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 metacogntive 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

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

Clusters defined in Shymansky, Kyle, & Alport (1993).

[a] significant at p<.05

[b] 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.

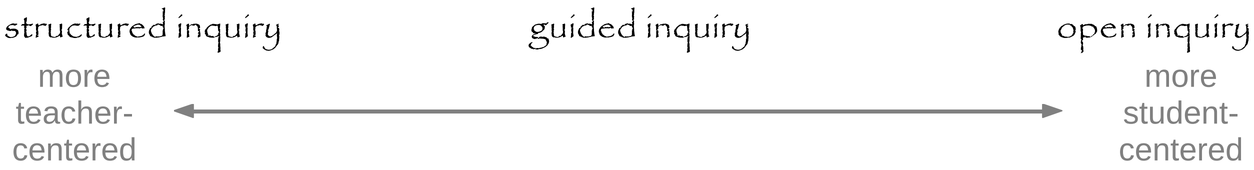

Figure 2. Continuum of inquiry activities

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 prescriptional 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).

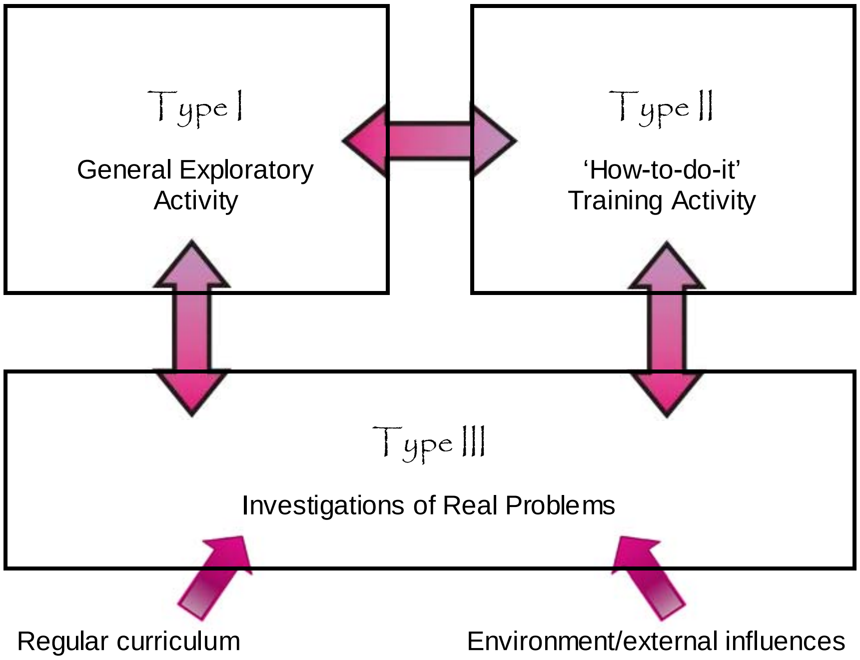

Figure 3. Enrichment triad model

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).

Table 3

A comparison of learning models applicable to science education.

Herron Scale	Levels of Inquiry	Enrichment Triad
n/a	Non-inquiry learning activity	Type I
0	Structured Inquiry	Type II
1	Structured Inquiry	Type II
2	Guided Inquiry	Type II
3	Open Inquiry	Type III

(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

Level	Type	Activity	Process
I	Existent	Recognize problem	Perceiving a situation as problematic; recognizing the existence of an evident problem
II	Emergent	Discover problem	Probing data for hidden, unclear, or incipient problem
III	Potential	Invent problem	Producing a problem or solution out of elements of a situation but not portending a problem event

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 has previously been presented that way, and the flexibility of the model is therefore often obscured in classroom application. In fact only recently has an alternative more open model been presented (Treffinger, Isaksen, & Dorval, 2005). 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 decontexualized 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 decontexualized 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).

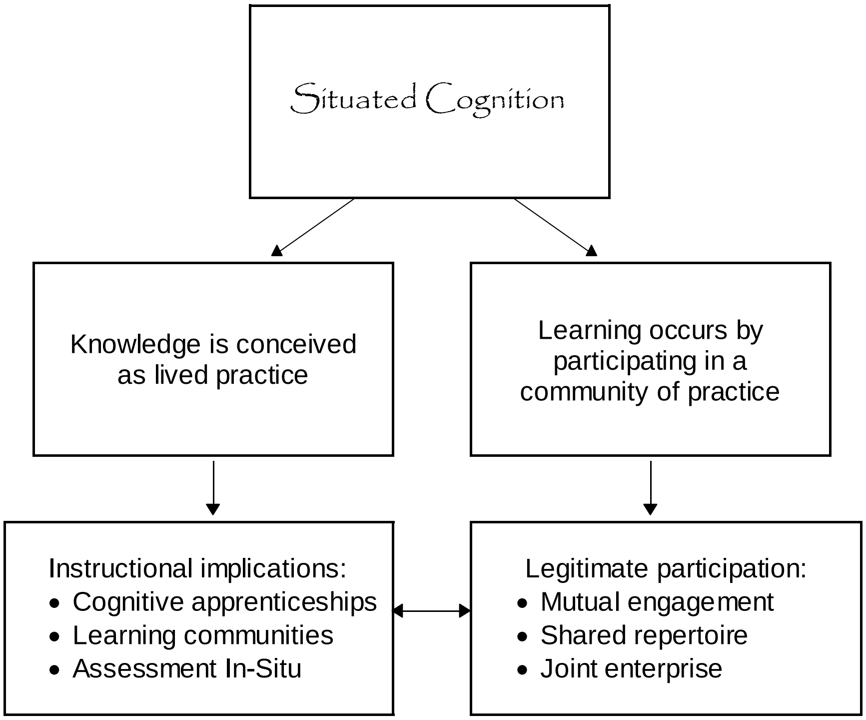

Figure 4. Summary of the situated cognition learning theory

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).

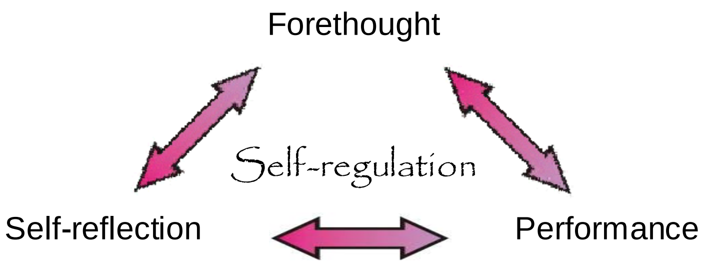

Figure 5. Bandura's cyclical nature of self-regulation

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.

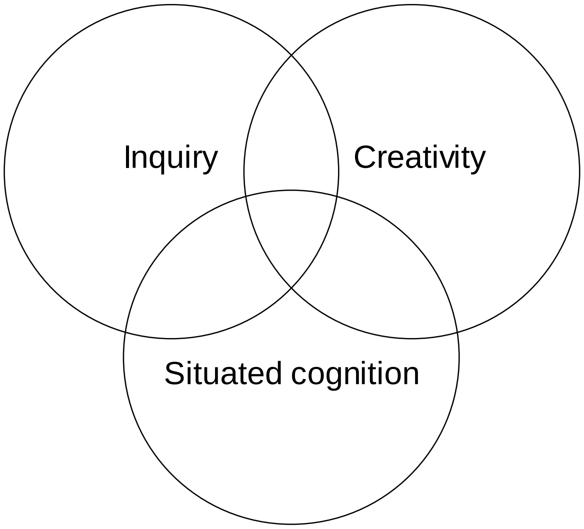

Figure 6. The relation between inquiry, creativity, and situated cognition.

Because of the limited studies of open inquiry as a lens to understading 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?