nobel Prize Ceremony  
\(^d\)Overall fair winner is termed the “Intel Young Scientist” and is shared by the top three category winners  
\(^e\)Tami was the Overall fair winner in 2006
Category clustering

As the student interview data were categorized, clusters began to emerge. All category definitions can be found in Appendix I. A sample of categorized data can be found in Appendix J. Clustering of these categories is defined in Table 9. Systematic grouping based on patterns and similarities within and between categories was achieved through a collaborative discussion of peers and science students. Eight overarching axial clusters were developed to describe data across cases. They were: creative thinking, entry point characteristics, reflexive behaviors, the scientist, inquiry strategies, critical thinking, situated learning, and teaching approach.

Most of the category clusters intersect ideas of creativity, inquiry, and situated cognition learning theory. However, some clusters (e.g., situated learning) focus more heavily on a specific concept (e.g., situated cognition learning theory). The eight categories presented here appear to be the most streamlined version of factors without losing clarity for interpretation of problem finding in open inquiry.
Table 9

Axial clustering of categories

<table>
<thead>
<tr>
<th>Category Cluster</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative thinking</td>
<td>1. creativity</td>
</tr>
<tr>
<td></td>
<td>2. flexibility</td>
</tr>
<tr>
<td>Entry point characteristics</td>
<td>1. interests</td>
</tr>
<tr>
<td></td>
<td>2. interests in science</td>
</tr>
<tr>
<td>Reflexive behaviors</td>
<td>1. goal</td>
</tr>
<tr>
<td></td>
<td>2. lesson learned</td>
</tr>
<tr>
<td></td>
<td>3. love of learning</td>
</tr>
<tr>
<td>Inquiry strategies</td>
<td>1. background research</td>
</tr>
<tr>
<td></td>
<td>2. characteristics of the scientist</td>
</tr>
<tr>
<td></td>
<td>3. inquiry</td>
</tr>
<tr>
<td></td>
<td>4. nature of science</td>
</tr>
<tr>
<td></td>
<td>5. problem finding&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>problem finding is listed in both the creative thinking and inquiry strategies cluster because it crossed these two themes.

Note. Category clusters are presented in the order of presentation in the chapter. However, the categories, themselves, are listed in alphabetical order, rather than by use, relevance, or prevalence.
Table 9 (continued)

Axial clustering of categories

<table>
<thead>
<tr>
<th>Category cluster</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical thinking</td>
<td>1. compartmentalization</td>
</tr>
<tr>
<td></td>
<td>2. conceptual understanding</td>
</tr>
<tr>
<td></td>
<td>3. critical stance</td>
</tr>
<tr>
<td></td>
<td>4. deep understanding</td>
</tr>
<tr>
<td></td>
<td>5. evolution of the project</td>
</tr>
<tr>
<td></td>
<td>6. project limitations</td>
</tr>
<tr>
<td></td>
<td>7. reverse engineering</td>
</tr>
<tr>
<td></td>
<td>8. skeptical</td>
</tr>
<tr>
<td>Situated learning</td>
<td>1. application</td>
</tr>
<tr>
<td></td>
<td>2. award</td>
</tr>
<tr>
<td></td>
<td>3. communication</td>
</tr>
<tr>
<td></td>
<td>4. community</td>
</tr>
<tr>
<td></td>
<td>5. comparison</td>
</tr>
<tr>
<td></td>
<td>6. hot topic</td>
</tr>
<tr>
<td></td>
<td>7. new opportunity</td>
</tr>
<tr>
<td></td>
<td>8. opportunity</td>
</tr>
<tr>
<td></td>
<td>9. ownership</td>
</tr>
<tr>
<td></td>
<td>10. professional contact</td>
</tr>
<tr>
<td></td>
<td>11. science fair process</td>
</tr>
<tr>
<td>Teaching approach</td>
<td>1. differentiated instruction</td>
</tr>
<tr>
<td></td>
<td>2. independent</td>
</tr>
<tr>
<td></td>
<td>3. role of the parent</td>
</tr>
<tr>
<td></td>
<td>4. role of the teacher</td>
</tr>
<tr>
<td></td>
<td>5. rules</td>
</tr>
<tr>
<td></td>
<td>6. teacher interests</td>
</tr>
<tr>
<td></td>
<td>7. textbook</td>
</tr>
</tbody>
</table>

Note. Category clusters are presented in the order of presentation in this chapter. However, the categories, themselves, are listed in alphabetical order, rather than by use, relevance, or prevalence.
Creative thinking

Creative thinking was a key feature for student problem finding. In fact, within the scope of this study creativity manifested itself best as problem finding. Students’ defined creativity as the ability and willingness to come up with a new problem or approach a preexisting problem from a new point of view. Questioning and posing new problems seemed to be the essence for the creative behaviors of these student-scientists. Their successes were derived from knowing that there was something new, innovative, and novel to discover, create, or build.

Creativity and problem finding. The majority of students (see Table 10) defined creativity in terms of problem finding. Students also defined creativity in terms of problem solving. Only a few used more of an amorphous definition focused more generally around curiosity and “thinking outside the box.”

Table 10

Definitions for creativity

<table>
<thead>
<tr>
<th>Definition</th>
<th>Problem finding</th>
<th>Problem solving</th>
<th>Curiosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>13</td>
<td>5(^a)</td>
<td>3</td>
</tr>
<tr>
<td>Number of adults</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)one student and one mentor defined creativity in terms of both problem finding and problem solving.
There was relatively little variation between the students, both from CSF and ISEF.

Examples of problem finding as a definition for scientific creativity are exemplified by the following statements:

I guess creativity is, it’s relevant to my science research, is finding a problem that needs to be solved. (Andrew)

I think if someone dares to raise questions about anything you want, then that person must be someone who is creative. Anything can be questioned; just not many people are willing to question everything. (Bobby)

I think creativity is being able to look at a problem and solve it in a new way. Or being able to find a new problem to solve. (Gabrielle)

I’d say that creativity is the ability to come up with different ideas and just have a different notion of things. To come up with something completely original. Something that hasn’t been thought of. (Igor)

The creativity definitely comes in – choosing an idea and coming up with something original. (Laura)

Creativity is coming up with an original idea that nobody’s done before. Or somebody has looked at before and you look at it at your own angle or a new angle. (Nathan)
Creativity, in the hacker sense, is taking something with a purpose and using it for something other than that purpose. That’s not really a very broad definition of creativity.

I don’t know, maybe that is. (Ryan)

I think creativity is being able to, in one sense, take ideas that are already there and either do something new with them or improve them. Also, it’s being able to look at a problem or a research, whatever you’re looking at, in a way that’s different from how other people are looking at it (Tami).

Adults, including mentors and a fair director, also defined creativity as problem finding:

I’d say coming up with novel ideas. Also problem solving. (Ryan’s mentor)

[Creativity is] just being able to come up with ideas for things. Coming up with new ways to do things, new ways to look at things. (Caitlin’s mentor)

Creative thinking is looking at a problem, that’s already been looked at, from another perspective. I think that’s creativity: that’s a creative approach. I think creativity is thinking about a new problem. Maybe the problem is an old one, but you come up with a new technique, for example. Novelty is related to creativity: you do something new. (Gabrielle’s mentor)
Creativity would be explained] probably best is a new approach to solving a problem. You couldn’t get at it the traditional way because of lack of resources, lack of ability, lack of skills. You found another way. That I think is the key to it. (Science Fair Director)

*The novel approach to a problem.* CSF documents, including abstracts and registration paperwork were examined for finalists across the fair to see if there were salient features to the types of projects that were evaluated to be in the upper quartile by the CSF judging panel. Projects fell into one of four categories: (a) literature review, (b) technical, (c) technical with value, or (d) novel approach (see Table 11).

**Table 11**

*Classification of projects and judging designation*

<table>
<thead>
<tr>
<th>Project type</th>
<th>CSF Third Honors</th>
<th>CSF Finalist Projects</th>
<th>ISEF Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature review</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Technical</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Technical with value</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Novel approach</td>
<td>0</td>
<td>6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

<sup>a</sup>the two CSF students who attended ISEF had novel approach projects. They are reported in both columns
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.

Students completing technical projects engaged in experimental inquiry by examining a well known question with well known outcomes. These types of projects often used predetermined procedures and frequently had predictable results.

The finalists’ projects fell into the last two categories: (a) technical with value, and (b) a novel approach to a problem. A project termed technical with value generally examined a phenomenon by standard methods. The student usually was seeking to measure differences in two or more groups by some specific strategy. For example, a student might have measured some environmental phenomenon like water quality and looked at multiple points along a river that might be influenced by different pollution sources. Or perhaps a student was conducting an astronomy project examining how sunspots and solar storms affected radio transmissions in a specific region. There is a level of sophistication associated with both of these examples. Both were collecting technical data which was most likely unique: the data had a unique niche that other practicing scientists might not have been directly observing.

These projects had a level of value because the data had the ability to contribute to the scientific knowledge base in some way. This would be significantly different from a technical project that did not contribute to new knowledge. For example, a project that measured the absorbency of paper towels or a project that tested different types of flour to see which caused muffins to rise best. Although a simple technical type of project might generate a positive learning experience for the student, it would be poorly received at a science fair, where an authentic audience of judges from academia and industry evaluate it.
A project with a novel approach to a problem was generally received better than a project with technical excellence. Students conducting a novel approach project asked a novel question or determined a novel method to solve a preexisting question. Novel approach had a level of creativity and innovation that may not have been present in a project with technical excellence. Of the projects in this study, the majority were described as novel approach to the problem.

During interviews, students easily distinguished different types of projects and identified the nature of a novel approach project. They recognized that a student who conducted a non-novel project might have had a positive experience. However, the novel project students explained that there was a level of innovation that differentiated their projects from those with technical with value. The students articulated the idea, and it was reinforced by a science fair director:

You see so many projects that say the plants will grow better in red light than they will in green light. The red light/green light project will never be a successful [science fair] project because it has been done so many times. We know the answer. You have to search for something that is not already out there. It’s possible to go in depth into something that’s meaningless, and that won’t be a good project. It has to be innovative and novel. (Laura)
I saw a lot of projects that were interesting, but they all had to do with like measuring the water quality of a specific building. Measuring the way sewage flow worked in a specific river. And while I think that that is really interesting, those projects are all taking methodology that is out there already and reapplying it to a specific study. And they are great as studies, but in terms of experimental development, it’s not like they are finding out anything that others could build on. Knowing the pollution quality of a river is important – it’s a good thing to know. But it’s not like measuring it is anything new.

(Gabrielle)

A science fair director, when asked to differentiate between finalist projects and truly innovative projects stated the following:

I think [the success of a project comes down to] the students’ ability to sell the idea. Maybe more so than the idea itself. Although in many cases, the differentiating factor is the creativity that is apparent in looking at the work, as opposed to the work. If you had just an absolutely outstanding project that went through all of the scientific method, all of the controls, whatever it took to do the work and perfect laboratory routine. And that sort of goes against a loosely organized project, which is a brand new idea. The brand new idea is going to win (Science Fair Director).
Students who conducted novel approach-types of studies indicated that there was a level of sophistication for their projects that made them stand above a technical project:

I love coming up with the ideas. I love it on the day when I realize, “Hey I can do it like this, and I don’t think anyone’s done anything like this before.” (Ryan)

I think being novel is important, because it sticks out in people’s minds. People say, “Oh, OK, she must be doing something fantastic, if it’s on the cutting edge.” (Jessica)

The thing about my project was, I think it was sort of elegant. The way I went from a theory in a book and a theory that is used for other things like proteins and polymers and then applied this theory in a slightly different way towards nanotubes and was able to come up with my own experiment, design my own instrument. I think it was just an elegant process of going from the theory to the final conclusions and making a new discovery (Scott).

You can be a good scientist, and you can be thorough without being creative, but I don’t think you’re actually going to make anything that will change the world, or discover anything, or think of anything if you’re not going to be creative and think differently (Tami).
But creativity is what makes an engineer and scientist better than a technical person. If you can understand how stuff is working, that’s half the battle. But if you can try to explore and make new things happened, that’s what makes an engineer successful (Eric).

Mentors thought that the novel approach would often be challenging for students, and, at times, discouraged it. They often felt that it was either too much work for the student or the student might not have the prerequisite knowledge or skill set to accomplish the task. However, those students who chose to pursue a novel approach project were successful and did meaningful, valuable research:

Coming up with a significant question I imagine would be the really most difficult part of what a kid could do. (Scott’s mentor)

So she’s doing something new. That almost, in itself, makes it good, I think. She’s addressing a question that no one has addressed before. A lot of people try to repeat things others have done. I’m not terribly excited by doing these types of experiments. And neither is she. (Jessica’s mentor)
One mentor actually described how he allowed students to go through the process of the novel approach, because of the benefit he felt it had for his students:

Many times I have to hold myself back and say, “I would do it this way.” And I try not to do that, because, (a) I don’t know if I’m always right, and (b) even if I know I am right, I know from my own experience that there is a huge advantage to figuring something out on your own, as opposed to having someone tell you how to do it. I think it is an advantage in teaching you how to think, and it’s an advantage because you’re gaining self-confidence. (Gabrielle’s mentor)

Mentors recognized they could not provide students with projects or force them to do what they, as mentors, wanted, because the student development of a novel idea would not happen:

We used to say with my Ph.D. advisor that he gave us enough rope to hang ourselves. And I really do that same thing with my students. I don’t baby sit them and tell them to do this do this do this. You really have to be an independent thinker (Scott’s mentor).
A science fair director verified that the novel approach project always had an advantage over the technical excellence project:

Answering a new question, that in real winning projects, is a question that the student comes up with. It should be a very novel question that gets researched. A mentor might inspire it. It might be the result of discussions with a mentor. It might be the student’s own research into some topic that causes him or her to pose a new question that hasn’t been asked before or a new way to look at an issue. That, I think, is the key to this whole thing (Science Fair Director).

Documents from national and international popular press about the ISEF verify that novel approach projects are the dominant type (see Table 12). Of the 98 articles retrieved from the Lexis Nexis Database, almost everyone discussed students and their projects. Only 9 (9%) were solely about the event and 14 (14%) reported student awards. In terms of student projects, 61 (62%) referenced novel approach projects, while only 16 (16%) discussed projects of technical excellence.
Table 12

Content of popular press articles about ISEF (2003-2006)

<table>
<thead>
<tr>
<th>Content</th>
<th>Number of articles</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel approach projects</td>
<td>61</td>
<td>62(^a)</td>
</tr>
<tr>
<td>Technical with value projects</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Awards to students</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Event happenings(^a)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^a\)one article discussed both awards to students and events happening. Therefore calculations of percents were based on 99 total articles whereas the total column reports the number of occurrences.

\(^b\)most of the event articles were about experiences for students. For example, attending a seminar with Nobel Laureate scientists, or social mixers at a science museum.

In summary, creative thinking as demonstrated through a science fair project, best manifested itself as problem finding. The best types of entries were novel approach projects. Good projects often focused on observing and analyzing phenomena. However, great projects offered a novel solution to a problem.
Entry point characteristics

Students’ temperament for science research. The majority of students in this study (n=17 of 20) conducted their studies under the auspices of a formal school program. Ten of these students participated in a formal science research program or course, dedicated solely to science projects. Five completed a project as a requirement of a traditional science course in which they were enrolled. Two completed the project as part of an independent study program. Of the three who did not complete their research project in a formal school program, one (Bobby) was an exchange student attending a private school, another (Scott) was home-schooled, and the last (Quincy), attended a private school in South Africa.

Therefore, there was a high degree of self-selection for completion of a research project. All students participating in formal research classes elected to be members of their respective program. Eight of the 10 took a traditional science class in addition to their research class. The students that completed a project as part of their formal science coursework expressed a strong desire to achieve at a level higher than the expectations of the school or class:

When I got to earth science, I had really liked [the content of the class]. A science fair project is a requirement if you took an honors class. I asked my teacher if there [were] any more opportunities I could have. Or how can I go further with this. And that’s how it all started up. (Tami)
One of our requirements every year is to do a project for the local science fair. So every year, a lot of people are looking for science ideas, and basically I wanted to put more effort into it. You can actually get away with it pretty easily without a lot of work, but I wanted to put more effort because I enjoyed it. (Nathan)

Ever since I was little, I’ve been building stuff. I love talking about the stuff I build. And now I can go somewhere and people actually want to hear about what I’ve built. And I’ve been to ISEF two times. There’s a bunch of electronic projects every year from that lab to go to our regional fair. But they’re usually pretty bad. (Ryan)

In addition to survey data and semi-structured interviews, the USRT Scale was used to measure students’ temperament for science. Standardization of USRT scores were based on college freshmen science majors (n=274) and group score comparisons are reported in Table 13 and Figure 9. Individual scores for students participating in this study are reported in Table 14. Construct validity was achieved because the general population of science students, most of whom have not had a authentic science research experience, had a wider distribution of scores with a lower mean than the students in this study, the majority of whom completed high-quality independent projects.
Table 13

*USRT score standardization using college freshmen science majors compared with high school students participating in this study*

<table>
<thead>
<tr>
<th>Descriptive factor</th>
<th>Standardized scores</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>274.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Mean</td>
<td>19.73</td>
<td>23.60</td>
</tr>
<tr>
<td>Median</td>
<td>20.00</td>
<td>24.00</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>6.15</td>
<td>5.34</td>
</tr>
<tr>
<td>Standard error of measurement</td>
<td>±3.30</td>
<td>±3.30</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>37.00</td>
<td>37.00</td>
</tr>
<tr>
<td>Percentiles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>15.00</td>
<td>19.00</td>
</tr>
<tr>
<td>50</td>
<td>20.00</td>
<td>24.00</td>
</tr>
<tr>
<td>75</td>
<td>24.00</td>
<td>26.75</td>
</tr>
</tbody>
</table>
Figure 9. Boxplot distribution of USRT standardized scores compared with students in this study.
Table 14

*Summary of USRT Scores for subjects*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Total Score</th>
<th>NCE%&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>17 ± 3.30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.6</td>
</tr>
<tr>
<td>Bobby</td>
<td>19</td>
<td>50.9</td>
</tr>
<tr>
<td>Caitlin</td>
<td>18</td>
<td>44.0</td>
</tr>
<tr>
<td>Dana</td>
<td>19</td>
<td>47.5</td>
</tr>
<tr>
<td>Eric</td>
<td>23</td>
<td>61.3</td>
</tr>
<tr>
<td>Felipe</td>
<td>29</td>
<td>81.9</td>
</tr>
<tr>
<td>Gabrielle</td>
<td>21</td>
<td>54.4</td>
</tr>
<tr>
<td>Hannah</td>
<td>25</td>
<td>68.1</td>
</tr>
<tr>
<td>Igor</td>
<td>22</td>
<td>57.8</td>
</tr>
<tr>
<td>Jessica</td>
<td>29</td>
<td>81.9</td>
</tr>
<tr>
<td>Kyle</td>
<td>26</td>
<td>71.5</td>
</tr>
<tr>
<td>Laura</td>
<td>27</td>
<td>75.0</td>
</tr>
</tbody>
</table>

<sup>a</sup>NCE% (Normal curve equivalent) scores based on instrument standardization using freshmen college science majors (n=274).

<sup>b</sup>All scores are subject to a standard error of measurement of ± 3.3
Table 14 (continued)

Summary of USRT Scores for subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Total Score</th>
<th>NCE%&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maggie</td>
<td>17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.6</td>
</tr>
<tr>
<td>Nathan</td>
<td>26</td>
<td>71.5</td>
</tr>
<tr>
<td>Oliver</td>
<td>22</td>
<td>75.0</td>
</tr>
<tr>
<td>Paige</td>
<td>26</td>
<td>40.6</td>
</tr>
<tr>
<td>Quincy</td>
<td>26</td>
<td>71.5</td>
</tr>
<tr>
<td>Ryan</td>
<td>37</td>
<td>99.0</td>
</tr>
<tr>
<td>Scott</td>
<td>28</td>
<td>78.4</td>
</tr>
<tr>
<td>Tami</td>
<td>15</td>
<td>33.7</td>
</tr>
</tbody>
</table>

<sup>a</sup>NCE% (Normal curve equivalent) scores based on instrument standardization using freshmen college science majors (n=274).

<sup>b</sup>All scores are subject to a standard error of measurement of ± 3.3

When compared to the instrument’s standardized mean average, 15 of the 20 subjects (75%) scored higher. Of the 15, 10 were in the top quartile (50% of the total sample), and 1 was above the 99<sup>th</sup> percentile. There did not appear to be a difference between top CSF students and ISEF students in their temperament for science research. The majority of the students had an affirmative indication to their positive temperament for science research, both by the USRT and through their interview comments.
Previous experience. Research in science is often very specialized. Professionals have very distinctive areas that they study, even within fields. Rarely would a scientist classify him or herself as a biologist, or even a geneticist. Rather terms like bacterial geneticist, or *Drosophila* geneticist, or proteomics specialist would be more commonly used. Thus, there is a distinct characteristic and description of these researchers: their area of expertise is narrow and focused. In order for some students to conduct sophisticated projects, they, too, needed to develop specialized expertise.

Often this expertise came through some experiential situation that occurred before the problem finding experience even began. Some students engaged in cognitive apprenticeships, working in an internship-like position to gain knowledge, skills, and dispositions to research in a specific field. This experience gave them the background knowledge and understanding to ask questions that others without the expertise would not have even conceived. In essence, they learned things they never knew they never knew.
Some of these students, through their research experience progression, became successful in a situated setting by advancing from neophytes or novices to having some level of expertise. This process became critical to their success because they developed the necessary capabilities to conduct a sophisticated project. The process may have taken place in a formal research setting, may have developed from years of experience conducting research, or may be a facet of practical life experiences:

And that’s really where, I mean, since my freshman year project, I’ve made incredible leaps forward. This project would still take me a while to do, but my freshman year project I could actually do now in a day, because there wasn’t much to it. So I just think it’s that and so much more complicated. I can see as I’ve been getting older how I can look at something and how much clearer it is to me than it used to be. (Ryan)

Ninth grade, I did a project that studied the effects of albino fruit flies and immune responses and wound healing, which was basically a disaster. But it taught me the basics. It was the first time that I worked with *Drosophila*, and I’ve worked with them ever since. It was a good “crash course” in research. (Maggie)

So I think, just doing things throughout my life, building things in construction and making things, just doing projects at home and building things has helped me be careful and taught me how to precisely do these things in the lab. (Scott)
What I found is that doing [a project] in my junior is actually beneficial because I was very directed more so than I would have been if I hadn’t had the knowledge I had learned in the two years of science that preceded it. (Kyle)

And the longer you do projects, the more experience you get. I guess time is what I would say, mostly, and trial-and-error and things that you learn from that. Learning from your mistakes really benefits. And really having the luxury of background knowledge and luxury of knowing what will and won’t work is what makes the difference. (Gabrielle)

I’ve built computers a lot. I’m building another one and I guess I just spent a lot of time around cooling systems naturally. Really, in the past, I previously looked at circulating mercury. That really was the precursor to this project. About a year ago, I was using a propane torch and heated up glass tubing, and started making another type of pump. I tried to get mercury. That didn’t turn out so well. (Nathan)

We cleaned the Hope diamond with this polymer. We cleaned the Kech telescope in Hawaii, the biggest telescope in the world, with this polymer. The Hubble telescope. It cleans surfaces so well, better than any other processes. So I was excited to work on that project too, because I felt like, wow, I can actually be improving this product that’s just an amazing, amazing polymer. (Scott)
I spent a semester out in Colorado working at the High Mountain Institute. And I got really interested in environmental studies and environmental science and when I came back home, I really got into it. (Igor)

**Reflexive behaviors**

**Motivation.** Many students described their motivation for conducting a project describing their passion for scientific inquiry. Their descriptions often focused on descriptive characteristics of the creative scientist and their perception of the rewarding experiences associated with it:

The things that I knew, and the predispositions that I had, the foreknowledge that I had, was what led me to do what I did. (Kyle)

Students associated this motivation with their internal drive and sense of wonder and curiosity:

I have an extreme amount of curiosity. If I’m interested in something, I want to find out everything about it. I’ve always been a good student. I think of myself as an intelligent student, but research is different. (Jessica)

I think you always need to be curious and you should never, never be afraid to raise new points or do something that people haven’t done before. So I should always be brave to raise new questions, be brave to think, and be a creative person. (Bobby)
Students also appreciated the opportunity to conduct a project that did not necessarily mirror the type of learning that occurs in a standard classroom. They described the opportunity as more exciting because they were participating in a different type of inquiry: one that allowed them to be independent, self-reliant, and creative. Their projects had legitimate real-world application, with a legitimate audience, not just a classroom teacher:

It was pretty intellectual, but I think actually working with my hands in the lab, building the instrument, and taking the data. You have to be creative. You have to have a very intuitive feel for whatever topic you’re studying. (Scott)

It’s not something – it’s not an SAT-type of intellect that it takes to do research. It’s a different kind of sense. (Maggie)

You need to be passionate about it. You need to have the right attitude for it. You need to commit yourself to it. That, combination along with having a really great project idea, will really make you successful. (Jessica)

The students also described the importance of valuing their work for its own worth, not necessarily to win an award:

You mustn’t do a project because you think you can win [a science fair] or you think it’s going to work. You must really do a project that’s in your interest and that you are really passionate about. Because it takes a lot of hard work. (Paige)
I got $50 from the Army, a bond or something at the special awards [ceremony of the CSF]. I felt proud of my project even before that. I had learned a lot. Some of the stuff was really complicated. I was proud that I had my own ideas and was able to choose this. It felt that these were skills I could apply later. (Hannah)

Mentors also desired to work with students that were self-motivated, self-directed learners. Their role, as a facilitator of student research, was enjoyable because of the independence displayed by the students:

I want to be able to will work with the student who has some kind of directive within themselves. It comes from some internalization on their own. This is important to them, and I suspect that's what the biodiesel is to [Eric]. (Eric’s mentor)

Whenever he doesn’t know something, he will go away and then find the information on his own, and has the ability to self-learn. Basically, any concept he decides is important enough to know. (Kyle’s mentor)

[Scott] really did the work that I would say is the equivalent to a Ph.D. student in chemistry or physics in a matter of a couple of months. I feel like it’s really on a peer level that I interact with [Scott]. And I think his math is a little better than mine, actually. (Scott’s university mentor)
Descriptions of self. Students were asked to describe themselves, in terms of their science project, using three different adjectives each. The question, “Name three adjectives that describe you as a person in terms of your science project,” elicited responses, and were followed by elaboration of their definitions. The descriptions fell under three major categories that were in alignment with Renzulli’s three-ringed conception of giftedness (1986). These categories were (a) above average ability, (b) creativity, and (c) task commitment (see Table 15).

A very small subset of the adjectives (n=3) did not meet the criteria for any of the Renzulli domains. However, these three responses all related to the applicability of the project to an audience or community outside of the traditional school setting, which is a goal of gifted behavior (Renzulli & Reis, 1986).

Table 15

Student adjectival descriptions of themselves

<table>
<thead>
<tr>
<th>Students</th>
<th>Above average ability</th>
<th>Task commitment</th>
<th>Applicability to an audience</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSF Third Honors</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>CSF Finalists</td>
<td>0</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>ISEF Category Winners</td>
<td>1</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>25</td>
<td>32</td>
</tr>
</tbody>
</table>

The majority of the adjectives fell into the creativity (40%) and task commitment (52%). Students, almost exclusively, did not refer to their ability when describing themselves. In their
creativity, they described their problem finding and problem solving. In their task commitment, they described their insatiable drive to come up with solutions:

I think the first one is creative. I think creativity for me was the paramount, because in solving any problem, a creative solution has to be reached. (Quincy)

The ingenuity is when you are faced with a problem you figure out how to get around it. I didn’t work in a lab. So I [did] a lot of things due to equipment I didn’t have. Things I had to get around. A large part of my project is separating out a protein. And I don’t have the gels available that I could have done that with. So I used chromatography instead. It was less expensive, so it turned out to be a good thing anyway. (Laura)

I guess dedication would be one. I spent a lot of time on that. Pretty much dedication because I really never gave up on the project and eventually, it worked. There were a lot of points where I probably should have. (Nathan).

Thorough. I’m very, I don’t know how to describe it, except in a condescending way, but [I’m] OCD with all of my work and everything. I write every single detail down and keep really detailed notes, so I think that that’s helped a lot. Because when something doesn’t look right, I’m easily able to go back and figure out. Oh, I have a decimal point 10 pages of data ago that I messed up. (Tami)
Scott discussed, not only working consistently, but maintaining that diligence even when the challenge of a situation made it difficult. Scott noted that he needed to consider both the project challenges, but the personal ones as well:

I’d have to say perseverant. I think there were a lot of points where maybe some other people, maybe even myself, if I were in a different mindset. Maybe I would have given up or just been so stymied, that I would have just thought that, oh I don’t think I’m going to get through this problem. . . And even when the problems were hard and I wasn’t getting anywhere, I still came in and I still thought about it when I was sick or when I wasn’t feeling well. I still worked and I still tried and I continued to proceed and make more progress (Scott).

Table 16

*Sample adjectives in each category*

<table>
<thead>
<tr>
<th>Above average ability</th>
<th>Creativity</th>
<th>Task commitment</th>
<th>Applicability to an audience</th>
</tr>
</thead>
<tbody>
<tr>
<td>smart, confident</td>
<td>novel, creative,</td>
<td>determined, focused,</td>
<td>valuable,</td>
</tr>
<tr>
<td></td>
<td>ingenuitive, skeptical,</td>
<td>persevering, lazy,</td>
<td>environmental,</td>
</tr>
<tr>
<td></td>
<td>curious, innovative,</td>
<td>responsible, studious,</td>
<td>public</td>
</tr>
<tr>
<td></td>
<td>curious, adaptable,</td>
<td>passionate, dedicated,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>eccentric</td>
<td>intrepid</td>
<td></td>
</tr>
</tbody>
</table>

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Mentors also tended to describe their mentees primarily with task commitment adjectives, but would more readily make reference to the students’ above average ability (see Table 17). They generally described the students’ work ethic when considering descriptors.

Table 17

*Mentor adjectival descriptions of students*

<table>
<thead>
<tr>
<th></th>
<th>Above average ability</th>
<th>Creativity</th>
<th>Task commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>4</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>Sample adjectives</td>
<td>Brilliant, smart,</td>
<td>clever, creative,</td>
<td>tenacious, energetic,</td>
</tr>
<tr>
<td></td>
<td>ability to learn</td>
<td>intuitive</td>
<td>diligent, committed,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>motivated, persistent,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>responsible, frustrated</td>
</tr>
</tbody>
</table>

Kyle’s mentor describes Kyle as brilliant. Even within his explanation of above average ability, creative factors emerge:

In terms of brilliant, he basically took a hunk of iron, or a microscope, that really had very little use; an older IR microscope. And he really self-educated, self taught all the concepts of fluorescence and fluorescent microscopy and took that old piece of equipment and basically built it into something that was cutting edge in terms of technology and application. (Kyle’s mentor)
Ryan’s mentor discussed Ryan’s creativity in terms of the problem finding and problem solving encountered during his engineering feat:

Definitely creative. Creative in the sense that there were definitely obstacles to overcome. He had to figure out how to do things and he’d have the oscilloscope here and he’d be looking at the waveforms. So he’d come up with some neat investigative techniques to figure. He really reverse engineered this DLP [computer chip], because [the manufacturer] doesn’t give out much information on it, because they want you to use it with their own chips. (Ryan’s mentor)

Eric’s mentor discussed the significant amount of time that Eric dedicated to his project:

Energetic. He was here just about every day for at least a half an hour to an hour. He’s constantly looking for new kinds of things to do, more physical properties to measure, different techniques to put towards the biodiesel. Just to look to elucidate his characterization skills more. So I find that makes him very strong (Eric’s mentor).
A science fair director confirmed that task commitment is a common standard feature of those conducting superlative projects:

In all cases, they are all highly committed to making it happen. They’ll put in whatever hours it takes to reach their goal. There’s no doubt about it. The commitment is with true zeal. You don’t need someone flogging them. They’re flogging themselves. They’re driving themselves as hard as they possibly can to reach their goals. They’re goal driven people, clearly. That’s a common theme in all of our successful students. (Science Fair Director)
Inquiry strategies

The nature of scientific inquiry. Perhaps one of the most striking similarities between and among students was their understanding of the idiosyncratic nature of conducting scientific research. The students did not feel there was a standard formula to arrive at a solution. Rather, they developed logical, analytical, and creative strategies to solve problems. The students did not choose to define their problem finding or solving as a step-by-step sequence. Their questions drove their research, not some predetermined prescriptive method of approaching scientific inquiry:

Research in itself is a different animal. You have to approach it differently. A thousand things can go wrong with it. You have to look at it from so many angles. You need to know how to look at it in the right fashion and know how to approach it. (Jessica)

A lot of people have the perception that if you’re a scientist, you work very much in a linear fashion. But I’ve found that the greatest scientists are those who are able to think, actually. And who can draw knowledge from a number of sources. I find that when you’re doing science, you have a single problem, but there may be 20 ways to approach that problem. And someone who has that liberal balance: that more creative element to him, compared to the scientist who only has that tunnel-vision and can only see things one way. (Quincy)

It’s just a great feeling to have this problem that you’ve been working on. Stumbling with. Being frustrated with. And then finally solving it. (Scott)
I don't understand everything and I probably never will. I almost certainly never will. But everything is capable of being understood, because there are rules and laws which govern how they work. (Kyle)

I think sometimes it was frustrating because there’s no right answer. No real direction you should be going in with the project. So a lot of times when I was working through my experiment and how to set it up, it would be tough, because I wouldn’t have any idea if I was on the right track or not. Or if what I was doing would eventually become productive. (Gabrielle)

It's just a given, because as your experiment progresses, you’re going to come to new conclusions and you’re going to see new things that you wouldn’t have thought you’d see. (Felipe)
Forms of inquiry. Through this sophisticated understanding of the nature of science, students were not bound by the confines of expectations to follow a prescriptive methodology. They were certainly not bound by a hypothesis-based testing strategy. They utilized multiple forms of inquiry to clarify their ideas and instead, they did what they thought was necessary to answer the questions that interested them:

So I think that involves a lot of quote-unquote three-dimensional thinking than regular schoolwork that we are doing at this point. Because it requires a more holistic approach to solving a problem. It’s a lot more like real life, I think. (Gabrielle)

So I think I spent a long time on research and consulting before I actually began my lab work. So that might be something that happened that helped me to do better lab work, instead of doing some random work. So that makes my project as a whole: it flows very well from beginning to end. (Bobby)

I have methods, I have procedures, I have results, I have ideas of what’s going on. So it was an all-you-can-eat-hands-on buffet. (Eric)
Background research. Pre-experimentation background research, in order to build a knowledge base, was a common, critical factor for students. Many used multiple resources: online databases, university libraries, books, experts in the field:

There was an online tools-type thing that deals with different types of cooling technology. There was an article on pumping liquid metal. Usually they do it with liquid sodium. That’s basically where the idea came from. (Nathan)

That [were] a lot of Internet searches. I didn’t really get into any bookwork in the beginning. I was just mainly thinking of the project and what to decide on. There was a little bit of theory work. (Oliver)

I actually went to many department stores and malls to look at the products and buy some products that people have made. I also searched online for what ideas people have to solve this problem. So, basically, I wanted to have as broad an image as I could of what people have done. Then I could figure out a new way that no one has ever thought about. (Bobby)

So on my vacation, I went and visited the [aloe vera manufacturing] factory. I called the people before and asked if I could come and do some interviews with them. So I talked to a lot of people there. So they gave me a lot of references to farmers that have been using this. I found those farmers and talked to them. (Paige)
**Situated learning**

*Ability to communicate well.* Students conducting research have an uncanny way of being able to communicate their needs effectively. They interact, not only with their peers and teachers, but also with professionals in academia and industry. Some build mentorship-partnerships with these adults, some only seek information to clarify their understandings or ideas. They demonstrate that there needs to be involvement with a topic or area of interest to ask a good question, to be engaged, and to learn well:

> Then I asked my teacher and also some college professors. I asked their ideas – I asked if my idea is practical or if there is anything that could be improved to make the product have a better quality. It is very hard to know everything that goes on in science. So I think to talk to as much different people as you can is really helpful for a project. (Bobby)

> My strength lies in being able to communicate with almost anyone in this small community. I've gotten into numerous talks with people about different alternate fuel types. I would not have been able to do this as effectively if I hadn’t done a project. (Igor)

> And ever since this research began, you have to talk to people. You have to be able to explain yourself no matter what you’re saying. So I think a huge part of the research for life, in general, has been communication. That’s definitely something that I’ve been able to improve upon for myself: that I don’t think a lot of people have the chance to do. (Tami)
Interaction with other people, sharing ideas with other people, that causes me to be creative. I get my ideas from them. (Andrew)

This effective communication ability transcends the problem finding stages. Students can communicate their problem solving effectively to others. The science fair director explains top students’ ability to communicate at the fair:

In terms of oral communications, the ability to expand on the idea and fill in the blanks really quickly in a way that conveys the idea to you and excites you, makes a huge difference in the success of the student and the project. It’s my experience, in terms of the top students that we have, one thing is for sure. If they don’t go on in the sciences and engineering, they will probably go on to careers that depend on their strong communication skills, because they have them. That’s almost invariant. (Science Fair Director)

*Applying knowledge.* Students recognize that the knowledge they are gaining from an open-inquiry project is often more sophisticated than a traditional academic class. The information they seek and learn transcends isolated facts of a textbook, because it is in context. The information has relevance to both them and the community of practice:

I could work a complex equation on paper or a computer program and it appeared to work, but then I had to design a system that [would] be able to be tested on the ground and actually prove and confirm the results. (Oliver)
The concept of being able to discover something and really, because I had worked in the past, and that was really dry, and textbooks. But this is really getting in there and doing something, so that is really appealing to me. (Maggie)

If you’re learning in the science class, you’re just learning about other people’s conclusions, and other people’s data, and stuff like that. So I was actually able to go and do my own stuff instead of learning about other people’s. (Felipe)

[Non-research students] don’t realize the other parts of [research and self reward and] they don’t fully realize their capacity until they conduct a science project. So they learn a concept in physics, but they will think, “This is not really useful. How am I going to use this?” And I’ve learned the same concept in physics and I’ve used it and gone and applied it in building a rocket. (Quincy)
Application of the research and relevance to the greater community. As students designed and executed their research, they recognized that it should have value beyond the classroom, teacher, or school walls. In other words, their projects had authentic audiences: real people or organizations that would value the information that was generated from the project. This community was defined in different ways by the students, depending on who would benefit from the research: a local environmental organization, the medical field, the computer gaming industry, the space administration, or genetics researchers, to name a few:

[My study of the chapparell ecosystem is] very interesting, and also it relates to environmental issues, which a lot of people are very interested in nowadays. (Jessica)

[My method to effectively isolate the anticoagulant for the treatment of horses is] also something that’s practical. I can see me using it. Even personally, the people that I know who horseback ride with me. It’s something that could actually be used. It’s actually needed for horses. (Laura)

And [a local farmer] started using aloes, and since then, he hasn’t lost one cow since then. He hasn’t used any chemicals, just aloe. His farm is doing very well and he’s making a lot of money. It’s important that my project is valuable to people in my area. (Paige)
If you can use paper repeatedly, this would avoid using too much wood or using too much energy to recycle it. That’s the ideal part. I thought maybe I could make paper that I could use repeatedly, and maybe I could use water [as ink], because water is very environmentally friendly. (Bobby)

What we're trying to do is grow the corals as quick as we can under the conditions that will make them reproduce the fastest. We can take one colony and then take them out and give them to other aquarists. So less and less colonies will have to be taken from the wild and more are being aquacultured. (Felipe)

One student summarized the applicability of projects well. The project had to have an authentic audience, but may not be the be-all-end-all of research done in a field:

You need to find a question, to a certain degree, that is relevant, and something you feel can be productive. What I mean by relevant is that your research is part of the bigger picture, because even at a high school level, you’re not going to be able to cure cancer. The conclusion and results from your project could at some point be applied to another field and used by some other researcher. (Gabrielle)
A mentor clarified the importance of the applicability of a student’s project. He elucidated upon the idea of creativity and its relation to applicability:

The creativity in science is that you have got to take a concept and make it practical. In the process of making it practical, you can bring a relatively new concept, or a new concept that has usefulness. To bring it to the light such that it will make our lives better (Eric’s mentor).

**Critical thinking.**

*Specialized understanding.* When students developed problems using a creative, innovative approach to inquiry incorporating situated learning strategy, they often demonstrated a sophisticated understanding of concepts. First and foremost, they developed a complex understanding of the content related to their project. This understanding was often much more specialized than the content knowledge associated with a traditional science class and often incorporated traditional knowledge and experiences. The students explained their projects and their ideas using a refined, scientific vernacular:

The chaparral plants actually help to stabilize the environment. The unique characteristics of the chaparralaral are what drew me into it. Wildfires promote their growth. I thought that was so – almost like a paradox. (Jessica)
[I’m] developing a medication that can help horses with navicular disease. Because it is incurable. It's a degenerative condition. It evolved to actually becoming an anticoagulant. (Laura)

Because last year I worked with Prozac in fruit fillies. So I knew enough about serotonin in the fly to know that this wasn’t a coincidence. (Maggie)

I knew the chemical nature of the oil. I knew other techniques – calorimetry, gel point – what chemically was happening, viscosity – I understand all the units. I understand the physics aspect. I also understand the chemistry aspect. (Eric)

It makes sense to work with zooanthids because they’re hearty corals, and they're really popular within aquarists. So a lot of people want them. (Felipe)

However, a lot of corrosion occurs at very high temperatures. The cesium, it wasn’t really viable. Liquid metal pumping has been tested before, which is where the pump came from. But that use was not really for cooling. Really, in the past, I previously looked at circulating mercury. That really was the precursor to this project. (Nathan)
In rocketry there is an ingredient which is called ammonium perchlorate, which is very
difficult to find in South Africa. But I came with the idea, that OK, adding ammonium
perchlorate, what other substance can I use for that? For me, it was looking for another
oxidizer, but it has to be common, and it so happens that we had a lot of potassium
nitrate. (Quincy)

Stuff that I’ve done, like reflowing a VGA chip, or like soldering surface
nanocomponents by hand that are that small, or floating something that complicated in
VHDL, or getting something that massive to spin stably. Just like the things leading up to
making my project work were complicated in themselves. (Ryan)

Deep understanding. Although students had a high content-level understanding as they
developed and carried out their projects, they also understood the nature of their projects viewed
through different lenses. This deep understanding usually went beyond scientific knowledge.
This was more of a conceptual understanding with scientific, social, political, interpersonal,
theoretical, and practical realizations. These students saw the big picture, beyond the scope of the
scientific aspects of the project:

Initially what made it stand out was that these seeds benefit from their ecosystem being
burned down. That’s the kind of cleansing process that it goes through. It can be applied
environmentally. (Jessica)
No one had ever found this before, so I had to go back and look at what was happening. And from what I can figure out, it makes sense chemically, and I don’t know why scientists have never picked up on this. (Maggie)

The first thing was cost. I wanted to really reduce my costs [for the fuel I developed,] having the goal of making space more accessible to a lot more countries. Particularly for their safety. Having considered cost and safety, another critical issue was environmental sensitivity. (Quincy)

My results, particularly my gel point results, [that say] that you could use biodiesel at about five degrees Fahrenheit, were hugely important to making the field have a practical use. Because, most alternative fuels aren’t really practical. That’s why when they’re not used very often. (Eric)

So I looked through textbooks, and I looked through journal articles and then I finally realized that this method, this dynamic light scattering, wasn’t the correct approach. And actually it wouldn’t give you any information about solubility. So that was really my start, my beginning of working on this project (Scott).
The fact that ticks can’t form a resistance to this is a very, very good point. Each year, farmers have to switch to a different chemical on their farm, because ticks keep building a resistance to it. With this product, you don’t have to keep changing it, because ticks can’t build a resistance to it. Also, you don’t use any harmful chemicals that are bad for the natural environment, so that’s also a bonus (Paige).

*Reverse engineering.* Because students often lacked the worldly experience of domains of science that a formally trained scientist would, they often had to critically and creatively figure things out without personal expertise or experience. This critical process came in the form of working backwards from what is termed reverse engineering. Reverse engineering, more frequently associated, but not limited to the engineering field, 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 something apart and analyzing its workings in detail (Rekoff, 1985). Reverse engineering, within the scope of inquiry and creativity, took the role of knowing or having information and decoding for a useful purpose within the scope of a project. Students commented on the significance of reverse engineering, sometimes using the term, and other times describing it:

I had to reverse engineer my project. For the past four years I started with my need and my knowledge base. Then trying to figure out OK if I do this with what I already know what’s going to happen? No one had ever found this before, so I had to go back and look at what was happening. (Maggie)
And sometimes the amount of expertise that I had to gain before attempting the project was also quite a challenge, i.e. learning CAD software, handling composite materials, learning how to give effective presentations in order to get funding. (Quincy)

Like what I did with reverse engineering the DLP. The way that I did it. If I wanted to solder the VGA chip and do it the proper way, I would have had to have bought a $10,000 reflower. I bought a $50 toaster oven. I wrote some programs and made it act like a reflower. (Ryan)

I try to figure out simple ways to do complicated things. I think of taking complicated problems and breaking it down. Thinking of some sort of trick I can do to the problem to make it easier. Or just try to think of any possible combination of ideas I could put together. (Scott)
A science fair director who is a multi-patent-holding research engineer comments on reverse engineering and students:

Well that’s how all of us learn how things work. I think it’s that simple. Why do they approach things that way? That may be the only way. We look at things as black boxes. You have something you don’t know what mechanism is inside the box, but you apply stimuli and look at its responses, and develop a model based on those relationships. I think that’s a very common denominator in all discovery-type work. I think some of these students don’t have the necessary experience, or expertise, or tools, or training, or resources to do certain things. And because they don’t, they have to come up with alternative ways to do things (Science Fair Director).

Teaching approach

Role of parents in the problem finding process. All students reported interaction with adults as part of the processes of problem finding and problem solving. A summary of the roles of parents can be found in Table 18. The majority of students accessed their parents in a utilitarian fashion. Parents were often involved in the mechanical processes of editing work, helping with layout of posters, or listening to talks. This role took place, generally after the problem solving was complete and the student was preparing to report the findings of the research to the greater community:

They offered great advice and assistance in the designing and making of my poster.

(Bobby)
She drove me to the JSHS. (Gabrielle)

Mainly my mother helped me practice presenting and answering questions about my research (Scott)

Even parents who had professional expertise in scientific or engineering disciplines were generally utilized for menial tasks:

My mom helped pasting onto my poster board. (Andrew)

He looked at my paper and listened to my talk. (Felipe)

However, parents also provided support and encouragement to students. The support often was emotional and financial:

I’ve always built things and experiments around the house, often to the chagrin of my mother. (Kyle)

They helped me acquire some of the materials that I needed to produce my research. (Laura)
While being very supportive, they allowed me to live by myself in [a hotel] for eight weeks over the summer so that I could complete my research, they did not directly assist me in my research. (Maggie)

They funded my research and were able to tolerate the explosions my propellant caused in the kitchen . . . . I was brought up in a home where I was encouraged to be creative in thinking. (Quincy)

Parents were rarely involved in the problem finding aspects of the study. Of the 20 students in the study, only 4 report parent interaction during the problem finding phase of the project. Three of the four shared ideas together, while the fourth actually utilized her mother’s expertise:

Actually, my mom is the one who cut out the article from the paper that was about the cleansing of the forests in California with the wildfires. So she was the one who actually came to me and said, “You should look into doing this. This is really neat.” So I took it and looked into it for myself. (Jessica)

She had just read [a newspaper article about leeches and surgery]. And she was so surprised by the fact that they actually put live leeches on humans. They do that still during reattachment surgeries. She said, “I guess they have some sort of blood thinner in them,” and all this other stuff. It was actually at that moment that I decided, “Oh, an anticoagulant. That is something I can use and build off of.” (Laura)
He knows what a resistor is and that’s the end of his electrical engineering knowledge. He’s good with ideas. He’s good with visualizing things. He majored in pure math in college. So he’s good with that kind of stuff. He’s not good with the technical. Actually how to build this, but he’s good with “yeah well you’re going to need something that looks sort of like this.” So we talked about it, and by the end of that day, I knew what I had to do. (Ryan)

[My mom] grew up with farming sheep. She loved working with sheep. She really was very excited about this project and she really helped me out a lot. She gave me a lot of tips about how to dose the sheep. How to count the ticks on the sheep. Where you would find the most ticks on the sheep, because she has a lot of sheep. She helped me with my information and helped me gather it. (Paige)
Table 18

*Role of parents in students’ projects*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Project area</th>
<th>Role of parents</th>
<th>Science expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>Algorithm development</td>
<td>Support, encouragement</td>
<td>Computer science</td>
</tr>
<tr>
<td>Bobby</td>
<td>Applied chemistry</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Caitlin</td>
<td>Meteorology</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Dana</td>
<td>Human behavior</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Eric</td>
<td>Alternative energy</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Felipe</td>
<td>Marine biology</td>
<td>Support, encouragement</td>
<td>Ecology</td>
</tr>
<tr>
<td>Gabrielle</td>
<td>Cell/organism culturing</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Hannah</td>
<td>Genetics/human systems</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Igor</td>
<td>Alternative energy</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Jessica</td>
<td>Ecology</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Kyle</td>
<td>Engineering</td>
<td>Support, encouragement</td>
<td>Engineering</td>
</tr>
<tr>
<td>Laura</td>
<td>Chromatography</td>
<td>Support, encouragement,</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>discussion of ideas</td>
<td></td>
</tr>
<tr>
<td>Maggie</td>
<td>Genetics/behavior</td>
<td>Support, encouragement</td>
<td>None</td>
</tr>
<tr>
<td>Nathan</td>
<td>Computer science</td>
<td>Support, encouragement,</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>funding</td>
<td></td>
</tr>
<tr>
<td>Oliver</td>
<td>Computer science</td>
<td>Support, encouragement</td>
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</tr>
<tr>
<td>Paige</td>
<td>Animal science</td>
<td>Support, encouragement, ideas,</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>assistance with research</td>
<td></td>
</tr>
</tbody>
</table>
### Role of parents in students’ projects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Project area</th>
<th>Role of parents</th>
<th>Science expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quincy</td>
<td>Aerospace engineering</td>
<td>Support, encouragement, funding</td>
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</tr>
<tr>
<td>Ryan</td>
<td>Electrical engineering</td>
<td>Support, encouragement, discussion of ideas</td>
<td>Mathematics</td>
</tr>
<tr>
<td>Scott</td>
<td>Analytical chemistry</td>
<td>Support, encouragement, teacher, provide opportunity at university</td>
<td>None</td>
</tr>
<tr>
<td>Tami</td>
<td>Geology</td>
<td>Support, encouragement, funding</td>
<td>None</td>
</tr>
</tbody>
</table>

*Role of teachers and mentors in the problem finding process.* Teachers and mentors were utilized in the problem finding process. Their roles are summarized in Table 19. For some students in this study, the science teacher was the mentor. Some students used the science teacher from a traditional class, while others worked under the auspices of a formal science research program. Others worked with mentors in higher education or industry.
No participants in this study received their project idea directly from a teacher or mentor. They all developed their own ideas, based on their interests. Students often elicited conversations with these adults which helped them to focus their ideas into a problem that the student was capable of solving within the framework of limited expertise and resources:

And my mentor really helped me elaborate and focus on a certain topic and aspect of it . . . Just talking to him and getting in touch with other people through him. It’s educational, because you learn things that you wouldn’t have thought about. Also, it’s helpful because you can bounce ideas off of them and you get positive and negative feedback from them. It’s very helpful. (Jessica)

It was really an independent thought process, but I really couldn’t have done anything without the teacher of my science research class. Because a kid can do anything from an experiment in a wind tunnel to learning and memory to engineering. And he’ll become an expert in what you want to talk about, so you’re able to bounce ideas off of him . . . I couldn’t have done anything without being able to talk to him along the way. No matter what you have to say to him, it’s always a learning experience. (Maggie)

So my science teacher played a big role. He was very understanding. He took some time out of school to help me out: finding supplies, buying chemicals. So helped me a lot, and he helped me with my theory as well. (Quincy)
My mentor, the guy at the company. We usually just end up talking. We talk about random stuff. We talk about everything. Usually we talk about my project a lot. And we talk about, “Oh, you don’t have to make that that complicated. You can just do this.” Because a lot of it is refining the idea. (Ryan)

I was influenced by [my science research teachers]. Obviously, [because of their expertise] they didn’t know a lot about the field. But they would be able to tell whether or not the idea was solid and whether or not the direction I was going would be productive. [My university mentor] helped me figure out whether or not ideas were practical, because he had a lot more knowledge in the field. So what he was able to do was a question that would have taken me a few days of research and a lot of reading and a lot of fruitless online searching to solve. He would just know because he’s been working with it so long. So he helped me because I don’t have the background knowledge that a lot of people who work in this field have. (Gabrielle)
The mentors agreed with their students. They perceived their role in the problem finding experience as a support function, trying to facilitate student idea generation rather than direct students. For all students, regardless of level of success at a fair, teachers and mentors were calculating in their strategy to allow students to develop their own ideas rather than present them with an avenue of study:

I tried to take her interests. I didn't try to impose what I thought would be a good project or my interests. I tried to take her interests, “What are you interested in?” And then say, “Okay see if you can find what other research is being done in this area. See if you can investigate that area.” [This would help] point where those ideas might come to you. (Caitlin’s teacher-mentor)

I know from my own experience that there is a huge advantage to figuring something out on your own, as opposed to having someone tell you how to do it. I think it is an advantage in teaching you how to think. And it’s an advantage because you’re gaining self-confidence. It makes you feel that you know what you’re doing. Which is equally important to being able to think correctly. (Gabrielle’s mentor)

I don’t want to say I mentored him. Ultimately, I was just somebody to bounced ideas off of. To me, that's not a full-fledged mentor. Maybe it is. He is a very self driven, very independent. That is one of his strengths. (Kyle’s teacher-mentor)
I’d say my role was more of a guidance role. Because sometimes we would sit here for a few hours and not working on it, but just throwing ideas back and forth. Just from my experience, I was trying to tell him things to look out for. Like things where I thought he was going down a dead end. Sometimes, he would give me a call on the weekends on my cell phone. He said, “Oh, you know, this one thing is not working right.” And we would discuss ideas. (Ryan’s mentor).

We discussed a lot of the theory behind that. I would show him some things – some fundamental derivations. He would finish them halfway through. I was really a guiding mentor and we would discuss things and discuss feasibility and things. Occasionally I would pull him back to reality and say, “Why don’t we just do this?” or, “Let’s go a little slower and make sure we understand this part and then we’ll do the next part.” I think that was really my role (Scott’s mentor).

Perhaps Eric’s teacher-mentor summarizes the role best:

So I just became his manager . . . if you will. (Eric’s teacher-mentor)

Ryan’s mentor eloquently summarizes his job:

So I try to foster their creativity too. Not just pushing them into one solution. (Ryan’s mentor)
Mentors were often aware of potential pitfalls students would encounter with the choices they were making, but often deferred their expertise in order to have the student have a learning experience:

I didn’t want to see him get caught up in all these new complexities. Sort of like going off on a tangent. I was thinking he would get so bogged down in all the complexities of interfacing directly to that chip, but he really accomplished a lot and really expanded the learning experience. (Ryan’s mentor)

My impression was that he just started tinkering. Yet, my biggest concern for him was could I help him create a project that would really make use of [Kyle], and really challenge [Kyle]. (Kyle’s teacher)

From an instructional standpoint, part of the challenge for a teacher acting as the mentor for multiple students in a formal program, is their lack of expertise for the wide variety of projects that students wanted to conduct. Therefore the teacher needed to maintain the role of the facilitator rather than the dispensary of information:

Part of the difficulty for me this year, was coming from a chemistry and an analytical background, and inherit 20 to 25 kids who are all doing different things I think part of the creativity for that type of teacher, is to be able to know just enough about what they’re going to do to be able to give them guidance, and say “This is a good idea. That's a bad idea.” (Kyle’s teacher)
So, I think the lack of expertise was really what kind of forced them to find their own ideas. All I could do was refer them to resources that would hopefully help them. I didn’t try to impose what I thought would be a good project or my interests. (Caitlin’s teacher)
### Table 19

**Role of teachers and mentors in students’ projects**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Project field</th>
<th>Role of teacher</th>
<th>Area of expertise</th>
<th>Role of mentor</th>
<th>Area of expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>Algorithm development</td>
<td>Program administrator</td>
<td>Neurobiology</td>
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<td>n/a</td>
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<td>Bobby</td>
<td>Applied chemistry</td>
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<td>Chemistry</td>
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<tr>
<td>Caitlin</td>
<td>Meteorology</td>
<td>Program administrator, mentor</td>
<td>Medical technology</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>Dana</td>
<td>Human behavior</td>
<td>Program administrator, mentor</td>
<td>Medical technology</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Eric</td>
<td>Alternative energy</td>
<td>Program administrator, mentor</td>
<td>Physical chemistry</td>
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<td>Felipe</td>
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<td>Mentor</td>
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<td>n/a</td>
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<td>Gabrielle</td>
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<td>Program administrator, mentor</td>
<td>Analytical chemistry</td>
<td>Advice, loan of equipment, utilization of lab resources</td>
<td>Cell biology</td>
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</tbody>
</table>

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### Table 19 (continued)

**Role of teachers and mentors in students’ projects**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Project field</th>
<th>Role of teacher</th>
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<th>Role of mentor</th>
<th>Area of expertise</th>
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<tr>
<td>Hannah</td>
<td>Genetics/human systems</td>
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<td>Genetics</td>
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<td>Igor</td>
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<td>Mentor&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Jessica</td>
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<td>Physical chemistry</td>
<td>Discuss ideas and results via email</td>
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<tr>
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<td>Laura</td>
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<td>Program administrator, mentor</td>
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<td>Discuss ideas, utilization of facility</td>
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</tr>
<tr>
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<td>Program administrator</td>
<td>Engineering</td>
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Table 19 (continued)

*Role of teachers and mentors in students’ projects*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Project field</th>
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<th>Area of expertise</th>
<th>Role of mentor</th>
<th>Area of expertise</th>
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<tr>
<td>Oliver</td>
<td>Computer science</td>
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<td>Quincy</td>
<td>Aerospace engineering</td>
<td>Technical support</td>
<td>Physics</td>
<td>Discuss ideas and results via email</td>
<td>Rocketry</td>
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<tr>
<td>Ryan</td>
<td>Electrical engineering</td>
<td>Program administrator</td>
<td>Physics</td>
<td>Discuss ideas, utilization of facility\textsuperscript{a}</td>
<td>Electrical engineering</td>
</tr>
<tr>
<td>Scott</td>
<td>Analytical chemistry</td>
<td>n/a</td>
<td>n/a</td>
<td>Discuss ideas, present a problem, provide resources, utilization of facility, externship opportunity\textsuperscript{a}</td>
<td>Chemical physics</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Chemical physics
<table>
<thead>
<tr>
<th>Subject</th>
<th>Project field</th>
<th>Role of teacher</th>
<th>Area of expertise</th>
<th>Role of mentor</th>
</tr>
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<tbody>
<tr>
<td>Tami</td>
<td>Geology</td>
<td>Mentor matching</td>
<td>Chemistry</td>
<td>Provide internship, participate in field studies utilization of facility</td>
</tr>
</tbody>
</table>

*a*not applicable

*b*teacher or mentor was a subject in this study
Summary

Data collected from multiple sources (students, teachers, mentors, fair directors, documents) and methods (interviews, document analysis, surveys) were categorized to delineate salient features of the problem finding phenomenon in an extended open inquiry setting. Based on the categorization of data, seven axial category clusters emerged from the data.

The first category cluster, creative thinking indicated that student and adult scientists tend to define creative activity in science as problem finding. In addition, there appears to be a dichotomy of the types of projects that top students complete: novel approach and technical with value. Novel approach projects are generally better received and honored.

The second category cluster was entry point characteristics. Students who completed projects had a positive temperament for science. Also, students who completed high level projects tended to have had previous research training experiences before finding their problems for their projects.

Reflexive behaviors titled the third cluster. Students tended to have very high motivation, regardless of the outcome of their projects, they were self-regulating, and tended to describe themselves in terms of creativity and task commitment. Mentors more often commented on these students’ above average ability.

When describing their inquiry strategies, the fourth cluster, students described an idiosyncratic nature to scientific investigations. All students conducted extensive background research to build their specialized scientific knowledge base.

The fifth cluster was situated learning. The data from this cluster indicated that students have the ability to communicate well with other students and adults regarding their projects. Their specialized knowledge and deep understanding (critical thinking cluster) developed from a
prolonged situated experience. In addition, their problems had applicability to a greater community outside the confines of the school environment.

Finally, the seventh cluster, teaching approach, indicated roles of adults in the problem finding process. Parents were generally non-to-peripheral participants in the problem finding process. Teachers and mentors acted more as facilitators than knowledge disseminators and used their expertise to help students pursue student passion, rather than the adults’ interests.
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 flexibility 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 “sage on the stage” and a “guide on the side.” 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.
REFERENCES


Intel ISEF Categories and Subcategories

The categories have been modified with the goal of better aligning judges and student projects for the judging at the Intel ISEF. Local, regional, state and country fairs may or may not choose to use these new categories, dependent on the needs of their area. Please check with your affiliated fair(s) for the appropriate category listings at that level of competition.

Please visit our website at [www.sciserv.org/isef/students/rules/rules4.asp](http://www.sciserv.org/isef/students/rules/rules4.asp) for a full description and definition of the Intel ISEF categories (subcategories may adjust):

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<tr>
<td>EARTH SCIENCE</td>
<td>Climatology, Weather, Geochemistry, Mineralogy, Paleontology, Geophysics, Planetary Science, Territorics, Other</td>
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<td>Algebra, Analysis, Applied Mathematics, Geometry, Probability and Statistics, Other</td>
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<td>MEDICINE &amp; HEALTH SCIENCES</td>
<td>Disease Diagnosis and Treatment, Epidemiology, Genetics, Molecular Biology of Diseases, Physiology and Pathophysiology, Other</td>
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<td>MICROBIOLOGY</td>
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<td>CHEMISTRY</td>
<td>Analytical Chemistry, Inorganic Chemistry, Organic Chemistry, Physical Chemistry, General Chemistry, Other</td>
</tr>
<tr>
<td>ENGINEERING: Materials &amp; Bioengineering</td>
<td>Bioengineering, Civil Engineering, Construction Eng., Chemical Engineering, Industrial Engineering, Processing, Material Science, Other</td>
</tr>
<tr>
<td>ENGINEERING: Electrical &amp; Mechanical</td>
<td>Electrical Eng., Computer Eng., Controls, Mechanical Engineering, Thermodynamics, Solar, Robotics, Other</td>
</tr>
<tr>
<td>ENVIRONMENTAL ANALYSIS</td>
<td>Air Pollution and Air Quality, Soil Contamination and Soil Quality, Water Pollution and Water Quality, Other</td>
</tr>
<tr>
<td>ENVIRONMENTAL MANAGEMENT</td>
<td>Bioremediation, Ecosystems Management, Environmental Engineering, Land Resource Management, Forestry, Recycling, Waste Management, Other</td>
</tr>
</tbody>
</table>
APPENDIX B: SEMI-STRUCTURED INTERVIEW SCHEDULES
Student Interview Schedule, version 1.4 (Pilot Study)

Nature of problem finding

1.4.1. Describe the process you went through to get your idea for your research project. How did you go from a general idea, to a focused problem/project?

1.4.2. What were some of the rewards? Obstacles?

1.4.3. What kind of advice would you give to another student who wanted to conduct research?

1.4.4. Many students conduct research, yet your project was selected [to attend CSF][as a finalist project at CSF][to attend ISEF][as an award winner at ISEF]. What makes you more successful than all of the other students?

Creative processes

1.4.5. What is creativity?

1.4.6. Are science and creativity related?

1.4.7. How are you creative?

1.4.8. When are you creative?
Role of the scientist

1.4.9. What are some words to describe a scientist?

1.4.10. What are some words that don’t describe a scientist?

1.4.11. How are scientists different/similar from artists/musicians? Journalists? Politicians? Salespeople?

1.4.12. How are you different/similar to students who don’t conduct research, but may be of similar intellect?

1.4.13. How are you different/similar to students who do research but have less experience than you do?

1.4.14. How are you different/similar to your mentor?
Nature of problem finding

2.2.1. Describe the process you went through to get your idea for your research project. How did you go from a general idea, to a focused problem/project?

2.2.2. What were some of the rewards? Obstacles?

2.2.3. How long did it take you to come up with the idea for your project?

2.2.4. Does your project tie in with your hobbies and extracurricular activities, or is it purely a school activity to you?

2.2.5. What are some of the frustrations with coming up with your idea?

2.2.6. What kind of advice would you give to another student who wanted to conduct research?

2.2.7. What makes your project a good project?

2.2.8. Did you create your project with wanting to help local or global issues?

2.2.9. Name three adjectives that describe you as a person in terms of your science project.

2.2.10. Who influenced you in determining the idea for your project? What was the contribution?

2.2.11. Many students conduct research, yet your project was selected [to attend CSF][as a finalist project at CSF][to attend ISEF][as an award winner at ISEF]. What makes you more successful than all of the other students?
Creativity

2.2.12. What is creativity?
2.2.13. Are science and creativity related?
2.2.14. How are you creative?
2.2.15. When are you creative?

Role of the scientist

2.2.16. How are scientists different/similar from artists/musicians? Journalists? Politicians? Salespeople?
2.2.17. How are you different/similar to students who don’t conduct research, but may be of similar intellect?
2.2.18. How are you different/similar to students who do research but have less experience than you do?
2.2.19. Tell me about your mentor. What are some of the personal qualities that you respect or admire in your mentor?
Nature of problem finding

2.7.1. What made you want to do a project?

2.7.2. What are some of the first things you did?

2.7.3. Describe the process you went through to get your idea for your research project. How did you go from a general idea, to a focused problem/project?

2.7.4. How long did it take you to come up with the idea for your project?

2.7.5. How did you know that you had a good idea?

2.7.6. What were some of the rewards? Obstacles?

2.7.7. Does your project tie in with your hobbies and extracurricular activities, or is it purely a school activity to you?

2.7.8. What are some of the frustrations with coming up with your idea?

2.7.9. What kind of advice would you give to another student who wanted to conduct research?

2.7.10. Do you think you had a good project? How do you know?

2.7.11. Name three adjectives that describe you as a person in terms of your science project.

2.7.12. Who influenced you in determining the idea for your project? What was the contribution?

2.7.13. Many students conduct research, yet your project was selected [to attend CSF][as a finalist project at CSF][to attend ISEF][as an award winner at ISEF]. What makes you more successful than all of the other students?
Creative processes

2.7.14. What is creativity?

2.7.15. Are science and creativity related?

2.7.16. How are you creative?

Role of the scientist

2.7.17. How are scientists different/similar from artists/musicians? Journalists? Politicians? Salespeople?

2.7.18. How are you different/similar to students who don’t conduct research, but may be of similar intellect?

2.7.19. How are you different/similar to students who do research but have less experience than you do?

2.7.20. Tell me about your mentor. What are some of the personal qualities that you respect or admire in your mentor?
Student Interview version 3.0 (ISEF)

**Nature of problem finding**

3.0.1. Were you surprised with your success at ISEF?

3.0.2. What made you want to do a project?

3.0.3. What are some of the first things you did?

3.0.4. Describe the process you went through to get your idea for your research project. How did you go from a general idea, to a focused problem/project?

3.0.5. How long did it take you to come up with the idea for your project?

3.0.6. What were some of the rewards? Obstacles?

3.0.7. Does your project tie in with your hobbies and extracurricular activities, or is it purely a school activity to you?

3.0.8. Do you think you had a good project? How do you know?

3.0.9. Name three adjectives that describe you as a person in terms of your science project.

3.0.10. Who influenced you in determining the idea for your project? What was the contribution?

3.0.11. Many students conduct research, yet your project was selected [as a category winner at ISEF]. What makes your project successful?

**Creative processes**

3.0.12. What is creativity?

3.0.13. Are science and creativity related?

3.0.14. How are you creative?
Role of the scientist

3.0.15. How are scientists different/similar from artists/musicians? Journalists? Politicians? Salespeople?

3.0.16. How are you different/similar to students who don’t conduct research, but may be of similar intellect?

3.0.17. How are you different/similar to students who do research but have less experience than you do?

3.0.18. Tell me about your mentor. What are some of the personal qualities that you respect or admire in your mentor?
The student

M.1.0.1. Can you tell me about [STUDENT’S NAME]? Tell me about some of [HIS/HER] academic, social, and personal qualities.

M.1.0.2. List three adjectives that describe [STUDENT’S NAME] in terms of [HIS/HER] science fair project.

M.1.0.3. How did [STUDENT’S NAME] come up with the idea for [HIS/HER] project?

M.1.0.4. What role did you play in [STUDENT’S NAME]’s project?

M.1.0.5. What do you think were some of the frustrations and milestones that [STUDENT] encountered while doing [HIS/HER] research project?

M.1.0.6. How do you balance your expertise with allowing the student to be independent? How do you think you did in this role? What would you change if you mentored another student in the future?

M.1.0.7. What made [STUDENT’S NAME]’s project a good project?

Creative processes

This study focuses on student’s creativity while examining its relation to the logical/analytical processes in science. I would like to get some of your impressions about science and creativity

M.1.0.8. What is creativity?

M.1.0.9. Are science and creativity related?

M.1.0.10. How are you creative?

M.1.0.11. When are you creative?

M.1.0.12. How are scientists different/similar from artists/musicians? Journalists? Politicians? Salespeople?
Parent/Mentor/Teacher Interview Schedule, version 1.1 (CSF & ISEF)

The student

M.1.1.1. What role did you play in [STUDENT’S NAME]’s project?

M.1.1.2. List three adjectives that describe [STUDENT’S NAME] in terms of [HIS/HER] science fair project.

M.1.1.3. How did [STUDENT’S NAME] come up with the idea for [HIS/HER] project?

M.1.1.4. What do you think were some of the frustrations and milestones that [STUDENT] encountered while doing [HIS/HER] research project?

M.1.1.5. What were some of your frustrations and rewards while [STUDENT] worked on the project?

M.1.1.6. How do you balance your expertise with allowing the student to be independent? How do you think you did in this role? What would you change if you mentored another student in the future?

M.1.1.7. Do you think [STUDENT’S] project is a good project? How do you know?

Creative processes

This study focuses on student’s creativity while examining its relation to the logical/analytical processes in science. I would like to get some of your impressions about science and creativity

M.1.1.8. What is creativity?

M.1.1.9. How are you creative?

M.1.1.10. How are scientists different/similar from artists/musicians? Journalists? Politicians? Salespeople?
F.1.0.1 What are some of the milestones of your fair?

F.1.0.2 What are some of the most memorable student projects? What makes them special?

F.1.0.3 How is a science fair project different from science labs that take place in many classrooms?

F.1.0.4 I would like you to think about some of the great projects that have come through your science fair over the years. Can you please comment on these students' creativity? Intellectual ability? Task commitment?

F.1.0.5 Again, thinking about some of the great projects, what differentiates them from other high caliber, finalist level projects?

F.1.0.6 What do you perceive as the role of parents in these high quality projects?

F.1.0.7 Can you give me three adjectives to describe top science fair students in terms of their projects?

F.1.0.8 Communication appears to be an important part of the science fair process. Can you comment on top students and the role that communication plays in their projects, both from a design/research perspective and a poster session presentation perspective?

F.1.0.9 Many top students have commented on the reverse engineering that occurs as they do their projects. I am using a definition that is broad, not necessarily referring to only the engineering field. Why do you think so many students talk about figuring things out in a reverse fashion?
APPENDIX C: CONNECTICUT SCIENCE FAIR APPROVAL
January 7, 2007

Frank LaBanca

Dear Frank:

On behalf of the Board of Directors, I am pleased to report that the Connecticut Science Fair will participate in your doctoral research project. We will provide you with the opportunity to distribute literature to prospective student-subjects during setup on March 13, 2007 as well as discuss your project with individual students at the finalist judging on March 15, 2007. It is understood that student interviews will take place subsequent to the fair.

We will help you identify a range of quality of projects for your sample as well as provide contact information for those students. The Board requests a copy of your IRB approval documentation when it is available and prior to the fair. We look forward to learning the results of your study.

Sincerely,

G. Robert Wisner
Chairman, Board of Directors
Greetings Connecticut Science Fair Student-Scientist and parent/guardian,

About 18 years ago, I was a high school student and presented my science fair project. I congratulate you on your accomplishment of making it to the 2007 Connecticut Science Fair and wish you good luck. It takes a real star to persevere and produce a high quality project.

I am writing to invite you to take part in a study that I am conducting as part of my dissertation research at Western Connecticut State University. I am a doctoral student there, and also a science teacher at Newtown High School. I am conducting research to examine how students get their ideas for their science fair projects. The study will consist of an interview with you, and possibly your parent, guardian, and/or mentor. I will also ask that you complete two short surveys that help me understand you better.

Interviews will take approximately 30 minutes, and will take place either at your school or over the telephone, whichever is more convenient. Surveys can be completed either on paper or online. You may refuse to answer any question, and you are free to withdraw from this study at any time. If you do not wish to participate, it will not have any effect on your science fair participation or evaluation.

To protect your privacy, your name will not appear in this study and will be held in the strictest of confidence. No one besides my research team will have access to your replies. When the results of this research are published, it will be impossible to identify you or any other student.

If you are willing to participate, please sign the student portion of the consent form on the back of this sheet, and ask a parent or guardian to sign their portion. Please return the signed consent forms directly to me in the envelope provided. An identical copy of this letter has been included and is yours to keep. If you or your parent/guardian have any further questions about the study, please contact me at the email address or phone number below.

I look forward to hearing from you!

Sincerely,

Frank LaBanca

www.labanca.net
“Impact of problem finding on the quality of authentic open-inquiry science research projects”
Frank LaBanca, Principal Investigator

Student Consent

I have read the description of the research project and agree to participate. I am aware that the results will be used for research purposes only, that my identity will remain confidential, and that I can withdraw at any time.

Name: ___________________________ Signature: ___________________________

Phone number: ___________________________ email address: ___________________________

Parent/Guardian Consent

I have read the description of the research project and agree to let my child participate. I am aware that the results will be used for research purposes only, that my child’s identity will remain confidential, and that he/she can withdraw at any time.

Name: ___________________________ Signature: ___________________________

Relation to student: ___________________________ Phone number: ___________________________ /

email address: ___________________________
May, 2007

Greetings International Science Fair Student-Scientist and parent/guardian,

About 18 years ago I was a high school student and presented my science fair project. I congratulate you on your accomplishment for becoming a finalist at the 2007 International Science and Engineering Fair and wish you good luck. It takes a real star to persevere and produce a high quality project.

I am writing to invite you to take part in a study that I am conducting as part of my dissertation research at Western Connecticut State University. I am a doctoral student there, and also a science teacher at Newtown High School in Connecticut. I am conducting research to examine how students get their ideas for their science fair projects. The study will consist of an interview with you, and possibly your parent, guardian, and/or mentor. I will also ask that you complete two short surveys that help me understand you better.

Interviews will take approximately 1 hour, and will take place over the telephone. Surveys can be completed online. You may refuse to answer any question, and you are free to withdraw from this study at any time. If you do not wish to participate, it will not have any effect on your science fair participation or evaluation.

To protect your privacy, your name will not appear in this study and will be held in the strictest of confidence. No one besides my research team will have access to your replies. When the results of this research are published, it will be impossible to identify you or any other student.

If you are willing to participate, please sign the student portion of the consent form on the back of this sheet, and ask a parent or guardian to sign their portion. Please return the signed consent forms directly to me in the envelope provided. An identical copy of this letter has been included and is yours to keep. If you or your parent/guardian have any further questions about the study, please contact me at the email address or phone number below.

I look forward to hearing from you!

Sincerely,

Frank LaBanca
www.labanca.net
(203) 947-2850
“Impact of problem finding on the quality of authentic open-inquiry science research projects”
Frank LaBanca, Principal Investigator
www.labanca.net

Student Consent

I have read the description of the research project and agree to participate. I am aware that the results will be used for research purposes only, that my identity will remain confidential, and that I can withdraw at any time.

Name: ___________________________ Signature: ___________________________

Phone number: ___________________ email address: ________________________

ISEF Project Number: ________________

Parent/Guardian Consent

I have read the description of the research project and agree to let my child participate. I am aware that the results will be used for research purposes only, that my child’s identity will remain confidential, and that he/she can withdraw at any time.

Name: ___________________________ Signature: ___________________________

Relation to student: ___________________ Phone number: ___________________

email address: ________________________
Parents and mentors of science fair students:

I am a doctoral student at Western Connecticut State University and a science teacher at Newtown High School in Connecticut, currently conducting research examining how students get and develop their ideas for their science fair projects. I am excited to have the opportunity to work with your [RELATION], [NAME], who will be a subject in my study.

In order to have good trustworthiness and dependability in my study, I am looking to triangulate my data by interviewing those adults who have had an impact on [NAME]’s study. I am hoping to have the opportunity to conduct an interview with you to improve the quality of my findings.

Interviews will take approximately 15 minutes, and will take place over the telephone. You may refuse to answer any question, and you are free to withdraw from this study at any time.

To protect your privacy, your name will not appear in this study and will be held in the strictest of confidence. No one besides my research team will have access to your replies. When the results of this research are published, it will be impossible to identify you or any other individual.

If you are willing to participate, please sign the consent form on the back of this sheet, and ask a parent or guardian to sign their portion. Please return the signed consent forms directly to me in the envelope provided. An identical copy of this letter has been included and is yours to keep. If you have any further questions about the study, please contact me at the email address or phone number below.

I look forward to hearing from you!

Sincerely,

Frank LaBanca
www.labanca.net
WESTERN CONNECTICUT STATE UNIVERSITY
in cooperation with THE CONNECTICUT SCIENCE FAIR ASSOCIATION AND
SCIENCE SERVICE’S INTERNATIONAL SCIENCE AND ENGINEERING FAIR

“Impact of problem finding on the quality of authentic open-inquiry science research projects”
Frank LaBanca, Principal Investigator
www.labanca.net

Consent

I have read the description of the research project and agree to participate. I am aware that the results will be used for research purposes only, that my identity will remain confidential, and that I can withdraw at any time.

Name: ____________________________  Signature: ____________________________

Phone number: ______________________ email address: ______________________

Role: [ ] Parent [ ] Guardian [ ] Mentor  to: ________________________________
Greetings Connecticut Science Fair Participant!

Good luck with your project. I am conducting a study in conjunction with Western Connecticut State University and the Connecticut Science Fair Association to learn about strategies that students use to develop their science research projects.

I might contact you to be a potential participant. If you will give serious consideration to participating. The attached papers are for your information. It is not necessary to fill out the forms at this time.

If you have questions, please contact me at [email protected] or www.labanca.net

Frank LaBanca, Principal Investigator

P.S. Your picture will be available online through the CSF website: www.ctsciencefair.org
Greetings International Science & Engineering Fair Participant!

Good luck with your project. I am conducting a study in conjunction with Western Connecticut State University and ISEF to learn about strategies that students use to develop their ideas for their science fair projects. This project has been approved and is sanctioned by the International Science and Engineering Fair and Science Service.

I am requesting that you be a participant in the study. I hope you will give serious consideration to participating. This envelope contains two copies of a consent form, instructions for completing online surveys, and a prestamped envelope. Please sign and mail ONE COPY of the consent form to me in the enclosed stamped envelope as soon as possible.

If you have questions, please contact me at [redacted] or [redacted].

Frank LaBanca, Principal Investigator
Thank you for agreeing to participate in my study about science fair students. Participation requires you to complete two online surveys and a telephone interview with me. Below are the instructions for completing the surveys.

Go to www.labanca.net. Click on the “Study of Science Fair Students”

Click on the “Demographics Survey.”
Complete the “Demographics Survey” and the “USRT Scale”
Newtown High School Teacher Is Starting His Doctoral Study

By Laurie Bobst

"The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill."

The above statement is from Albert Einstein, perhaps the greatest physicist ever. And that idea of his, that finding the right question is of utmost importance, is the gist of the doctoral work being done by Newtown High School biology teacher Frank LaBanca.

Mr. LaBanca has been involved in applied research with his students for seven years. He has accompanied many students to science fairs and observed many students' projects.

His teaching experience has led him to ask, "How do students who excel at science fairs find good problems?"

"Schools have done a good job of teaching problem-solving skills," Mr. LaBanca stressed. "Students are creative, which is necessary for solving problems."

He added that in the classroom setting, students are often presented with a problem by the teacher due to time constraints.

When the time is available, there are several steps a student must follow to problem find. The creative piece is still part of the process. The student considers what topic is of interest to him/her. Once a topic is determined, the student must evaluate if he or she has the ability, knowledge, equipment, etc. to reach a successful conclusion.

As with any good scientific research, the scientist must review the existing literature. Has the question been studied in the past? Were any productive outcomes reached? Did the experimentation lead to other questions?

While the students work through their research, they will encounter snags and obstacles that alter their investigations. Sometimes, they are sent back in the process, needing to investigate further, or change the question completely.

As Mr. LaBanca formulated his study, he investigated previous research. Very little study has been done on the subject of problem-finding.

"One psychology text had about 80 pages on problem-solving, and just a couple on problem-finding," he stated.

Mr. LaBanca has performed a pilot study in a structured environment observing students engaged in research activities. He found that students who performed well had had apprenticeship periods where they learned about the instruments, vocabulary, and techniques required for scientific inquiry.

Having explored student problem-solving, Mr. LaBanca has turned his attention to "What are the techniques students use to come up with ideas for research projects? What skills, concepts, and knowledge are needed to get to the final project?"

To answer his questions, Mr. LaBanca will draw from students presenting at science fairs, specifically, the Connecticut Science Fair (CSF) hosted by Quinnipiac University and the International Science and Engineering Fair (ISEF) held in Albuquerque, N.M., in May.

Mr. LaBanca will select students who excel and those ranked average based on the judges' scores. This approach will provide an objective sample based on scoring by professionals in science. He will strive to include state, national, and international students in his sample.

Through surveys and questioning, Mr. LaBanca hopes to determine if there are techniques that lead to good ideas and, ultimately, great science fair projects.
Cutting Edge Research At Newtown High School

By LAURIE BORST

High school science teacher Frank Labanosa is a research scientist himself who wants to see his students succeed at applied research. To that end, he offers a course that allows students to conduct research on a topic of their choosing. And NHS students are stepping up with projects involving gel electrophoresis to metamaterials to bioremediation.

“The applied research setting gives real world skills, like time management, creativity, reasoning,” Mr. Labanosa explained. “Authentic research provides information people want, like river study projects students have done in the past.”

Scott Regnery, a senior, is studying “The Health of Local Streams and The Effect of Stocked Brook Trout On Native Populations.” Scott has been engaged in soil and water sampling and testing. Besides chemical analysis of environmental factors, Scott is studying which macroinvertebrates (insects) live in local streams. Some macroinvertebrates have zero tolerance for pollution, therefore, which insects are present is another indication of stream health.

“A fish is a fish, which has zero tolerance,” Scott stated. “Therefore, water quality must be very good.”

Another question he hopes to answer is, are the trout native or stocked, or a hybrid? He will use sludge to obtain DNA samples and gel electrophoresis is a common procedure that separates DNA, creating patterns in the gel that are analyzed to determine what genes are present in the fish.

Supervisor Grant Kozicki has chosen to investigate “Holographic Recognition System For High Security Plants Digital Camera.” While recognition software already exists, Grant would like to write a program that will simplify the process and compare retrieval images through a connection to a digital camera. To accomplish his goal, Grant has been learning Java, a programming language. He will test his code through a game he is developing. Grant is a member of the tech club and plans to take computer science in college.

Senior Drew Taylor is no stranger to applied research. Last year, he attended the International Science and Engineering Fair in Indiana. This year, Drew is researching “The Simulation, Fabrication, and Testing of a Novel Metamaterial As a Near-Infrared Frequency.”

“Metamaterials consist of three-dimensional arrays of hoops, rods, or other shapes

Senior Matt Berk performs a titration as part of his chemistry exam. “A titration uses color change as the indicator of reaching the endpoint.” Matt was pleased when he reached the expected color change.

Drew tried to break it down into terms nonphysicists can understand. Basically, metamaterials bend waves around them, with the waves meeting up on the other side, essentially making whatever is placed inside the material, invisible.

“I’m trying to make a material that works within a narrow infrared range,” Drew explained.

Metamaterials intrigue scientists who dream of cloaking devices like those the X-Men have on their suits. An invisibility cloak is a la Harry Potter, although it will be some time before you can buy one at the local wizard’s shop. The more practical application of metamaterials is their ability to protect what might be placed inside them.

Maritae Colon, also a senior, is researching “The Chemical Degradation Of Polychlorinated Biphenyls Using Pseudomonas Grown On Biodegradable Beans.” Maritae has performed other water studies in the past.

This study looks at using Pseudomonas, a group of red-shelled bacteria, to remediate PCBs, which are the byproducts of manufacturing done by General Electric. The Hudson River and Hurricane River have both been polluted by these PCBs.

With the help of Western Connecticut State University biology professor, Dr. Ruth Goren, Maritae was able to obtain Biodegradable beans. She will grow Pseudomonas on

Scott Regnery, a senior at NHS in the applied research class of Frank Labanosa, is identifying macroinvertebrates, i.e., aquatic insects, crustaceans, mollusks, and worms, whose presence indicates the health of a stream. This will help Scott in study of native brook trout.

Senior Matt Berk is investigating converting Pyrolysis oil from the cafeteria into biodiesel. Using titration to determine amounts of reagents, Matt then prepared a test batch. After obtaining the reagents, Matt used a separation funnel to drain off the heavier byproducts leaving the biodiesel.

Matt plans to build a refining and increase the amount of biodiesel he can produce. He hopes to acquire a diesel-powered motor in which to run his fuel. He will analyze emissions in exhaust from the engine to determine how clean the fuel is burning.

Teaching The Teachers

With a grant from the Connecticut Department of Higher Education, professors at Western Connecticut State University and secondary science teachers from area schools developed the WestConn Institute for Science Teacher Research (WIRST), which held its first workshop last July.

The goal of the program is to train secondary school science teachers to do research with their students. Newton High School biology teacher Frank Labanosa introduced attendees to the topic of how to develop good questions, the subject of his doctoral research.

“This is a working program with residency in a professor’s lab for teachers,” said Dr. Theodore Finn, assistant professor and secondary science education coordinator at Western Connecticut State University. Teachers acquire inquiry, safety, and content experience not available in day-to-day classes.”

After completing the workshop, each participant developed a research project in conjunction with a mentor that are being carried out over the course of two semesters. In May, outcomes of the research will be presented at WCST.

Those attending the workshop were 20 percent educators and 80 percent certified teachers. The workshop provides some idea of the reality of being a teacher in the classroom, Dr. Finn explained.

The state grant covers 18 months, and if the grant is renewed, the faculty hopes to offer the research program every other summer.
APPENDIX E: SCIENCE SERVICE APPROVAL
December 6, 2006

Frank LaBanca

Dear Frank,

As per our email exchange and phone conversation, I presented your research at our internal Intel ISEF staff meeting and am happy to inform you that we at Science Service are in agreement that we will aid you in your research project. This will involve providing to you the numerical results of the Intel ISEF competition on Thursday morning so that you might interact with a small sub-set of students to identify potential subjects in your study.

It is most likely that the best methodology for providing these results to you will be to provide you with a list of top scorers based on the average normalized rank score that is provided to the judging groups to begin their caucusing. Therefore, it will reflect the numerical scoring process and ensure that the students are “winning” students, but will not provide you with the final determination of student awards. We can discuss further what universe of students that we will provide you with so that you may select the 10-15 students you will actually pursue as subjects in your study.

Before we release results to you, we will ask that:

1) The ISEF SRC reviews the IRB documentation and approval that you receive from your institution and confirm that they are comfortable with involving Intel ISEF students in the study.

2) You sign a confidentiality statement ensuring that you will not share the results you are provided. This will also cover the understanding that you will be making initial contact with Intel ISEF finalists for their future involvement in your study, but that you will not be conducting interviews or presenting confidential information to them via your interaction onsite at the fair.

3) It will be agreed that prior to the fair we will collectively establish a list of students for which there are any considerations of confidentiality or conflict of interest. We will use this list to ensure that the results provided to you are absent any information regarding these students or their potential to win (i.e. by eliminating students from those categories, etc.)

We look forward to working with you and in learning of the results of your study.

Sincerely,

Michele C. Ghidzen, Director
Science Education Programs
Science Service

A Program of Science Service Since 1950
Science Service 1799 N Street, N.W. Washington, D.C. 20036
Tel: 202.785.3255 Fax: 202.785.1243 sciencet@scienceservice.org
Frank:

We are pleased to support you in your dissertation study examining the impact of problem finding on the quality of student research projects. Science Service agrees to provide you with confidential judging results for a sub-set of student projects so you can recruit subjects for your study. This information will be provided to you either Wednesday evening, May 16th, or Thursday morning, May 17th.

It is agreed that:
1. You will hold any information provided by Science Service in the strictest confidence, and will not release it to any person.
2. You may recruit subjects during the Thursday during the public viewing session. You may not inform any student of the judging status of their project.
3. It is understood that you will be making initial contact with ISEF finalists for their future involvement in your study, but that you will not be conducting interviews or presenting confidential information to them via your interaction onsite at the fair.
4. You will not receive any information in EV – Environmental Sciences, since you have mentored a student competing in that category. This is to avoid any potential conflicts of interest.
5. Science Service will provide a follow-up email to your potential subjects after the fair to encourage their participation and explain that the study is a Science Service-sanctioned activity.

We look forward to working with you and learning the results of your study. If you agree to the guidelines set forth above, please sign this document and return it to us.

Sincerely,

Michele Glidden, Director
Science Education Programs
Science Service

I, Frank LaBanca, agree to Science Service's stipulations, as outlined above, for conducting research at the 2007 International Science and Engineering Fair.

Signature: ____________________________ Date: ___________
APPENDIX G: USRT SCALE
Directions: Below is a list of terms frequently used to describe people. Click on the one term of each pair that best describes you. Even if neither term describes you exactly, select the one term of each pair that is nearest to being a description of yourself. Because these terms are personal to each individual, there are no "right" or "wrong" answers.

Remember, participation in this study is voluntary and you are free to withdraw at any time. Thank you for participating in this research!

1. Reliable
   ○ Imaginative

2. Constructive
   ○ Original

3. Self-controlled
   ○ Practical

4. Impulsive
   ○ Inhibited

5. Independent
   ○ Thoughtful

6. Leading
   ○ Persevering

7. Easy going
   ○ Self-confident

8. Conventional
   ○ Egotistical

9. Formal
   ○ Eccentric

10. Poised
    ○ Creative

11. Self-confident
    ○ Friendly

12. Reliable
    ○ Curious

13. Assertive
    ○ Cautious

14. Tactful
    ○ Practical

15. Formal
    ○ Easy-going

16. Curious
    ○ Friendly

17. Contented
    ○ Imaginative

18. Reserved
    ○ Self-confident

19. Assertive
    ○ Patient

20. Inhibited
    ○ Eccentric

21. Patient
    ○ Imaginative
<table>
<thead>
<tr>
<th>No.</th>
<th>Trait</th>
<th>Choice 1</th>
<th>Choice 2</th>
<th>Choice 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Practical</td>
<td>Original</td>
<td>Inhibited</td>
<td>Independent</td>
</tr>
<tr>
<td>25</td>
<td>Impulsive</td>
<td>Poised</td>
<td>Egotistical</td>
<td>Emotional</td>
</tr>
<tr>
<td>28</td>
<td>Constructive</td>
<td>Creative</td>
<td>Self-confident</td>
<td>Impulsive</td>
</tr>
<tr>
<td>31</td>
<td>Knowledge-seeking</td>
<td>Egotistical</td>
<td>Habit-bound</td>
<td>Meticulous</td>
</tr>
<tr>
<td>34</td>
<td>Worrying</td>
<td>Impulsive</td>
<td>Eclectic</td>
<td>Constructive</td>
</tr>
<tr>
<td>37</td>
<td>Practical</td>
<td>Reliable</td>
<td>Inflexible</td>
<td>Leading</td>
</tr>
<tr>
<td>40</td>
<td>Thoughtful</td>
<td>Curious</td>
<td>Meticulous</td>
<td>Original</td>
</tr>
</tbody>
</table>

Submit  Clear Form

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FORM SUBMITTED. THANK YOU FOR PARTICIPATING IN THIS RESEARCH.

Click [Image]

Click [Link] to return to the Biology Resources Home Page

Click [Link] here to take the demographic survey
Click [Link] here to take the USRT Scale
APPENDIX H: DEMOGRAPHICS SURVEY
Please fill in the information below. You may want to print this page first, if you do not have all of the information immediately available. If some information is unknown or not applicable, please leave it blank. We will contact you if I need additional information or clarification.

Thank you for participating in this research! Remember, this information is confidential and will only be used by the research team and you are free to withdraw from this study at any time. Please feel free to email questions to me at franklabanca@sbcglobal.net

<table>
<thead>
<tr>
<th>DÉMOGRAPHIC SURVEY</th>
</tr>
</thead>
</table>

**Name:**

<table>
<thead>
<tr>
<th>Address:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>City/State/Zip:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Phone number:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Alternate phone number:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>email:*</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Age:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Grade:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>School Name:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>School Address:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>School City/State/Zip:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>School phone number:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Principal:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Guidance counselor:</th>
</tr>
</thead>
</table>

**Current High School courses:**

Please provide a list of courses that you are currently enrolled. Be sure to indicate the level (e.g. AP, Honors, College Prep, etc.).

<table>
<thead>
<tr>
<th>Teacher who helped with your project most:</th>
</tr>
</thead>
</table>

259
Teacher's phone number: 

Teacher's email: 

What subject does this educator teach?: 

Area of expertise: 

How did this teacher help you?: 

Parent(s)/Guardian(s) name(s): 

Parent/Guardian phone number: 

Parent/Guardian email: 

Did your parent(s)/guardian(s) help with your project?: 

How?: 

Mentor's name: 

Mentor's affiliation: Where does this person work? 

Area of expertise: 

Mentor phone number: 

Mentor email: 

How did your mentor help you?: 

Is there any additional information or clarification to the above information that you would like to provide? 

Notes: 

Submit  Clear Form
FORM SUBMITTED. THANK YOU FOR PARTICIPATING IN THIS RESEARCH.

Click here to return to the Biology Resources Home Page

Click here to take the demographic survey
Click here to take the USRT Scale
<table>
<thead>
<tr>
<th>Category</th>
<th>Category cluster</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Situated learning</td>
<td>Having an application for the greater community</td>
</tr>
<tr>
<td>Award</td>
<td>Situated learning</td>
<td>Winning an award</td>
</tr>
<tr>
<td>Background research</td>
<td>Inquiry strategies</td>
<td>Conducting background research</td>
</tr>
<tr>
<td>Characteristics of the scientist</td>
<td>Scientist</td>
<td>Characteristics of the scientist</td>
</tr>
<tr>
<td>Communication</td>
<td>Situated learning</td>
<td>The ability to communicate both spoken and written</td>
</tr>
<tr>
<td>Community</td>
<td>Situated learning</td>
<td>The community of practice</td>
</tr>
<tr>
<td>Comparison</td>
<td>Situated learning</td>
<td>Making a comparison of self to others</td>
</tr>
<tr>
<td>Compartmentalization</td>
<td>Critical thinking</td>
<td>Compartmentalizing part of the project. This often occurs when a student has conducted [a] project[s] for many years. The project often has facets and different areas of study. The project's big concept is examined through different lenses</td>
</tr>
<tr>
<td>Conceptual understanding</td>
<td>Critical thinking</td>
<td>Bringing factors together to understand a concept. Understanding in context.</td>
</tr>
<tr>
<td>Creativity</td>
<td>Creative thinking</td>
<td>A factor of creativity</td>
</tr>
<tr>
<td>Critical stance</td>
<td>Critical thinking</td>
<td>Taking or identifying a critical stance</td>
</tr>
<tr>
<td>Category</td>
<td>Category cluster</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Deep understanding</td>
<td>Critical thinking</td>
<td>Having a deep understanding. This understanding usually goes beyond scientific knowledge, which would be coded as 'specialized understanding.' This is more of a conceptual understanding with scientific, social, political, interpersonal, theoretical, and/or practical realizations. It is seeing 'the big picture,' beyond the scope of the scientific aspects of the project.</td>
</tr>
<tr>
<td>Differentiated instruction</td>
<td>Teaching approach</td>
<td>Differentiated instruction</td>
</tr>
<tr>
<td>Evolution of the project</td>
<td>Critical thinking</td>
<td>How the project developed and changed over time</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Creative thinking</td>
<td>Having the willingness to change or adjust based on new information. Creating ideas from multiple perspectives</td>
</tr>
<tr>
<td>Goal</td>
<td>Reflexive behaviors</td>
<td>The goal of the project</td>
</tr>
<tr>
<td>Hot topic</td>
<td>Situated learning</td>
<td>A current issue or hot topic</td>
</tr>
<tr>
<td>Independent</td>
<td>Teaching approach</td>
<td>Working freely and independently. Having the freedom to choose.</td>
</tr>
<tr>
<td>Inquiry</td>
<td>Inquiry strategies</td>
<td>Methods of inquiry</td>
</tr>
<tr>
<td>Interests</td>
<td>Entry point characteristics</td>
<td>Personal intellectual interests</td>
</tr>
<tr>
<td>Interests in science</td>
<td>Entry point characteristics</td>
<td>Personal interests in science</td>
</tr>
<tr>
<td>Lesson learned</td>
<td>Reflexive behaviors</td>
<td>A lesson learned</td>
</tr>
</tbody>
</table>

Category definitions *(continued)*
<table>
<thead>
<tr>
<th>Category</th>
<th>Category cluster</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation</td>
<td>Reflexive behaviors</td>
<td>Personal motivation</td>
</tr>
<tr>
<td>Nature of science</td>
<td>Inquiry strategies</td>
<td>A general nature of science statement</td>
</tr>
<tr>
<td>New opportunity</td>
<td>Situated learning</td>
<td>A new opportunity</td>
</tr>
<tr>
<td>Novel approach</td>
<td>Creative thinking</td>
<td>A novel approach to solving a problem</td>
</tr>
<tr>
<td>Opportunity</td>
<td>Situated learning</td>
<td>An external opportunity, outside of the traditional classroom.</td>
</tr>
<tr>
<td>Ownership</td>
<td>Situated learning</td>
<td>Personal ownership in a project. Not relying on adults, but directing their facilitation</td>
</tr>
<tr>
<td>Previous experience</td>
<td>Entry point characteristics</td>
<td>Previous personal experience</td>
</tr>
<tr>
<td>Problem finding</td>
<td>Creative thinking</td>
<td>Problem finding, identifying a problem. See Chapter 1, definition of terms</td>
</tr>
<tr>
<td>Problem solving</td>
<td>Inquiry strategies</td>
<td>Problem solving</td>
</tr>
<tr>
<td>Professional contact</td>
<td>Situated learning</td>
<td>Making a contact with an industry or higher education professional. Utilizing professionals over the course of the project</td>
</tr>
<tr>
<td>Project limitations</td>
<td>Critical thinking</td>
<td>Identified limits of a project</td>
</tr>
<tr>
<td>Reverse engineering</td>
<td>Critical thinking</td>
<td>Reverse engineering. See Chapter 1, definition of terms</td>
</tr>
<tr>
<td>Reward</td>
<td>Reflexive behaviors</td>
<td>Personal rewards or satisfaction</td>
</tr>
<tr>
<td>Category</td>
<td>Category cluster</td>
<td>Definition</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Role of the parent</td>
<td>Teaching approach</td>
<td>The role of the parent</td>
</tr>
<tr>
<td>Role of the scientist</td>
<td>Teaching approach</td>
<td>The role of the scientist</td>
</tr>
<tr>
<td>Role of the teacher</td>
<td>Teaching approach</td>
<td>The role of the teacher or mentor</td>
</tr>
<tr>
<td>Rules</td>
<td>Teaching approach</td>
<td>Rules of the school or rules of a science fair</td>
</tr>
<tr>
<td>Science fair process</td>
<td>Situated learning</td>
<td>Factors or regulations that influence the way a student conducts a project. This includes interaction with judges, answering questions for judges, preparing the poster, going to the fair, assuring that the research complies with the fair regulations</td>
</tr>
<tr>
<td>Self evaluation</td>
<td>Reflexive behaviors</td>
<td>A self evaluation that does not fit into other categories.</td>
</tr>
<tr>
<td>Skeptical</td>
<td>Critical thinking</td>
<td>A skeptical situation</td>
</tr>
<tr>
<td>Specialized understanding</td>
<td>Scientist</td>
<td>Specialized understanding of scientific concepts</td>
</tr>
<tr>
<td>Teacher interests</td>
<td>Teaching approach</td>
<td>The interests of a teacher. How a teacher might influence student projects</td>
</tr>
<tr>
<td>Textbook</td>
<td>Teaching approach</td>
<td>Textbook knowledge as compared to applied, practical knowledge</td>
</tr>
<tr>
<td>Trials</td>
<td>Inquiry strategies</td>
<td>Trying things, procedures, or experiments many times. Conducting multiple trials</td>
</tr>
<tr>
<td>Work habits</td>
<td>Entry point characteristics</td>
<td>Work habits</td>
</tr>
</tbody>
</table>
The Process

#-Z3
What made you want to do a project?

$-PREVEXPERI
I got involved in the science research program, starting in my 9th grade year just because the idea of being able to get my hands dirty - it was intriguing to me. And it was shortly after that I realized I was in over my head, because I wasn't sure how a 9th grader was supposed to come up with this new, fabulous, scientific idea. The concept of being able to discover something and really - because I had done math research in the past, and that was really dry, and textbooks. But this is really getting in there and doing something, so that is really appealing to me. 9th grade, I did a project that studied the effects of albino fruit flies and immune responses and wound healing - which was basically a disaster. But it taught me the basics. It was the first time that I worked with Drosophila, and I've worked with them ever since. It was a good "crash course" in research. I did projects the years following. The proposal I came up with for my 9th grade year has continued with me until this day. I've been working on this for three years. The actual project I competed with at ISEP was kind of an accident of me continuing the project. It was an offspring of it. But essentially it was a continuation.

#-Z4
What are some of the first things you did?

$-OPPORTUNIT
I flew out to the University of Wisconsin - I was doing my research there. I was familiar with the protocols and I sort of knew what I wanted to do and it was a very hands-off lab. So once they taught me the protocols and knew that I was safe, I was really on my own. I was doing a completely different experiment. For the past two years I worked with fruit flies and memory and sleep. I was using protocols that
monitored sleep and monitored memory
formation. What this project really
\textbf{came out of... normally the data}
that was being compiled just feeds
\textit{into a computer and then a scientist}
\textbf{would look at it at the end. But I}
\textbf{was so afraid I was going to do}
\textbf{something wrong, I was pulling it out}
at every point and examining it. I
\textbf{was seeing patterns that I knew,}
because I've worked with memory
\textbf{patterns and sleep for 2 to 3 years in}
flies. I knew something was wrong.
\textbf{So I thought it was me. So I did it}
again and again. It turned out not to
be me. It turned out to be this
hidden variable. And therefore,
\textbf{studying that variable became my}
\textbf{project. After ISEF last year - I}
was a team project with my best friend
and we actually won first place and
best in category in the team category,
\textbf{and we won the European Young}
\textbf{Scientist contest last year. This}
\textbf{year I was alone. Last year I was}
part of the team. I had been working
on the subject area since 9th grade.
And my partner was going to do
\textbf{something else for the summer, but I}
declared that I wanted to stick with
\textbf{it. So after ISEF, I basically came}
home and mailed my resume and my paper
to almost everyone on my bibliography
- looking for job positions. I had
\textbf{offers at Harvard, UPenn and}
\textbf{Wisconsin. But Wisconsin really}
offered the hands-off without being
\textbf{too hands-off. An environment that I}
\textbf{was looking for with the resources I}
\textbf{was looking for. I know if I went}
into a summer program, which is very
\textbf{common - that's what my partner did -}
she wasn't as tied to the project idea
as I was. I had done a program two
summers ago. I went to the Russian
Academies of Sciences and I was handed
\textbf{a project on archaeology. And while 104}
you still learn a lot, it was
\textbf{different than starting it from}
\textbf{scratch. There was a strange}
confidence in me that I didn't even
\textbf{think - I thought it was misplaced}
\textbf{trust. Because Ph.Ds and MD were}
\textbf{suddenly saying, 'Yeah, just don't}
\textbf{mess up the material and do what you}
\textbf{want. We trust you. So I guess my}
paper had proven that I \textit{clearly wasn't}
going to go in there and destroy
270


§-ROLESTACHE §-ROLESCIENT

myself. I was lucky that it was 116 -§-
hands-off enough, that mid-way through 117
when I saw these results that were 118
unexpected. She thought that I was a 119
total idiot, and thought I had messed 120
up. But there was enough hands off 121
that she said that if you had the 122
time, and you wanted to pursue it, 123
then pursue it. 124 -§-

§-22

Describe the process you went through to 126 -§-
get your idea for your research 127
project. How did you go from a 128
general idea, to a focused 129
problem/project? 130

I just remember that the data was coming 132
up and I was studying for the past two 133

§-PREVENTER

years what could improve memory. In 134 -§-
my previous project, we had found that 135
sleep deprivation hinders long-term 136
memory formation, but then we found 137

*EVOLVEPROG

drugs to remedy that. So I was 138 -§-
following down that path. I don't 139
even remember every variable that I 140
was working with at the beginning of 141
the summer, just because of the path 142
that the project took. But I went to 143
my mentor and basically that hidden 144
variable was a genetic marker. 145
Scientists will change something 146
physical about the organisms just to 147
that they can observe changes. So I 148
was working with flies that had a 149
white eye, instead of a red eye. I 150
noticed that these flies were 151
remembering, but had incredible memory 152
capabilities, but were also lethargic. 153

§-ROLESTACHE §-ROLESCIENT §-TEACHERINTER

I brought it to my mentor - I saw her 154 -§-

%-NOVELLAPPRO %-QUITEME

maybe once every two weeks. She 155 -§-
basically rolled her eyes at me and 156
said, "Scientists have been using this 157
marker for over 30 years. You didn't 158
find anything new." So I said, "Well, 159
then I really messed something up and 160
I'll have to start again." And she 161
basically looked annoyed and said, "If 162
you want to do it, go ahead and do it. 163

%INDAPENDEN

It doesn't matter to me as long as 164 -§-
you get everything else done." I was 165 -§-
also being a lab assistant. I was 166
[inaudible] their flies. I was 167
breeding flies. So I kept doing it. 168

%INDAPENDEN

So at the end of the 8 weeks - I was 169 -§-
living alone, because it wasn't part 170
of a program. So I was in a Marriott 171

%COMMUNICAT

for 8 weeks. So there was a lot of 172 -§-
downtime to write papers, because 173
there wasn't much of anything else to 174

*SKEPTICAL
do. At the end of eight weeks, I brought two papers to her and she looked at my results and said, "Are you sure? You must have done something wrong." She checked out the raw data, and she checked out the