The Effects of a Technological Problem Solving Activity on FIRST™ LEGO™ League Participants' Problem Solving Style and Performance

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ABSTRACT

This study investigated the effects of a technological problem solving activity, specifically the 2004 No Limits FIRST™ LEGO™ League Robotics *Challenge*, on student participants' problem solving styles and performances. Previous research suggested that problem solving styles and performances could be influenced in children who are developing cognitively. Thirty-six 9-14 year old males and females were selected from officially registered FLL teams in the Virginia Department of Education Regions 6 & 7 of Southwest Virginia. Student participants self-assessed their technological problem solving confidence, approach/avoidance styles, and personal control during said activity three times over an eight week period. Two raters directly observed four dimensions of technological problem solving (problem clarification, developing a design, modeling/prototyping, and evaluating the design solution) at four points during the same eight-week time frame. Simple ANOVA, Repeated Measures ANOVA, MANOVA, Regression Analyses, and Qualitative Analyses were used to analyze the data. Female FLL student participants aged 9-14 perceived their overall technological problem solving style no differently than did 9-14 year old males. Gender alone showed no significant differences in performance; however, without any formal training or coursework, 9-14 year old FLL student participants showed significant increases in confidence, overall technological problem solving styles, problem clarification, developing a design, evaluating a design solution, and overall technological problem solving performance in only eight weeks.

Dedication

For Moma

Acknowledgements

Many people have supported me throughout my tenure as a doctoral student. Some very inspiring people, without whom the journey would have been considerably less rewarding, surrounded me, nurtured me, and helped me to grow to a place I never imagined I could be.

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Chapter 1
Introduction to the Study

Educational reform is an issue that has continued to persist as long as compulsory education has been established. Events, such as the October 4, 1957 launching of Sputnik, initiated changes in math and science curriculum across the nation. Since then, many efforts have been made to update and integrate science, technology, engineering, and mathematics (STEM) content and methods. In some instances, a more progressive education has ensued, inducing an individualized learning approach that allows students to improve their critical thinking skills and problem solving performance abilities no matter the age, gender, level of experience, or problem solving style.

Additionally, the use of standardized tests used to measure student achievement levels and the effectiveness of teaching methods has become the norm in education. One example of this assessment practice is the Third International Mathematics and Science Study (TIMSS, 1995), renamed the Trends in International Mathematics and Science Study (1999, 2003). TIMSS is the largest attempt to measure and compare student achievement levels globally. TIMSS showed that U.S. 4th grade students' math and science achievement scores were among the highest in the world. While 8th graders scored high in science and low in math, 12th grade students were among the lowest achievers in math and science.

"Troubled by a lack of emphasis on the importance of science in our schools, [Dean] Kamen launched FIRST™ (For Inspiration and Recognition of Science and Technology) to encourage kids to pursue careers as engineers, scientists, and inventors" (Portz, 2002, p. 17). In 1989, Kamen founded the FIRST™ Organization. The purpose of FIRST™ is:

To inspire an appreciation of science and technology in young people. Based in Manchester, N.H., the 501© 3 non-profit organization designs accessible, innovative programs to build self-confidence, knowledge and life skills while motivating young people to pursue opportunities in science, technology, and engineering. (U.S. FIRST™, 2004a, About FIRST, ¶ 1)

While the FIRST™ Corporation has hired several private research companies to study the impact of FIRST™ programs on students' appreciation of science and technology, no formal, peer reviewed educational research studies have been conducted to determine the effects of the robotics experience on students' learning. Singh, Granville, and Dika (2002) report, "Attitudinal and affective variables such as self-concept, mathematics/science interest and motivation, and self-efficacy have emerged as salient predictors of achievement in mathematics and science" (p. 324). However, before achievement can be measured effectively, it is important to understand what educational and personal benefits students are receiving through participation, especially in the FIRST™ LEGO™ League (FLL) Robotics *Challenge*.

Statement of the Problem

The problem of this study was to determine what effects a technological problem solving activity has on problem-solving styles and the problem solving performances of 9, 10, 11, 12, 13, and 14-year-old FLL student participants. Since 1992, private corporations and the federal government have contributed large amounts of money to support the FIRST™ Corporation and the FLL

Robotics *Challenge* that began in 1998 (2004 FIRST™ Annual Report). Programs have continued to grow rapidly every year (Table 1). While FIRST™ claims a positive impact on students' problem solving skills, no formal assessments have been conducted, and no empirical data have been collected to determine to what degree student problem solving performance is affected by participation in said programs. The effects of FLL experiences will be examined in this study.

Table 1. ***U.S. FIRST™ Competition Participation Growth***

Year	FIRST™ Robotics Competition	FIRST™ LEGO™ League	
	# of Teams[a]	# of Teams	# of Student Participants
1992	28		
1993	--		
1994	--		
1995	59		
1996	94		
1997	151		
1998	199	200	1,600 (Pilot)
1999	269	1000	9,500
2000	372	1500	15,000
2001	515	1800	18,500
2002	643	2600	27,009
2003	787	3450	45,000 (Projected)
2004	927	5200	52,000 (Projected)

Note. Data reported on the U.S. FIRST™ Organization Web site: **http://www.usfirst.org**
[a]Dashes indicate no data was reported.

The decision to study FLL student participants in Southwest Virginia was influenced by the researcher's involvement with the National Science Foundation grant, *Partnerships in Engineering: A Robotics Challenge Program for Southwest Virginia*, funded through the Center for Power Electronics Systems (CPES) at Virginia Tech, A National Science Foundation Research Center.

Purposes of the Study

The purposes of this study were: 1) to determine the relationships among age, gender, and FLL experience levels with student participants' problem solving styles and problem solving performances; 2) to assess how well student participants' problem solving styles would predict their individualized problem solving performances, and 3) to determine the effect a technological problem solving activity has on student participants' problem solving styles and performances over time.

Significance of and Need for the Study

FLL is a design and problem-solving competition for upper elementary and middle school students and is considered to be the feeder program for the high school FIRST™ Robotics Competition. The purpose of FLL is to promote interest in science, technology, engineering, math (STEM), and related fields of study and careers. "FLL extends the FIRST™ concept of inspiring and celebrating science and technology to children aged 9 through 14, using real-world context and hands-on experimentation" (U.S. FIRST™, 2004b, What is FIRST LEGO League, 2). The need for this study is supported by the increase in student participation since the inception of FLL and the lack of peer reviewed research on how participation in the FLL Robotics *Challenge* affects student participants' learning and their technological problem solving abilities. There is a need to study problem solving in the context of technological design. Other important issues include the study of why girls' technological performances drop off after middle school and why they lose interest in technological activities. Student participants generally choose to take part in FLL during after school programs or in other out-of-school groups. This approach tends to perpetuate the digital divide. What societal implications are suggested through this means?

While Wu, Custer, and Dyrenfurth (1996) found no significant differences in technological problem solving styles among college students, they do imply that changes in technological problem solving would occur in students enrolled in grades 1 through 12. "The reason such earlier involvement (particularly elementary school level) might have a substantial effect on problem solving style is that the impact would be felt before critical style and attitudinal characteristics solidify in students (around ages 10-14)" (p. 69). They suggest that technological problem solving activities begin in elementary school. Children should be encouraged to explore and interact with technological problems while they are still in the process of developing cognitively. Longitudinal studies assessing the relationship between problem solving style and problem solving ability are particularly needed (Wu et al., 1996). Further discussion of the literature related to technological problem solving occurs in Chapter 2.

Assumptions

The following assumptions were made during this study:

1. The FLL coaches adhered to the guidelines and constraints of the 2004 No Limits FLL Robotics *Challenge* set forth by the FIRST™ Foundation.

2. The *Student Individualized Performance* (SIP) rubric is a valid and reliable measure of five levels of performance: novice, beginner, competent, proficient, and expert (Appendix A).

Limitations

The following limitations applied to this study:

1. The sample for this study was one of convenience and was limited to registered FLL team members in the Virginia Department of Education (VDOE) Regions 6 & 7 of Southwest Virginia (Appendix B).

2. FLL coaches are not required to attend any type of training sessions or to complete online tutorials pertaining to the competition.

Operational Definitions

FIRST™ LEGO™ League Robotics Challenge - "The FIRST™ LEGO™ League (FLL), considered the 'little league' of the FIRST™ Robotics Competition, is the result of a partnership between FIRST™ and the LEGO ™ Company. FLL extends the FIRST™ concept of inspiring and celebrating science and technology to children aged 9 through 14, using real-world context and hands-on experimentation" (U.S. FIRST™, 2004b, What is FIRST LEGO League? ¶ 1).

Heuristics - "Heuristics indicate likely directions to pursue or approaches to follow" (Andre, 1986, p. 181).

Problem solving ability - The competence exhibited during performance of a task, whether by natural aptitude or acquired proficiency.

Problem solving performance - Levels of behavior exhibited during a technological problem solving activity. Performance levels encompass the following progressions:

- Novice
- Beginner
- Competent
- Proficient
- Expert (Custer, Valesey, and Burke, 2001)

Problem solving style - The manner in which students are able to solve problems. Problem solving style is measured by an individual's reflection on and appraisal of their problem solving confidence, approach/avoidance style, and personal control during a problem solving activity (Heppner, 1998).

Technological problem solving activity - An exercise or experience guided by criteria and constraints in which students enhance higher levels of thinking by applying a non-linear problem solving process to create solutions to practical problems.

Chapter 2
Review of the Literature

A review of relevant literature was conducted to develop the theoretical foundations related to technological problem solving. Two fundamental themes, the theories of learning, and problem solving, build up to the principal element of how technological problem solving styles and performance are affected by a robotics and computer-control competition considered to be a technological problem solving activity. Cognitive theory and the domains of knowledge were explored in general and as related to the cognitive nature of 9 to 14 year old children. The different types of problems are presented, leading to a discussion of general problem solving and technological problem solving processes, strategies, and activities. Finally, findings concerning the development and growth of industrial robotics and educational robotics platforms and competitions are presented.

Overview

Grades 5 through 8 are "a critical period for American students regarding achievement in mathematics and science" (Singh et al., 2002, p. 323). Math and science achievement determines students' course-taking patterns in high school, which in turn influences access to higher education and career opportunities (Singh et al.). One way to increase student achievement in math and science may be to teach technological problem solving.

In 1986, Bjorkquist indicated that young people would face new problems that could not be imagined at that time, and as a result, a need to teach more generalization skills like problem solving exists. During that same time, Savage & Sinn (1986) proposed that a dominant theme in society must be innovation. Lux (1962) insightfully fostered the idea that because the world was changing so rapidly, teaching problem solving was a method certain to ensure effective solutions to new problems. The research on problem solving is "an extremely interesting and promising development, and its educational implications should be explored in detail" (Cyert, 1980, p. 3).

Berkemer (1989) reviewed the industrial-technical literature to find an ill-defined albeit consistent postulation for a problem-solving curriculum, which would include design and creativity. He indicates the need for teaching problem solving dwells within problem solvers value to society. Lodermeier (1989) supports this notion, but goes on to suggest that problem solving be taught systematically because we live in a dynamic technological society, which requires critical thinking skills. In so doing, "the techniques, elements, and influences that facilitate or inhibit" creative problem solving may be revealed (Berkemer, p. 15). More recently, research "suggests that the design process is an innovative model for strengthening students' creative problem-solving skills" (Davis, Hawley, McMullan, and Spilka, 1997, p. 20).

New learning theories and combinations of learning theories have evolved from the behavioral learning theories of Thorndike and Skinner where students are passive learners, and traditional cognitive theories, Piaget, for example, in which students are active learners. Since the accession of knowledge and technology has been increasing at a phenomenal rate, educators can no longer continue to use traditional teaching methods in the classroom (Lodermeier, 1989). Today in education, learning strategies that accentuate sequential facts in memory are inadequate (Davis et al., 1997). When the learning environment is made relevant and meaningful, students' motivation to learn can be heightened (Singh et al., 2002; Davis et al.). Applicably, more complex cognitive processes are pertinent to the transfer of learning and problem solving (Anderson & Krathwohl, 2001). Innovative teaching and learning allows students to endeavor new perspectives, and "facilitates transfer to new problems and settings" (Davis et al., p. 20).

Cohen & Ault (1984) purport the need for additional emphasis on creative, problem-solving activities. For students, learning creative problem solving is a self-directed (Berkermer, 1989; Davis et al., 1997) and self-motivating (Hill, 1979) process. Researchers agree that when learning is intrinsically motivated and self-directed, positive cognitive outcomes are more likely to occur (Ryan, Connell, & Deci, 1985; Singh et al., 2002). Building a creative problem solving foundation requires active participation on the part of the student, further enhancing the opportunity of student involvement and providing strong, positive motivation for learning (Berkemer). Besides promoting self-directed learning and assessment, teaching problem solving processes enhance "flexible thinking skills" and help to develop "students' interpersonal and communication skills" (Davis et al., p. 19).

Moreover, teachers must perform a considerable task in facilitating students' thinking skills. "Educators must instill in students a process to creative problem solving that transcends individual assignments, illustrates how learning applies to students' everyday lives, builds relationships across traditional school subjects, and increases students' comfort with the uncertainty that characterizes many problems" (Davis et al., 1997, p. 20).

One example of an innovative problem-solving model is STEM integration, which is supported by the American Association for the Advancement of Science [AAAS] (Johnson, 1989). Brusic (1991) suggests STEM integrated curricula are often founded on sound educational principles and are interesting and relevant to the educational requirements of young children. She claims STEM models can provide an interdisciplinary, application-oriented and cooperative learning environment. STEM learning activities cater to children's cognitive affective and psychomotor needs and abilities (Brusic). Specifically, students' development of problem solving abilities is endowed through the study of technology (Lodermeier, 1989; International Technology Education Association [ITEA], 2000). "Engineers, architects, computer scientists, technicians, and others involved in technology use a variety of approaches to problem solving, including troubleshooting, research and development, invention, innovation, and experimentation" (ITEA, p. 5).

Theories of Learning

John Dewey (1933) stated, "The major purpose of education is learning to think" (in Nummedal, 1986, p. 89). The basis for the conceptualization and development of models of learning, in which thinking processes are actualized, develops from cognitive theories. For example, Piaget's (1896-1980) *Theory of Cognitive Development* focuses on the development of knowledge in children aged 0 through 18 years. His stages of development are called *Sensori-Motor* (0-2 years), *Preoperational* (2-7 years), *Concrete operational* (7-11 years), and *Formal operations* (11-18 years). The processes through which these stages are realized include *Schema*, *Assimilation*, *Accommodation*, and *Equilibrium*. Moreover, Brunner's (b. 1915) *Theory of Cognitive Growth* observes more environmental and experiential components such as *Curiosity* and *Uncertainty*, *Structure of Knowledge*, *Sequencing*, and *Motivation*.

In an effort to facilitate communication among examiners, Bloom, Engelhart, Furst, Hill, and Krathwohl (1956) conceptualized a classification system of educational goals at the 1948 American Psychological Association Convention. Accordingly, six preeminent classes were developed: knowledge, comprehension, application, analysis, synthesis, and evaluation. The term 'cognitive,' as applied in this taxonomy, is intended to embody "activities such as remembering and recalling knowledge, thinking, problem solving, [and] creating" (p. 2). Additionally, the cognitive domain connotes "the development of intellectual abilities and skills" (p. 7).

Anderson and Krathwohl (2001), revised *Bloom's Taxonomy of Educational Objectives* to generate a two dimensional framework that includes cognitive process and knowledge (Figure 1). The magnitude of ideas "such as consciousness, awareness, self-reflection, self-regulation, and thinking about and controlling one's own thinking and learning" is emphasized in contemporary cognitive models (p. 43).

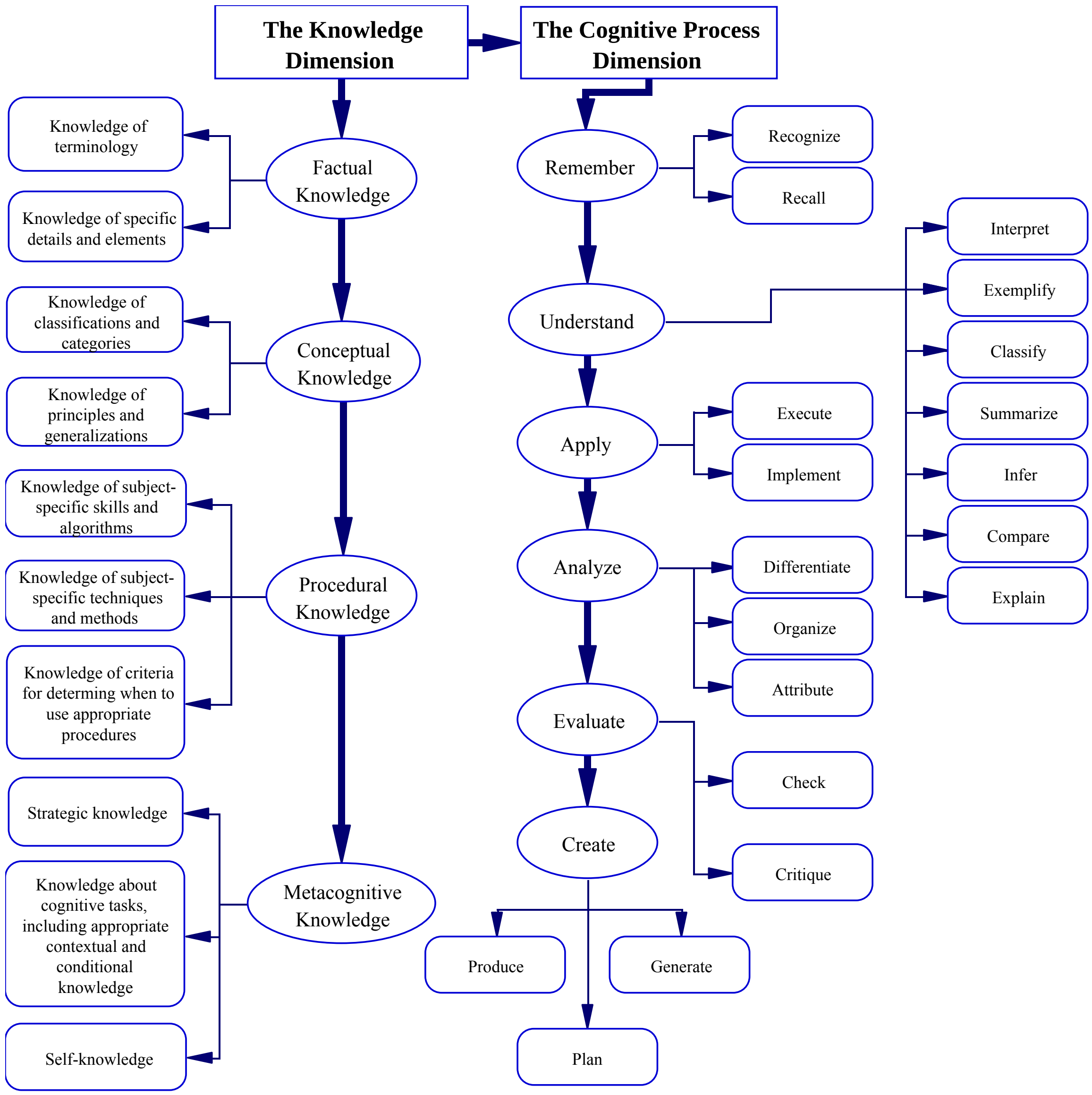

Figure 1. **Adapted from Anderson & Krathwohl's (2001) revised taxonomy.**

Presumed to be a cognitive progression, the categories of *Remember, Understand, Apply, Analyze, Evaluate,* and *Create* comprise the cognitive process dimension. The knowledge dimension, also assumed to lie on a continuum, is comprised of the *Factual, Conceptual, Procedural,* and *Metacognitive* components (Anderson & Krathwohl, 2001). Figure 2 shows Lodermeier's (1989) description of Cohen's (1971) higher order thinking skills. Cohen also indicates that real world problems are solved through discovery, prediction, and explanation and are results of productive thinking (Figure 3). In 1985, Presseisen introduced a model for basic thinking process skills and their characteristics (Figure 4).

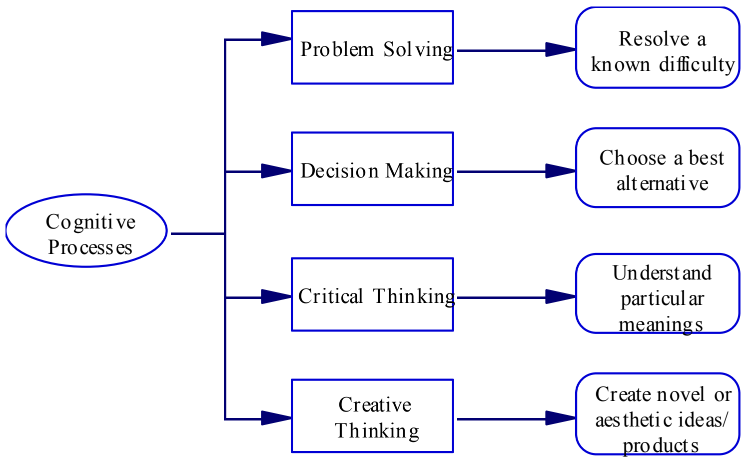

Figure 2. **Higher order thinking skills (Adapted from Cohen, 1971; Lodermeier, 1989).**

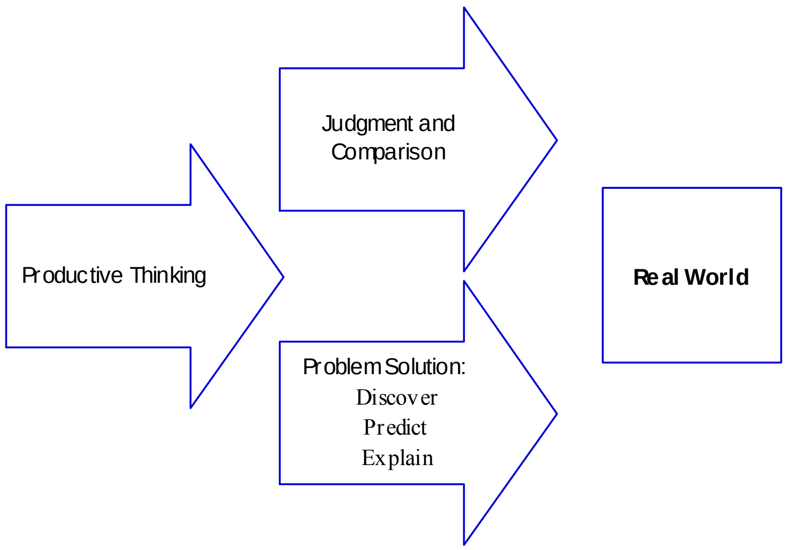

Figure 3. **Problem solution and the real world (Adapted from Cohen, 1971).**

Figure 4. **Basic thinking process skills (Adapted from Presseisen, 1985).**

Researchers agree on the importance of cognition in learning models, but no one model has been developed as the most effective or efficient model of learning. The question of what should be taught and how it should be taught remains to be answered comprehensively.

Aside from formal operational reasoning and the skills of logic and inquiry, general problem solving heuristics, and decision-making models are significant to students' cognitive development (Nummedal, 1986). Teaching through the cognitive area of problem solving may improve students' reasoning abilities. An extensive array of thinking skills may be incorporated into the teaching and learning process. "Although there exists some empirical support for using these methods to support learning to solve problems, we need research to clarify the roles of these methods" (Jonassen, 2004, p. xxiv).

Cognitive Theory and the Domains of Knowledge

Cognitive development progresses through four domains of knowledge: *Factual, Conceptual, Procedural,* and *Metacognitive* (Anderson & Krathwohl, 2001, p.5). A hierarchical progression is needed for more effective learning to take place. Once presented with the facts, students may begin to form concepts, develop procedures, and identify strategies. This model is developed from Gagné's (1977) hierarchy of learning that builds up to problem solving (Figure 5).

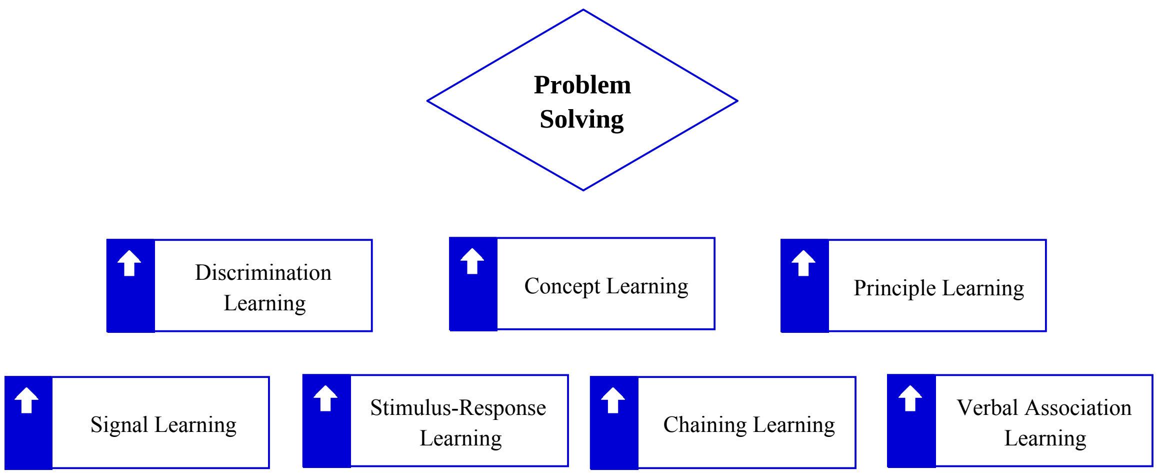

Figure 5. **Adapted from Gagné's Hierarchy of Learning.**

Students who are able to organize information into classifications and categories and then begin to understand the relationships between and among them have reached the *conceptual knowledge* domain. They are able to think in more complex knowledge forms. "Knowledge, then, plays a considerable role in determining the mental effort requirements of a problem-solving task" (Bjorklund, D.F., Muir-Broaddus, J.E., & Schneider, W., 1990, p. 101). Schemas, mental models, or implicit/explicit theories represent the knowledge about how a student perceives the organization and structure of any particular subject matter. Students begin to see how different bits of information are linked and are mutually relative in an orderly manner (Anderson & Krathwohl, 2001). Teaching relevant problem solving helps students to see how these bits function together in systems.

Creative processing skills or problem solving skills, which are a principal experience in education, are sharpened through learning experiences. Pressley & McCormick (1995) believe that if a student understands the significance of information, that understanding not only affects memory, but also affects problem-solving abilities. "One of the things that good learners do as they learn new ways to solve problems is that they construct explanations to themselves about the problem—that is, they relate a current problem to their prior knowledge" (p. 241). Prior knowledge is essential to problem solving and is gained through experience. "Knowledge and activity are reciprocal, interdependent processes (Fishbein and others, 1990)" (Jonassen, 2004, p.

7). Berkemer (1989) suggests students need more practice if they are "to internalize a framework of thinking for problem solving to the point where it is transferable to other contexts" (p. 185). He recommends the integration of teaching problem solving in all content areas.

Supporting this theory, "MacPherson (1998) found years of experience, cognitive technical knowledge, and critical thinking to be effective predictors of near transfer problem solving skills" (Custer et al., 2001, p. 6). The acquisition of knowledge through experience then is a prime factor in the development of problem solving abilities. To help students improve their problem-solving skills is to help them externalize the thinking process (Heiman & Slomianko, 1985).

"The influences of past experience, motives, and concepts available" govern the behavior of a problem solver (Hill, 1979, p. 48). Accordingly, Haskins & McKinney (1976) conclude that problem solving processes can be modified by individual differences. Berkemer (1989) found that college students pursuing technical majors could improve their creative and innovative problem solving skills as a result of taking a problem-solving course. Students benefit from "creative activities that challenge their abilities to think critically and solve problems" (Hill & Wicklein, 1999, Introduction, ¶ 1).

Technological problem solving will be discussed later in this chapter, but it is important to note here that DeMiranda and Folkestad (2000), and DeMiranda (2004) declare the link between cognitive science theory and technology education practice. A principal theme found in the cognitive science literature is relevant to technology education. That is, "When instruction and instructional materials are designed, they should be designed to help students acquire and integrate the cognitive and metacognitive strategies for using, managing, assessing, reorganizing, and discovering knowledge" (DeMiranda & Folkestad, p. 7). Active learning, reflecting on existing structures of knowledge, and communities of learning are three facets common between cognitive science and technology education and are indicated "in technology education through student design activities, production of artifacts, problem solving, and project-based activities" (DeMiranda, p. 65).

The Nature of 9-14 Year Olds

Since cognition occurs in some context (Bjorklund et al., 1990), it is important to consider prior experiences of problem solvers. Ideally, more experienced problem solvers will achieve higher levels of performance than those who are less familiar or unfamiliar with the information given to solve the problem (Bjorklund et al.). "Different organizational structures, different cultures, and different sociological mixes" affect the kinds of problems that arise and how students will solve them (Jonassen, 2004, p. 6). Thornton (1995) reports that even though a younger child may require greater effort to solve a smaller range of problems, "figuring out how to solve a new problem is also a challenging intellectual task, which pushes children to evaluate their own efforts, to discover new concepts, and to invent new strategies" (pp. 1-2). Therefore, problem-solving success depends more on the knowledge the solver holds and the strategies the solver is able to apply to the process of solving the problem (Thornton). Provided with relevant, real world problem solving experiences (Thornton, Davis et al., 1997; Berkermer, 1989) and the learned strategies that allow students to integrate information from different aspects needed to solve a problem, eight year olds can solve specific problems as easily as seventeen year olds (Thornton, pp. 42-43).

de Bono (1972) studied a group of 6 through 12 year olds in regards to development strategies for solving a series of problems. He found that age and cognitive style (along with SES and IQ) were interactive in producing more efficient problem solving behavior. Ten through twelve year olds assimilated to the conditions of problem solving through instructions more readily than other ages. Subjects in lower SES groups displayed more lack of confidence during a problem solving activity than did others. Based on the findings of Epstein (1978), Bame and Gatewood (1983) reported 10-12 year olds experience rapid brain development, and the occurrence of plateaus in brain growth in 8-9 year olds and 13-14 year olds. Though every child does not develop on the same timeline, the potential for cognitive development lies in the stages of brain growth.

Jonassen (2004) stipulates that students learn and comprehend more when they are solving problems. Thornton (1995) originally supported the ideal, "Knowledge and experience, rather than general ability or special intelligence, create expertise and simplify problem-solving" (p. 61). While knowledge might be more important than the ability to think when students are expected to pass exams, it may be of little use in helping people to live with themselves and with society (de Bono, 1972). Harter (1975), reports that in successful problem solving, children aged 4-10 seem to act more under motivation, while older children expect tasks to be more difficult, and therefore, if unfamiliar with the situation, may employ complex strategies that are inappropriate and may result in unsuccessful solutions. In 1989, Berkermer found "students appear to respond more quickly and perform better when guidelines and goals are spelled out clearly" (p. 141).

Davis et al. (1997) claim:

> Students who are comfortable with uncertainties in the early stages of problem solving are more likely to take calculated risks and to view failure as a way to learn rather than [as] a defeat. They also learn to suspend judgment until they view facts and circumstances from many vantage points. While this is a useful strategy for solving individual problems, it is also a strategy for life (p. 28).

In this way, "children derive substantial advantages from using multiple approaches" (Siegler & Jenkins, 1989, p. 27). Problems vary in the level of knowledge students need to solve them, the form in which the problems appear, and the processes students use to solve the problems (Jonassen, 2004). Students "learn to think laterally, generating many alternatives rather than progressing through a linear process to one right answer" (Davis et al., 1997, p. 27). Therefore, "the child's increasing success in solving problems is a social process much more bound up in feelings than we used to think: confidence can be more important than skill" (Thornton, 1995, pp. 4-5). In contrast to Thornton's theory, MacPherson (1998) found that problem solving styles, which includes a measure of confidence, to be the least important indicator of problem solving skills.

Problem Solving

Types of Problems

A problem can be seen as an obstacle (Merriam-Webster Online, 2004), a task (Soden, 1994), a situation (Andre, 1986), a challenge, or a question. It is "a state of difficulty that needs to be resolved" (Miller, 2004). Problems may involve "the discovery of a logical principle, acquisition of an experimental method, and/or the interpretation of the physical world" (Saxena, 1983, p. 16). Problems are sources of perplexity (Merriam-Webster Online). "First, a problem is an unknown entity in some context (the difference between a goal state and a current state). Second, finding or solving for the unknown must have some social, cultural, or intellectual value" (Jonassen, 2004). But no matter how one looks at a problem, thought and skill are required to envision a functional outcome and to derive a solution to the problem.

According to Andre (1986), problems consist of four components: The goal(s), the givens, the obstacles, and the methods or operations (Figure 6). Paraphrasing Newell and Simon (1972), Andre agrees, "A problem is a situation in which the individual wants to do something but does not know the course of action needed to get what he or she wants" (p. 170). Also based on Newell and Simon's concept of goal space (resources, processes, and goal thrust), Custer (1999) categorizes problems into three general classifications: social/interpersonal, natural/ecological, and technological. "Intellectually, problems vary in at least four ways: structuredness, complexity, dynamicity, and domain specificity or abstractedness" (Jonessen, 2004).

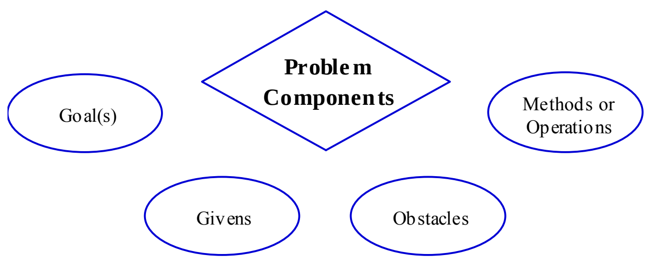

Figure 6. **Andre's components of problems (Adapted from Andre, 1986, pp. 170-1).**

Types of problems include *Well-Structured* problems, *Semi-Structured* problems, and *Ill-Structured* problems (VanGundy, 1988; Jonassen, 2004). Other problem structures include those of *Proactive* and *Reactive* (Baker and Dugger, 1986), and the *Ill-Structured/Well-Structured* continuum (Brightman, 1980). In well-structured problems, algorithms are commonly used to find the one correct solution. All the information needed to solve the problem is given. Heuristics are employed in solving semi-structured problems. They can have more than one answer where a combination of creative responses and a standard series of actions are requisitioned. "Well-structured problems also present all elements of the problem to the learners, and they have knowable, comprehensible solutions" (Jonassen, p. 3). Ill-structured problems challenge students to improvise and customize procedures because any functional solution could be considered correct. Little to no information is given as to the 'best' way to develop a solution (VanGundy, Jonassen). Divergent thinking and creative problem solving techniques are called for (Lodermeier, 1989). "This type of problem is almost never solved by looking for an algorithm, nor will heuristics ensure an acceptable solution" (Lodermeier, pp. 8-9). Jonassen establishes that ill-structured problems “do not necessarily conform to the content domains being studied, so their solutions are neither predictable nor convergent” (p. 3).

“Ill-structured problems are identified closely with the design process and creative problem solving. Solutions to ill-structured problems may utilize any or all of the complex thinking process skills of problem solving, decision making, critical thinking, or creative thinking” (Lodermeier, 1989, p. 19). In developing solutions to this type of problem students may call upon inference, intuition, invention, and innovation. Jonassen (2004) concurs and postulates students need to develop a “better understanding [of] design problems, which are perhaps the most important, albeit complex, kind of problem to learn to solve” (p. xxiii). He goes on to say, “Solving ill-structured problems requires intellectual flexibility that cannot be learned by memorizing any single interpretation of reality” (p. 103).

General Problem Solving

Problem solving is a dynamic process that is seen as a search for associations (Hill, 1979). It is the “application of relevant knowledge” (Soden, 1994, p. 26), which involves three components:

- Thinking (cognitive)
- Emotional or motivational
- Behavioral (Andre, 1986)

Representative of the emotional element is the confidence level a student possesses in the ability to solve a problem (Andre). Motivational and behavioral components involved in real-life problem solving are prominent. (Andre).

Many researchers have studied problem solving and developed definitions of the process. While each description may vary, two terms are common throughout the literature: thinking and learning. “Green (1966) observed two schools of thought: ‘one school feels that problem solving is but an extension of learning’; the other believes that learning is often problem solving in disguise” (Hill, 1979, p. 15).

In *The Conditions of Learning*, Gagné (1977) asserts problem solving to be a process of applying previously learned rules to arrive at a solution, which theoretically yields new learning. This new learning involves a higher order rule, "which enables individuals to solve other problems of a similar type" (p. 156). Problem solving is considered a form of learning in which new knowledge is acquired, at which time an "individual's capability is more or less permanently changed" (Gagnè, p.157). The test of problem solving occurrence is that a solution has been reached and transferred.

Cohen (1971) explains problem solving as:

> Using basic thinking processes to resolve a known or defined difficulty: assemble facts about the difficulty and determine additional information needed; infer or suggest alternate solutions and test them for appropriateness; potentially reduce to simpler levels of explanation and eliminate discrepancies; [and] provide solution checks for generalizable value (p. 5).

To show the relevance in similarities between the thinking required in problem solving and the thinking of everyday life, de Bono (1972) defines problem solving in everyday terms:

- Dealing with a situation
- Overcoming an obstacle
- Bringing about a desired effect
- Making something happen (p. 11)

Leone Burton (in Hill, 1979) postulates that "for Gagné, problem solving is at the pinnacle of the hierarchy for learning, for Duncker there is 'thinking in general or problem solving in particular,' [and] Mayer claims that thinking is problem solving"(pp. 8-9). "Barnes (1989) speaks of problem solving as a universal model for transforming knowledge" (Lodermeier, 1989, p. 5). The capacity to construct problem solutions by applying prior knowledge is considered an important aspect of problem solving (Berkemer, 1989). Problem solving generates "a framework of thinking for recognizing problems, thinking of possible solutions, and testing or evaluating the solutions" (Berkemer, p. 18). In problem solving, students learn "to make use of known concepts and rules to define a problem and find its solution; learning involves using internal process categories in seeking a solution" (Anderson and Krathwohl, 2001, pp. 264-265).

"Problem solving involves the process of coordinating previous experience, knowledge, and intuition in an attempt to determine a method for resolving a situation whose outcome is not known (Charles & Lester, 1982, p 10). "Problem solving is a critical skill that involves virtually all aspects of existence" (Custer, 1995, p.232). Students' cognitive, affective, and experience factors collaborate to determine success in problem solving (Charles and Lester). Figure 7 exhibits some of these factors.

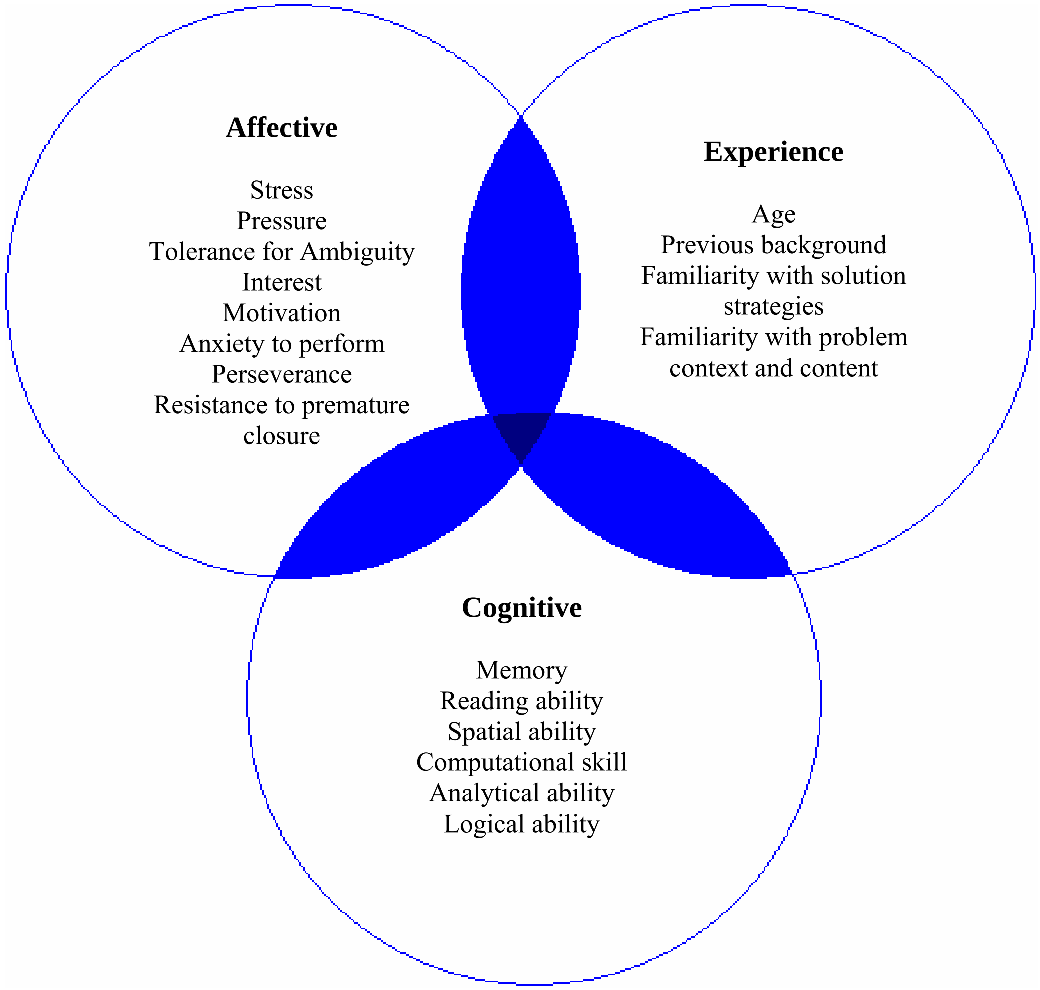

Figure 7. **Some factors influencing the problem solving process (Adapted from Charles & Lester, 1982, p. 12).**

Several kinds of problem-solving experiences exist. In readiness experiences students engage the emotional/motivational component. Charles & Lester (1982) concluded, "A willingness to engage in problem solving and self-confidence in one's ability to succeed [are] probably the most important characteristics a student can bring to the problem-solving situation" (p. 16). Other experiences include "exploring essential problem-solving strategies" and "solving various types of problems and discussing their solutions". Appropriate and relevant experiences will help to "establish positive attitudes toward problem solving" and will "enhance the development of the ability to visualize mentally the key components of a problem" (Charles & Lester, p. 16).

Processes and Strategies

In solving problems, certain processes, including divergent thinking, are engaged. These certain processes "refer to the mental operations that problem solvers employ to think about the representation of goals and givens to try to transform the givens into the goals and find a solution" (Andre, 1996, p. 181). Based on the work of Anderson, 1980; Hayes, 1981; Mayer, 1983; and Newell & Simon, 1972, Andre (1986) lists four problem solving approaches:

- Information or schemata (productions) in long-term memory
- Heuristic approaches
- Algorithms for problem solutions where available
- Metaphorical relationships with other representations

"Heuristics indicate likely directions to pursue or approaches to follow (Andre, 1986, p. 181). Following steps in a heuristic approach may lead to problem solutions and is most useful to problem solvers when they are unfamiliar with the subject matter of the problem (Andre). While prioritizing tasks to solve a problem is important in applying the heuristic approach, typical components of this process might include

- Recognizing the problem
- Defining the problem
- Selecting a strategy
- Attempting to solve by acting on a strategy
- Drawing conclusions and checking results (Lodermeier, 1989)

Over the years, many components and phases of problem solving approaches have been developed. Including as few as three stages and as many as ten, it seems that the underlying principles remain the same. Appendix C details selected problem solving approaches. Consequently, "efforts have been needed to more clearly define the primary processes involved [specifically] in technological problem solving" (Hill & Wicklein, 1999, p. 6).

At first glance, strategies for solving problems may seem similar to typical problem solving procedures. However, they differ in that procedures in general may have but one solution (Siegler & Jenkins, 1989). Accordingly, groups of students may employ any number of strategies to solve a problem, but every group will travel different paths and arrive at different solutions. For example, Lawson (1990) found that scientists are problem oriented and use analysis in their problem solving methods, and that architects are solution oriented and use synthesis in their problem solving methods; however, no significant differences in their use of strategies occurred. This would stand to reason, since strategies are deliberate, "goal-directed, mental operations that are aimed at solving" problems (Bjorklund et al, 1990, p. vi).

Forward search (Fikes & Nilsson, 1971; Winston, 1984) and *problem reduction* (Newell & Simon, 1972) are two general problem-solving strategies. The forward search approach encourages the problem solver to exercise the problem solving process step by step until the goal is met or the solution to the problem is attained (Bjorklund et al., 1990). Problem reduction involves subgoaling, in which the current state and the goal state differences are identified, and then a method of achievement is pursued (Bjorklund et al.). The mastery of a wide variety of problem solving skills and processes allows students to use those skills and processes in successful problem solving strategies (Charles & Lester, 1982).

Technological Problem Solving

The concept of general problem solving involving a definite focus on technological problems is known as technological problem solving (Halfin, 1973; Hill and Wicklein, 1999; Hutchinson and Hutchinson, 1991; Hutchinson and Karsnitz, 1994; ITEA, 2000; Todd, 1990). Technological problem solving involves hands-on, active learning situations that promote lateral thinking and cyclic processes, yielding no one correct answer (Davis et al., 1997; ITEA). Jonassen (2004) agrees, “Learning and problem solving are active processes. Learning from activity requires reflection on that activity” (p. xxiv). Two individuals can arrive at the same solution to a problem using different, correct methods (Charles & Lester, 1982, p. 12). Any number of a variety of approaches may be applied (Hill & Wicklein; Johnson, 1994; Johnson, 1996; Maley, 1986; Pucel, 1995; Savage and Sterry, 1990; Tidewater Technology Associates, 1986; Waetjin, 1989; Wicklein, 1986; Wright, Israel, & Lauda, 1993). Hill and Wicklein recommend considering this context when determining how problem-solving skills can best be developed.

Solving problems is fundamental to all aspects of technology (Tidewater Technology Associates, 1986, ITEA, 2000). Problem solving skills must be taught, “to ensure that our citizens will be able to adapt to the ever-changing world, [and] to meet personal needs as well as [the] needs of society as a whole” (Tidewater Technology Associates, p. 15). Developing problem solving abilities at an early age is essential to generating students’ technological literacy (Custer et al., 2001). For example, *Standards for Technological Literacy*: Chapter 3-The Nature of Technology, Standard 1F states, “In order to comprehend the scope of technology, students in grades 6-8 should learn that new products and systems can be developed to solve problems or to help do things that could not be done without the help of technology” (ITEA, p. 27).

Technological problems feature invention, development, and the employ of tools and objects for human purposes (Custer, 1999). Four major categories of technological problems “include invention, design, troubleshooting, and procedures” (Custer, p. 26). “The primary problem-solving approach in technology” is design (ITEA, 2000, p. 5). While not all technological problems are design problems, technological design is considered “the core problem-solving process of technological development” (ITEA, p. 90). Design or problem solving process literacy requires cognitive and procedural knowledge as well as familiarity with the processes carried out in making a product or system (ITEA). In addition to design, the ITEA identifies other problem types such as, invention and innovation, experimentation, research and development, and troubleshooting (ITEA).

Technological problem solving involves real-world, practical problem-solving methods. Technological design also promotes teamwork as a method by which people work together to accomplish a common goal. “If students know how problem-solving methods work, they can gain a better appreciation and understanding of technology” (ITEA, 2000, p. 90). Applying problem solving methods gives students the opportunity to practice interdisciplinary skills:

- Performing measurements, making estimates and doing calculations—using a variety of tools
- Working with two- and three-dimensional models
- Presenting complex ideas clearly
- Devising workable solutions to problems (ITEA, p. 90)

For example, LaPorte and Sanders (1996) developed the *Technology, Science, and Mathematics Connection Activities*; a teacher’s resource binder specifically related to technology, science, and mathematics connection activities. Presently, “curriculum and professional development efforts are directed toward developing problem solving abilities through authentic learning and problem-based teaching methodologies” (Custer et al., 2001, p. 5). Developing problem clarification abilities and using this ability to make sound decisions are central to technological problem solving activities; transforming "abstract ideas into tangible objects" builds confidence (Custer, 1999, p. 32).

Processes and Activities

Traditionally, teaching problem solving has been associated with school subjects like math, science, and social studies (Yi, 1996). Not until the mid-1980s did problem solving procedures and techniques specifically begin to appear in the technology education literature (Baker and Dugger, 1986; Johnson, 1987; Tidewater Technology Associates, 1986). In the 37th Yearbook of the Council on Technology Teacher Education (CTTE), Hatch (1988) wrote a chapter entitled, the *Problem Solving Approach*, in which he emphasizes the connection between problem types and thinking processes. Savage & Sterry (1990) suggest the technological problem solving process parallels the scientific method. Hein (1987), however, determined that while the discipline of science embodies the theory of problem solving skills, there had been no definition of a progressive development.

The technological problem solving process involves "a rational series of steps that the problem solver presumably goes through in solving a problem" (Andre, 1986, p. 174). Common factors among the reviewed problem solving processes include:

- Identifying and defining the problem
- Researching and analyzing relevant information
- Generating and implementing solutions to the problem
- Evaluating and revising the best possible solution

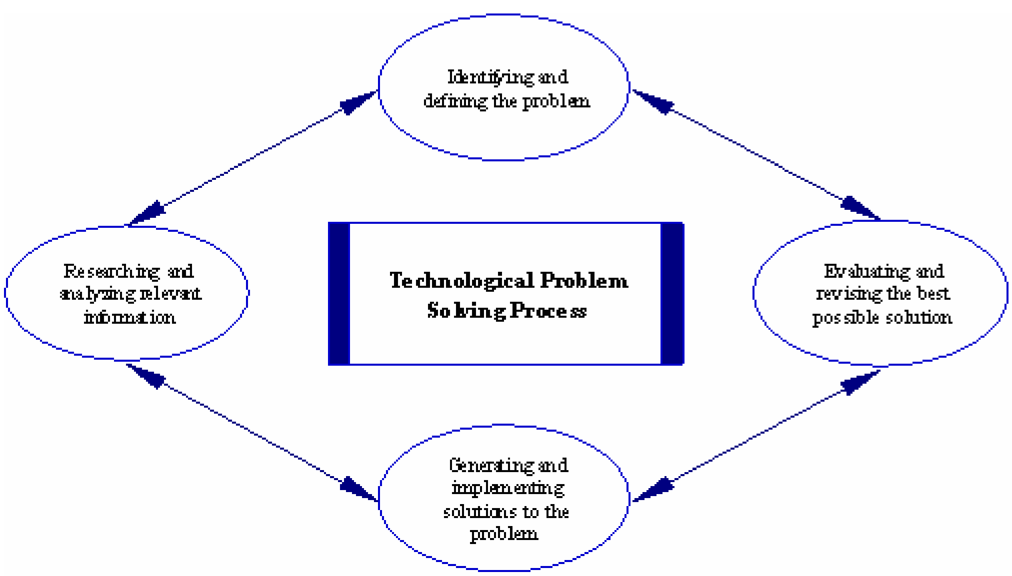

***Figure 8.* The technological problem solving process as a non-linear process.**

Figure 8 illustrates a non-linear process (Berkemer, 1989; Hill & Wicklein, 1999; McCormick, Murphy, & Hennessy, 1994). The phases pertinent to successful technological problem solving comprise components in a process that may sometimes be used simultaneously, successively, and/or iteratively (Hill & Wicklein). "By integrating these processes, technology educators can create comprehensive approaches to technological problem solving that are not limited to tools, equipment, and laboratories" (Hill & Wicklein, Recommendations, ¶ 34).

"Through carefully selected activities, students can increase their problem solving and decision making skills" (Lodermeier, 1989, pp. 1-2). Brusic (1991) defines a technological activity as a project devised to strengthen specific concepts by encouraging students to apply creativity, knowledge, and resources to solve practical problems. Berkemer (1989) found that projects "appear to emphasize problem solving (as opposed to creativity) to a greater extent than [he] originally assumed" (p. 186). This may be accomplished "through teaching a framework of thinking that facilitates creative three-dimensional, technical solution development" (Berkemer, p. 172).

A technological activity ought to be "guided by criteria and constraints" (Custer et al., 2001, p. 6). The objective of a problem solving activity is "to enhance creativity in students by helping them to understand and internalize that methodology, a repeatable and transferable framework for creative problem solving" (Berkemer, 1989, p. ii). Problem solving activities should "involve heuristics and creative problem solving processes which enhance higher levels of thinking" (Lodermeier, 1989, p. 62). Table 2 exhibits several sample strategies.

Table 2. ***Problem Solving Strategies***

Identifying and defining the problem	• Ask: What is the problem? • Ask: What information is provided in the problem? • Simplify the problem. • Draw a diagram representing the problem components. • Devise a plan.
Researching and analyzing relevant information	• Ask: Do I know similar problems? • Ask: Can I solve part of the problem? • Utilize appropriate resources.
Generating and implementing solutions to the problem	• Ask: Is more than one solution possible? • Develop solutions. • Ask: What is the best possible solution? • Prototype the solution.
Evaluating and revising the best possible solution	• Check results. • Make revisions.

Sources: Schoenfeld (1979); Heiman & Slomianko (1985); Pressley & McCormick (1995)

Problem Solving: Robotics

George C. Devol, Jr., patented the first industrial robot in 1954. The first Unimation Robot was sold to General Motors in 1961. Its name, "Unimate," meant universal automation. In the 1970s and early 1980s, assembly line robots became commonplace. Post-secondary curriculum efforts first began to emphasize the need for robotics personnel in the workforce in the United States in the early 1980s. Not until the 1990s did endeavors to recognize the study of robotics technology ensue at the elementary and secondary levels. Even then it was more like playing with toys than an actual co-curricular activity. In the last ten years, there has been an enormous increase in the development and implementation of robotics competitions for K-16 students. To date more than twenty-six educational robotics platforms and competitions have been developed.

Though the use of robotics in industry began in 1960, educational robotics platforms did not begin to surface until 1980. It was also around this time that robotics curriculum projects were undertaken albeit for students at the community college level. Currently, there are more than twenty-six experiential K-12 robotics programs throughout the United States. More of these exciting groups exist internationally. A few of these robotics platforms are designed for elementary school students, while most are for use in middle school, high school, and college/university settings. Many companies have developed mobile units, but some are scale models of industrial systems. The primary goal of all these companies is to promote the use of robotics in education for developing interest in STEM, and to motivate students to learn. Following is a list of some of the more prominent endeavors (This list is by no means exhaustive).

- Acroname Rug Warrior
- Aerial Robotics Competition
- Arrick
- Autonomous Underwater Vehicles Competition
- B.E.A.M.
- B.E.S.T.
- BattleBots IQ
- Esched/Intellitek
- Fischer Technic
- General Robotics
- Kiss Institute for Practical Robotics (K.I.P.R)
- LEGO™
- LynxMotion
- Mondotronics Muscle Wires
- NASA Robotics Education Project
- Oct Bot Survivor
- OWI Robotics, Inc.
- Parallax, Inc.
- Rhino Robotics
- Robix
- Robotix
- Teach Mover Systems
- Technic K'Nex
- Trinity College Firebot Challenge
- U.S. FIRST™
- Valient Technologies Roamer Robot

Depending on what the teacher intends to accomplish, the robotics program of choice can vary widely. OWI Robotics, Inc. provides several "science kits" that are appropriate for study in the classroom. LEGOs™ can be used in the classroom or for extracurricular purposes. Valient Technologies uses the Roamer robot and General Robotics uses the RB5X to teach pre-K through upper elementary students about math, science, programming, and technology.

The FLL Robotics *Challenge* as a Technological Problem Solving Activity

The LEGO™ Company distributes a robotics kit called *Mindstorms*™. This kit allows students to explore design concepts, autonomous robot construction, and programming. Traditional LEGO™ blocks are used to construct a mini-mobile robot of the students' own design. Students write programs using Robotics Invention System (RIS) or RoboLab icon-based software then transmit the program from the computer via an infrared (IR) transmitter to the "brick" (RCX) on the robot itself. The RCX is a microcomputer about the size of a bar of soap and was developed by Seymour Pappert for use with the Logo language and the *Turtle* robot. These kits are versatile and can be reused from year to year. Problems with this platform may include keeping up with small parts and dealing with the psychological issues that arise when children are required to disassemble their robots. *Mindstorms*™ for schools cost about $200 per kit.

FIRST™ Robotics

As previously mentioned Dean Kamen founded the FIRST™ Organization in 1989 to encourage kids to pursue careers as engineers, scientists, and inventors. His reasoning was that students in the United States were reported to be lacking in basic math and science skills as compared internationally. Before FIRST™ however, *Invent America* was set up by the U.S. Patent Model Foundation in 1986 to promote problem solving in education for the same reason. "The creation of this program was founded on the need for our country to remain competitive on the world market by providing students with opportunities to learn and apply higher level thinking skills at the elementary level" (Lodermeier, 1989, p. 11).

FIRST™ was conceived in an effort to bring education and corporations together in order to change the previously mentioned math and science statistics. At the high school level, teams of about 30 students participate in fundraising, engineering and design, CAD, product development and evaluation, and competition. During the challenge season, each team works with engineers and industry to come up with a solution to a challenge problem using a basic kit of parts. The kit may include servomotors, controllers, and other items important to the creation of an autonomous robot. This activity, however, is not necessarily student-centered. In other words, engineers do not act solely as mentors. They can actively participate in the design and construction of the full-scale mobile robot. Only students, however, can participate in the "human factors' component on the competitive playing field.

Similar to an after school sports team, students must try-out for their position on the team. This is usually done through an application and interview process. One advantage to this program is that students develop very marketable skills and are usually hired by their corporate sponsors as interns and employees.

Kamen recently received the distinguished Limelson-MIT Prize in the amount of $500,000. He donated this money to the FIRST™ Foundation to provide team grants. Advantages of this program include opportunities for participants to receive scholarships for higher education, which have increased from less than $10,000 in 1993 to more than $3,000,000 in 2003. One major disadvantage to this program is the cost to participate. The annual budget for any FIRST™ team ranges from about $28,000 to upwards of $150,000. Fundraising and corporate sponsorships are necessary.

Short-term Outcomes of the FIRST™ Robotics Competition

FIRST™ has identified nine short-term outcomes for the robotics competition:

- Attitudes about science and math
- Enjoyment of high school science and math classes
- Perceived knowledge of science and math careers
- Intentions to persist in STEM
- Educational aspirations
- Career aspirations
- Attitudes about teamwork
- Attitudes about the working world
- Self-images

FIRST™ hired the Goodman Research Group, Inc. (2000) to develop an assessment that would measure these outcomes. Their report is based on pre-test/post-test instrumentation regarding students' perceptions of these outcomes.

While students were already interested in math and science before participating in FIRST™, their reported attitudes about math and science increased significantly from the beginning to the end of the challenge season. However, their enjoyment of high school math and science classes did not change. "Students' perceptions of their knowledge of *science* careers did not change from pre to post, however, boys, white students and new students rated their knowledge of *math* careers lower after FIRST™" (Goodman Research Group, Inc, 2000, p. 19).

Intentions to persist in STEM did not change over the course of time. This could be due to the majority of participants' intentions to enroll in STEM courses before participating in FIRST™. However, the researchers concluded, "the more students know about science and math careers, the greater the likelihood that they will take advanced science and math classes in high school, take science and math classes in college, and pursue science and math careers" (Goodman Research Group, Inc, 2000, p. 22). Females reported more interest in education and medicine, while males reported more interest in computers and engineering. Attitudes about teamwork, the working world, and self-images were primarily positive before the FIRST™ experience; however, significant gains were measured in each of these variables after the experience.

The Goodman Research Group, Inc. (2000) reported differences between male and female participants in the areas of roles and responsibilities. "Girls were more likely than boys to assume public relations, marketing, video, and finance roles, while boys were more likely than girls to assume construction, controls, and operator roles." (p. 39). Forty-nine percent of student participants reported that students work together to solve problems, but overall "students believed that team members tended to work together rather than independently and that boys played a larger role on their team than did girls" (Goodman Research Group, Inc, p. 42).

In October 2003, FIRST™ contracted the Center for Youth and Communities at Brandeis University to modify the aforementioned measures for use with the FLL Robotics *Challenge*. Similar results were reported in August 2004. As reported by student participants and coaches, FLL had a positive impact on students by "increasing interest in and understanding of science and technology" and by "helping students strengthen a wide variety of skills" (U.S. FIRST™, 2004c, Slide 6). While students reported wanting to learn more about technology and interest in how science and technology can solve real world problems, student participants' understanding and problem solving skills were not measured.

FIRST™ and LEGO™

In 1998, the Educational Division of LEGO™ teamed up with the U.S. FIRST™ Organization to form the FLL. This competition is "considered the 'little league' of the FIRST™ Robotics Competition" (U.S. FIRST™, 2004d, FIRST LEGO League, ¶ 1). Participants work on teams to design, construct, and program a robot that will complete the Robotics *Challenge*. Teams compete on a 4' x 8' playing field where their robot must autonomously complete as many of the specified challenges (usually eight or nine) as possible. Student participants also engage in a problem-solving research component that is presented to a panel of judges. Other aspects of the competition include teambuilding activities that promote collaboration, cooperation, and real world engineering problem-solving skills. A first-year team can expect to pay about $600 to get started in this competition.

The FLL is intended to be the feeder program to the high school FIRST™ robotics experience. "FLL extends the FIRST™ concept of inspiring and celebrating science and technology to children aged 9 through 14, using real-world context and hands-on experimentation" (U.S. FIRST™, 2004d, FIRST LEGO League, ¶ 1). Participants solve real-world problems using "engineering and computer programming principles as they construct and program their unique robot inventions" (U.S. FIRST™, d, ¶ 2). The FLL *Challenge* history is documented in Appendix D.

The FLL annual competition season begins September 15, at which time FIRST™ announces the *Challenge*, which features "a current scientific or technological problem facing the world" (U.S. FIRST™, 2004d, Information and Resources: The Challenge) Registered teams, ranging from 4 to 10 members, then have 8 weeks to design, build, and program an autonomous robot to complete as many specific *Challenge* related tasks as possible in 2 minutes, 30 seconds. Though not an official FLL document, Bishop and Jennings (2003) of INSciTE (Innovations is Science and Technology Education) have developed a linear schedule, suggesting what should happen each week during the *Challenge* season. Schedules of important dates for the 2004 and 2005 FLL *Challenge* seasons are found in Appendix E. Digital images of student participants during practice sessions and the 2004 No Limits FLL Robotics *Challenge* may be viewed in Appendix F.

The number of teams and participants competing in this program has astoundingly increased since the 1998 pilot implementation and has reached global proportions (Table 3). FLL claims a concept of "problem solving and creativity" (U.S. FIRST™, 2004e). Teams of student participants employ skills for "building, programming, testing, [and] investigating solutions," then "compete with peers" in a regional or qualifying, sports-like tournament. Rapid growth has demanded an increase in the number of qualifying and state tournaments.

Table 3. ***FLL History of Teams and Tournaments Growth***

	Number of teams participating	Possible range of student participants	Number of tournaments
1998	200	800-2000	2
1999	1000	4000-10,000	9
2000	1500	6000-15,000	30
2001	1800	7200-18,000	50
2002	2600	10,400-26,000	82
2003	3450	13,800-34,500	120
2004	5200	20,800-52,000 (projected)	142

Chapter 3
Methodology

Design

The focus of this study was on technological problem solving styles and student participants' performance during a technological problem solving activity. The study builds upon the work of Heppner (1988), Wu et al. (1996), and Custer et al. (2001). The design of the study was correlational. A survey questionnaire was used to collect data on FLL student participants. Direct observations were conducted and scored using a performance rubric. Exit interviews were conducted at the end of the *Challenge* season.

Because there is a difference between personal and technological problem solving (Wu et al., 1996), technological problem solving should be examined more closely than it has been in the past. The Grade 5 version of the PSI-TECH (Appendix G) was administered to 9-14 year olds participating in the 2004 FLL No Limits *Challenge* during week one, and after weeks four and eight. Student participant performance behaviors were determined using the final revision of the SIP rating sheet (Appendix H). The area under study included the VDOE Regions 6 & 7 of Southwest Virginia (Appendix B).

Research Questions

1. Is there a relationship between student participants' FLL experience levels and their technological problem solving styles and performances?

2. Is there a relationship between FLL student participants' age and gender with their technological problem solving styles and performances?

3. How well do student participants' technological problem solving styles predict their technological problem-solving performances?

4. What effect does participation in a technological problem solving activity such as FLL have on student participants' technological problem solving styles and performances over time?

Pilot Study

During the week of August 30, 2004, a pilot study was conducted at a local middle school. Administrative approval was obtained before securing parental permission and photo release forms for each student participant. Letters and forms pertaining to the pilot study can be found in Appendix I.

Student participants were asked to design, construct, and program a solution to the following technological design brief.

> ***Challenge*:**
> The local post office recently changed their rates to be determined by the size of the package. They have decided to charge just two fees – one for packages a certain height and under, and one for packages over that height. Design a device that will separate packages by height into

two bins. Items of a certain height and under will go into one bin; items over that height will go into another bin. (Litowitz, n.d., p. 8).

The pilot study sample was one of convenience and included 37 sixth, seventh, and eighth grade students, 26 boys and 11 girls, enrolled in technology education courses (Table 4).

Table 4. ***Numbers of Pilot and FLL Study Student Participants***

	Pilot Study			FLL Study		
Age	Male	Female	Total	Male	Female	Total
9				5	0	5
10				3	0	3
11	8	7	15	2	4	6
12	6	3	9	6	5	11
13	10	1	11	4	5	9
14	2		2	2	0	2
Total	26	11	37	22	14	36

Implementation

During the week of August 30-September 3, 2004, a pilot study was conducted to explore the usability of the PSI-TECH and SIP with 9 to 14 year old technology education students. Administrative permission was obtained before the study began. Third and fourth period students were chosen to participate in the pilot study because of the time and availability of the two raters. Parental permission was obtained for each student to participate in the study. The pilot study lasted 5 days.

The second rater was selected on the basis of his background in engineering, and his interest in education and FLL. One week before the pilot study, the second rater was given a copy of the revised rubric (Appendix J), which contained four separate rating sheets for observations. Before direct observations began, the researcher (rater one) and the second rater reviewed and discussed the revised rubric. Topics of the discussion included the four dimensions to be observed and rated: Day Two SIP 1 – Problem Clarification; Day Three SIP 2 – Developing a Design; Day Four SIP 3 – Modeling/Prototyping; and Day Five SIP 4 – Evaluating the Design Solution.

On the first day of the pilot study, the PSI-TECH was administered to student participants and the technological problem was issued and explained. Student participants were randomly placed in groups by pulling names out of a cup. There were three groups in third period and four groups in fourth period. Each group was given a complete *Mindstorms*™ set, including parts for construction, an RCX with fresh batteries, and an IR tower. Prior to the pilot study, each kit was inventoried before distribution to ensure equality and the *Robotics Invention System* (RIS) software was installed on the computers in the technology education lab. No constraints were placed on the development of individual group dynamics and student participants were allowed to establish their own methods and procedures to solve the given problem. For the remainder of the pilot study, students designed, constructed, and programmed solutions for the technological problem. At the end of each day, the raters compared scores and notes, and discussed the day's events. At the end of the week, the researcher determined that the SIP rating sheets should be further revised before the FLL study. The reasoning behind further revisions was that the four rating sheets represented a linear problem solving process, while the behaviors of the student participants were indeed non-linear. Therefore, it was necessary to encompass all performance dimensions for scoring on one rating sheet.

Methods of the FLL Study

Population/Sample

The sample for the FLL study was one of convenience and consisted of registered FLL teams in VDOE Regions 6 & 7 of Southwest Virginia. There were 36 student participants, 22 males and 14 females (Table 4). Numbers of student participants on each teams ranged from 5 to 10 members aged 9, 10, 11, 12, 13, and 14. A random sample was drawn from teams that were registered on or before September 8, 2004. Official FLL registration was scheduled to end September 30, but was extended to October 8, 2004. In order to measure student participants' problem solving styles before the competition season began, sample selection ended and parental permission obtained before the *Challenge* was released September 15, 2004. Parental permission was required for participation in the study (Appendix K).

Since the sample was one of convenience and particular to the CPES NSF grant, *Partnerships in Engineering: A Robotics Challenge for Southwest Virginia*, the sample size was confirmed *a posteriori*. Using a sample sizes table (Hinkle, Wiersma, & Jurs, 1998), the following was determined: Sample size = 34, $\alpha = .05$, d = .50, $1\text{-}\beta = .80$; where α is the level of significance, d is the standardized effect size, $1\text{-}\beta$ is the power of the test, and the directionality of the test is two-tailed.

FLL experience levels typically range from no experience (0 years) to 5 years of experience. For example, if a 9-year-old student participant with no previous experience in 1999 participated every year beginning in 1999, for the 2004 *Challenge* season this student participant would be 14 years old and have 5 years of FLL experience. If a 14-year-old student participant has not participated before 2004, that student participant will have no experience (Appendix L). Total 2004 FLL experience levels corresponding to age possibilities could be:

- 9 years old 0 years experience
- 10 years old 0 or 1 years experience
- 11 years old 0, 1, or 2 years experience
- 12 years old 0, 1, 2, or 3 years experience
- 13 years old 0, 1,2, 3, or 4 years experience
- 14 years old 0, 1, 2, 3, 4, or 5 years experience

As reported on the *Student Participant Inventory* (Appendix M), 28 student participants had no previous FLL experience, 7 had 1-year experience, and 1 had 2 years previous experience (Table 5). FLL team coaches, volunteers, and mentors were also asked to complete surveys at the beginning of the *Challenge* season (Appendix N).

Table 5. ***FLL Challenge Experience***

	Males (*n* = 22)						Females (*n* = 14)						
	9	10	11	12	13	14	9	10	11	12	13	14	Total
0 Years	4	3	1	4	4	1			4	4	3		28
1 Year	1		1	2						1	2		7
2 Year						1							1
3 Years													
4 Years													
5 Years													
N	5	3	2	6	4	2			4	5	5		36

Procedure

The FLL *Challenge* season is 8 weeks in duration. During this period of time, student participants completed the technological version of Heppner's (1988) self-reporting instrument, the *Problem Solving Inventory* (PSI-TECH). Three administrations of the PSI-TECH took place during the weeks beginning September 20, October 25, and November 15, 2004. Student participants designed, built, and programmed autonomous mini-mobile robots capable of completing up to nine tasks within 2 minutes, 30 seconds. Raters directly observed and used the final revision of the *Student Individualized Performance* (SIP) rubric (Custer et al., 2001) to determine student participants' technological problem solving performance during practice sessions and regional tournaments. The data collection schedule is shown in Table 6.

Table 6. ***Data Collection Dates***

Week	Dates	Instrument
	September 15	Challenge released
1	September 20-24	PSI-TECH 1
2	September 27-October 1	
3	October 4-8	SIP Observations 1
4	October 11-15	SIP Observations 2
5	October 18-22	
6	October 25-29	PSI-TECH 2
7	November 1-5	SIP Observations 3
8	November 8-12	SIP Observations 4
	November 13-14	Regional Tournaments
	November 15-19	PSI-TECH 3
	December 5, 2004	VA FLL State Tournament

Instrumentation

Two quantitative instruments were used in this study. The technological version of the *Problem Solving Inventory* (PSI-TECH) measured student participants' perceptions of their technological problem solving confidence, approach/avoidance styles, and personal control during a technological problem solving activity. It also provided an overall score for technological problem solving style. Problem solving style was measured three times throughout the FLL

Challenge season (during week one, and again after four and after eight weeks). The *Student Individualized Performance* (SIP) rubric was revised and used by two raters to score direct observations of student participants' problem solving behaviors, placing them at one of five levels (Novice, Beginner, Competent, Proficient, and Expert) in four distinct dimensions (Problem Clarification, Developing a Design, Modeling/Prototyping, and Evaluating the Design Solution). Team members were observed throughout the FLL *Challenge* season as indicated in Table 6.

Problem Solving Inventory (PSI-TECH)

The PSI-TECH is a published instrument and is considered valid and reliable. Reliability and validity of this adapted version of the PSI-PSYCH were established in two studies: Wu, et al. (1996) and MacPherson (1998) (Table 7). "The primary difference between the original PSI [PSYCH] and the PSI-TECH is that the PSI-TECH focuses specifically on technological problem solving situations" (Custer et al., 2001, p. 14). The PSI-PSYCH was designed to assess a person's perceptions of his or her problem-solving behaviors and attitudes. The 35-item instrument measures an individual's awareness and self-concept regarding their problem solving styles (Heppner, 1988). Reliability estimates for the original PSI-PSYCH are reported in Table 8.

Table 7. ***PSI-TECH Internal Consistency Reliability***

		Problem Solving Confidence	Approach/ Avoidance Style	Personal Control
Heppner (PSI-PSYCH)	1988	.85	.80	.71
Wu, Custer, and Dyrenfurth	1996	.88	.81	.76
MacPherson	1998	--	--	--

Note. Dashes indicate no data was reported.

Table 8. ***PSI-PSYCH Test Reliability Estimates***

		N	α
Heppner & Peterson	1982	150	.90
Moss	1983	66	.90
Sabourin, Laporte, & Wright	1990	146	.91

Heppner (1988) employed a principal components factor analysis to identify the major factors of the instrument, and then a scree test was performed, which also implied three factors:

- Confidence in one's problem-solving ability
- An approach-avoidance style
- Perception of personal control" (p. 9)

Problem-Solving Confidence is a measure of self-assurance while engaged in problem-solving activities. "Low scores on this scale indicate that individuals believe and trust in their own problem-solving abilities" (Heppner, 1988, p. 1). The measure of *Approach-Avoidance Style* represents the general tendency of persons to approach or avoid said problem-solving activities. Indicating one's perceptions of *Personal Control* shows "the extent to which individuals believe that they are in control of their emotions and behavior while solving problems" (Heppner, p. 2). The *Total PSI* score may be "used as a single, general index of problem-solving appraisal" (Heppner, p. 1).

Among other environments, Heppner (1988) recommends the PSI be used in educational settings to assess students' problem-solving styles. Scores may also be helpful in predicting affective, behavioral, and cognitive variables useful in determining problem-solving style. Written on a fifth grade reading level, Form B of the PSI is usually "completed in 10 to 15 minutes" (Heppner, p. 4). A 6-point Likert scale is used: 1 = Really Agree, 2 = Mostly Agree, 3 = Agree, a little, 4 = Disagree, a little, 5 = Mostly disagree, 6 = Really Disagree. The inventory contains an equal number of expressions regarding problem solving.

"The standard error of measurement provides an approximate index of the reliability of an individual's scores and can be used for a band interpretation of scale scores" (Heppner, 1988, p. 6). Table 9 presents the number of items, range, and standard error for the original PSI-PYSCH scores. Theoretical true scores are reported to fall within ±1 standard error (*SE*) of the obtained score with 68% certainty and ±2 Se for 95% confidence. It should be noted that a sample of undergraduate psychology students were examined by Heppner to calculate test-retest correlations. Reliability measures for all four scores were computed for two weeks (N = 31; .83 - .89), three weeks (N = 64; .77 -.81), and two years (N = 29; .44 -.65). Moderate interscale correlations (PSC/AAS, r = .49; PSC/PC, r = .49; AAS/PC, r = .38) connote adequate independence among factors to justify separate scales.

Table 9. ***Number of Items, Range, and Standard Error of Measurement for Original PSI-PSYCH Scores***

			Males (n = 402)			Females (n = 498)		
Scale	N Items	Score Range	M	SD	SE	M	SD	SE
Problem-Solving Confidence	11	11-66	25.3	7.0	2.7	26.1	7.3	2.8
Approach-Avoidance Style	16	16-96	45.9	10.6	3.7	44.3	11.2	3.9
Personal Control	5	5-30	16.7	4.5	1.9	17.9	4.5	1.9
Total PSI	32	32-192	87.9	18.6	6.2	88.3	18.9	6.3

Note. Standard errors of measurement were computed on a sample of introductory psychology students.
Source: Heppner (1988)

For the FLL study, a reliability analysis (Cronbach's Alpha) was conducted to measure the internal consistency of the PSI-TECH. On the original 35-item scale, Heppner (1988) designated items 9, 22, and 29 as research items. Since his analysis does not include these three items, they were consequently omitted from the analysis of this FLL study. Items 1, 2, 3, 4, 11, 13, 14, 15, 17, 21, 25, 26, 30, 32, and 34 were reverse scaled to maintain scoring consistency between positively and negatively worded responses. The value of coefficient alpha for PSI-TECH 1 was .83, PSI-TECH 2 was .87, and PSI-TECH 3 was .92. The PSI-TECH grand total coefficient alpha was .87, indicating satisfactory reliability throughout the different administrations (Table 10).

Table 10. ***PSI-TECH FLL Study Reliability***

		Coefficient Alpha			
Administration Number	Date	Problem Solving Confidence	Approach/ Avoidance Style	Personal Control	Total
PSI-TECH 1	September 20-24, 2004	.73	.74	.57	.83
PSI -TECH 2	October 25-29, 2004	.68	.87	.73	.87
PSI-TECH 3	November 15-19, 2004	.84	.90	.79	.92
Grand Total		.75	.84	.70	.87

The Student Individualized Performance Rubric

The original *Student Individualized Performance* (SIP) rubric is an assessment tool designed to use direct observation methods in determining technological problem solving performance (Appendix A). Custer et al. (2001) identified four dimensions of technological problem solving: Problem & Design Clarification, Development of a Design, Modeling/Prototyping, and Evaluation of the Design. Each dimension is characterized by three subdivisions. Furthermore, each of these subdivisions contains "critical incidents," which aid in defining technological problem solving performance as novice, beginner, competent, proficient, or expert (Custer et al., p. 8).

While a panel of experts reviewed the original SIP rubric and minor revisions were made accordingly, interrater reliability issues existed with this instrument (α = .070-.501). This could be due to small sample sizes and insufficient length of time for rater training. The Custer et al. (2001) pilot study sample size consisted of three participants and two raters that only had two hours of training. The Custer et al. field test sample size was six. There were four raters having two hours of training (R. L. Custer, personal e-mail, June 15, 2004). For the FLL study, the researcher hoped to increase interrater reliability by training two raters familiar with the FLL Robotics *Challenge*, increasing the length of the rater training session, and having the raters use the assessment model in a pilot study (Table 11). The original SIP rubric was revised for use in the FLL pilot study. Redundant items were eliminated and the remaining elements were fashioned into four separate rating sheets according to category.

Table 11. ***Revised SIP Rater Training for Pilot and FLL Study***

	Pilot Study	FLL Study
Sample Size	37	36
Number of Raters	2	2
Length of Rater Training	2 hours	8 hours

During the FLL pilot study, raters were trained and preliminary interrater reliability calculated. For two hours prior to the FLL pilot study, raters were familiarized with the revised SIP. Interrater reliability was calculated. Pearson's *r* was equal to .184, which falls into the range of reliability reported by Custer et al. (2001). Because reliability was so low, the FLL pilot study SIP rubric was revised again for clarification of items and elimination of redundancy. The two raters spent eight hours using the revised SIP during the pilot study, then for about one hour after each observation day of the pilot study, discussed the performance items used that day. Item redundancy, technological problem solving dimensions measured by the SIP, item clarification, and the linear arrangement of the SIP were topics of discussion. The instrument was then revised again for use in the FLL study. Intended to measure all four dimensions of the original SIP in a cyclic fashion, the result was a 23-item performance rating sheet. Reliability measures for the final revision of the SIP are shown in Table 12. Overall Pearson's *r* was .939, indicating satisfactory reliability.

Table 12. ***Final Revision SIP Reliability for FLL Study***

Administration Number	Rater	Pearson's *r*
SIP Total 1	1*2	.472
SIP Total 2	1*2	.947
SIP Total 3	1*2	1.00
SIP Total 4	1*2	.987
Grand Total	1*2	.939

Organizing and Conducting the Study

Data Collection Method

FLL study data was collected from officially registered teams of FLL student participants. A database of registered teams and their contacts were obtained from the Virginia FLL Director. Telephone calls were made to inform coaches of the study, followed by an email describing the study. Initially, a random sample was taken in August 2004; however, few teams in VADOE Regions 6 & 7 had registered at that point causing the sample to be completely homogeneous. All five teams selected were from Montgomery County. These teams were replaced in the population so that a resample could be taken at a later date. The timing of the *Challenge* release and the delayed registration deadline can be frustrating for data collection purposes.

Ultimately, a random sample of four teams was selected from the total number of teams registered by September 8, 2004 in VDOE Regions 6 & 7 at which time forms indicating permission to participate were distributed. Although there were 33 registered teams in the sampling region after October 8, 2004, there were only 16 registered teams on September 8, 2004. Data collection schedules were coordinated and confirmed with team leaders according to their respective practice schedules (Appendix O). The researcher administered the PSI-TECH to

FLL participants. The researcher and the second rater conducted direct observations over the course of the 8-week activity. For the SIP, it was determined that four observation points would be made throughout the season. Note that no PSI-TECH administrations or SIP observations occurred during Week Two or Week Five. Data from the third PSI-TECH were collected after the regional tournaments, giving student participants time to reflect on their performances, and then report on their styles.

Demographic Variables

The demographic variables were student participants' age, gender, and level of FLL experience. According to the FIRST™ Foundation, participants in the FLL Robotics *Challenge* should be aged from 9 years to 14 years. There are no restrictions on how teams are formed (i.e., co-curricular, extra-curricular, after school organizations, home schools, neighborhoods, etc). The researcher expected older rather than younger FLL student participants to have higher problem solving confidence, to be more willing to approach problems than to avoid them, and to demonstrate higher levels of personal control during a problem solving activity. Younger student participants were expected to show greater growth rates over the eight-week period.

Student participants' FLL experience levels were collected in an interval data format. The range of experience was expected to be from 0 years of experience to 5 years of experience. The researcher expected experienced FLL student participants to have higher problem solving confidence, to be more willing to approach problems than to avoid them, and to demonstrate higher levels of personal control during a problem solving activity. Less experienced students were expected to show greater growth rates over the eight-week period. Male and female FLL experience levels, PSI-TECH scores, and SIP scores were compared.

Data Analysis

All statistical analyses were conducted using the SPSS computer software. Correlations were run to determine the relationships among age groups on PSI-TECH scores and SIP scores.

Simple ANOVA

A simple one-way analysis of variance was conducted to determine whether the means of the PSI-TECH scores and the means of the SIP scores were significantly different between males and females, among student participants with zero, one, and two years of experience, and among those aged 9, 10, 11, 12, 13, and 14 years.

Repeated Measures ANOVA

A one-way repeated measures analysis of variance was used to determine the variance among student participants, the variance among assessment occasions for the PSI-TECH and the SIP, and the residual variance or what variation was due to neither the individuals nor the assessment occasions.

MANOVA

A one-way multivariate analysis of variance was conducted to determine the effect of age and gender on technological problem solving styles and performances. A general linear model was produced to verify the findings.

Regression Analysis
A linear regression analysis was used to determine how well student participants' PSI-TECH scores predicted their SIP scores. The PSI-TECH grand total was the predictor and the SIP grand total was the dependent variable.

Qualitative Analysis
Exit interviews were conducted with each student participant during the week of November 15, 2004. The interview was used to clarify the researcher's questions and uncertainties that arose during the direct observations. Student participants were encouraged to speak freely about their experiences with the FLL 2004 No Limits Robotics *Challenge*. Eight questions were asked to gather insight as to what the student participants thought about the technological problem solving activity (Appendix P).

Chapter 4
Findings

The purposes of this study were: 1) to determine the relationships among age, gender, and FLL experience levels with student participants' problem solving styles and problem solving performances; 2) to assess how well student participants' problem solving styles would predict their individualized problem solving performances, and 3) to determine the effect a technological problem solving activity has on student participants' problem solving styles and performances over time. Case summaries are reported for all aspects of PSI-TECH and SIP scores for each student participant in Appendix Q.

Characteristics of FLL 2004 No Limits Student Participants

In order to gain a better understanding of student participants' previous experiences related to FLL, a survey was given at the beginning of the *Challenge* season. The FLL study sample for the 2004 No Limits *Challenge* consisted of 36 student participants, 61% male and 39% female. Seventy-eight percent of all participants had no previous experience in FLL, while 19% had one-year previous experience, having participated in either the 2002 City Sights *Challenge* or the 2003 Mission Mars *Challenge*. One student participant had two years previous experience competing in the 2000 Volcanic Panic *Challenge* and the 2003 Mission Mars *Challenge*. More males reported having previous FLL experience than did females. These statistics are reported in Table 13. The majority of student participants were 11, 12, and 13 years old (17%, 31%, and 25%, respectively). Nine, 10, and 14-year-old student participants made up the remaining 27%. Complete gender frequencies for the student participant survey are shown in Appendix R.

Table 13. ***FLL Student Participant Experience Level Comparisons By Age and Gender***

	Male						Female					
Age	Experience in years						Experience in years					
	0	1	2	3	4	5	0	1	2	3	4	5
9	4	1										
10	3											
11	1	1					4					
12	4	2					4	1				
13	4						3	2				
14	1		1									
Total	17	4	1				11	3				

When asked why they joined FLL, 56% of student participants reported that they wanted to learn more about engineering and technology (males = 55%, females = 41%). Two males said they had worked with LEGOs™ in technology education class at school (science, one; math, one; and other, three). No females indicated working with LEGOs™ at school. Approximately half of all student participants had played with LEGOs™ at home (males = 59%, females = 23%). Two males and two females (11% of all student participants) reported that they joined FLL because their parents signed them up for the team, and as opposed to 14% of all males, 36% of all females said they joined FLL because their friend was on the team.

Some FLL coaches designate roles for each team member, while others encourage all members to contribute to and participate in every aspect of the program. For this study, 4 males and 1 female reported that their responsibilities to the team included all four aspects of the *Challenge*: Design, construction, programming, and research. Many student participants recognized that they had specific roles on and responsibilities to the team. Males participating in only one *Challenge* category equaled 27%, while females equaled 14%. Males participating in two *Challenge* categories equaled 18% females, as did 14% of females. One male and one female reported having responsibility for three of the *Challenge* categories. Thirty-five percent of all student participants did not know or understand their respected roles for the *Challenge*. The issue of student participants having no previous experience could explain this lack of understanding. Also, the inventory was administered at the beginning of the season when some teams may not yet have had assigned roles.

Overall 33% of student participants (7 males, 5 females) reported that they solve their own technical problems, 50% (11 males, 7 females) said sometimes an adult tells them what to do, and 47% (12 males, 5 females) said they sometimes get help from a teammate. Not one student participant reported that an adult or a teammate always tells them how to solve a technological problem. However, 69% of all student participants (14 males, 11 females) said that the coach tells them what to do to learn about the FLL *Challenge* rules as opposed to student participants reading the rules manual or looking on the Internet.

Upon joining FLL, many student participants brought with them experiences from other organizations. Forty-seven percent (8 males, 9 females) had participated in 4H, 28 % (five males, five females) in Science Fair, 25% (7 males, 2 females) in Scouts, and 19% (4 males, 3 females) in Taekwondo. One student participant had previous experience with the Odyssey of the Mind science competition. No student participants indicated experience with the Technology Student Association or the Vocational Industrial Clubs of America.

Students may also gain unique experiences from the toys they play with. A list of the 24 most popular selling toys for children aged 9 to 14 was compiled and student participants were asked to indicate which toys they had played with in the last year. The top three toys chosen were Gameboy™ (86%; 18 males, 13 females), LEGOs™ (69%; 15 males, 10 females), and Playstation™ (69%; 16 males, 9 females). Three others worth noting were GameCube™ (44%; 10 males, 6 females), Nintendo™ (39%; 8 males, 6 females), and Xbox™ (39%; 10 males, 4 females). Only five males and no females had played with LEGO™ *Mindstorms*™ in the last year. It is interesting to note that 18 of the 24 top selling toys were electronic devices. All but one of the toys mentioned above were electronic devices.

Four teams were randomly selected to participate in the FLL study. Each team was required to have at least one coach aged 18 or older. Team One had three coaches, two males and one female. One male coach had one year of experience coaching FLL. The other two coaches had no previous experience with FLL. This team practiced on Mondays and Thursdays for about three hours each day. Team Two had two coaches, one male and one female, and two assistant coaches, both male. Both coaches had three years experience coaching in FLL. Both assistant coaches had two years experience as FLL student participants. This team practiced on Tuesdays and Thursdays for about two hours each day. Team Three had one female coach who had no previous FLL experience. This team practiced on Mondays and Wednesdays for about two hours each day. Team Four had one female coach with two years of previous FLL experience. Two assistant coaches, one male and one female, had no previous FLL experience. The team practiced on Tuesdays and Thursdays for about 1 hour 30 minutes each day. Coaches' ages ranged from 18 to 58. Fifty-five percent of the coaches were educators. Other coaches' occupations included a medical doctor, an engineer, and a financial advisor.

Each team was also allowed to have a mentor for technical support. Three teams had one mentor and one team had two mentors. There were three male and two female mentors. One female had two years previous FLL mentoring experience. The remaining four had no previous FLL experience. Their ages ranged from 21 to 39. Two males were graduate students studying technology education. Two females and the remaining male were undergraduate students studying engineering.

PSI-TECH

The PSI-TECH was administered three times over an eight-week period. Means, standard deviations, and standard error for each component of the instrument and the grand total were calculated and are reported by gender in Table 14. Student participants included 22 males and 14 females. The means and standard deviations were very similar for males and females. Male perceptions were slightly better on problem solving confidence and personal control, while female perceptions were slightly better on approach/avoidance style. Overall, males scored slightly better than did females. For the PSI-TECH grand total, scores ranged from 43 to 129, with median = 89.17 for males and median = 88.58 for females. For the PSI-TECH grand total scores, independent t-test results indicated no significant differences in the way males and females perceive their technological problem solving styles, *t* (34) = -.089, p = .05 (two-tailed), significance = .930. As previously noted, lower PSI-TECH scores indicate higher levels of problem solving style.

Table 14. ***Number of Items, Range, and Standard Error of Measurement for FLL Study PSI-TECH Scores***

			Males (*n* = 22)			Females (*n* = 14)		
Scale	*N* Items	Score Range	*M*	*SD*	*SE*	*M*	*SD*	*SE*
Problem-Solving Confidence	11	11-66	25.23	6.03	1.29	26.68	5.13	1.37
Approach-Avoidance Style	16	16-96	47.80	12.58	2.68	45.60	6.37	1.70
Personal Control	5	5-30	15.17	3.87	.82	16.44	4.40	1.18
PSI Grand Total	32	32-192	88.20	19.21	4.10	88.71	12.70	3.39

Note. Lower scores indicate higher levels of self-perceived problem solving style (confidence, approach/avoidance, and personal control).

Pearson correlation coefficients were computed on the PSI-TECH subscales, confidence, approach/avoidance, and personal control, for each of the three administrations. For PSI-TECH 1, *N* = 36 (Table 15), two of the three correlations were statistically significant and were greater than or equal to .36 (p = .05). The correlation between confidence and personal control, *r* = .131 (p = .05), was not significant. For PSI-TECH 2, *N* = 33 (Table 16), one of the three correlations was statistically significant, confidence*approach/avoidance *r* = .520 (p = .01). The correlations between confidence and personal control *r* = .242 (p ≥ .05) and approach/avoidance*personal control *r* = .245 (p = .05) were not significant. For PSI-TECH 3, *N* = 30 (Table 17), one of the three correlations was statistically significant, confidence*approach/avoidance *r* = .750 (p = .01). The correlations between confidence and personal control *r* = .353 (p ≥ .05) and approach/avoidance*personal control *r* = .248 (p ≥ .05) were not significant.

Table 15. ***PSI-TECH 1 Sub-scale Correlations***

		Measurement 1		
		Confidence	Approach/Avoidance	Personal Control
Confidence	Pearson Correlation	--	.601**	.131
	Sig. (2-tailed)		.000	.445
Approach/Avoidance	Pearson Correlation	--	--	.364*
	Sig. (2-tailed)			.029

** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

Table 16. ***PSI-TECH 2 Sub-scale Correlations***

		Measurement 2		
		Confidence	Approach/Avoidance	Personal Control
Confidence	Pearson Correlation	--	.520**	.242
	Sig. (2-tailed)		.002	.175
Approach/Avoidance	Pearson Correlation		--	.245
	Sig. (2-tailed)			.169

** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

Table 17. ***PSI-TECH 3 Sub-scale Correlations***

		Measurement 3		
		Confidence	Approach/Avoidance	Personal Control
Confidence	Pearson Correlation	--	.750**	.353
	Sig. (2-tailed)		.000	.056
Approach/Avoidance	Pearson Correlation		--	.248
	Sig. (2-tailed)			.186

** Correlation is significant at the .01 level (2-tailed).
* Correlation is significant at the .05 level (2-tailed).

SIP

The SIP rubric was used to score student participants' technological problem solving performance during direct observations at four points throughout the eight-week FLL *Challenge* season. Means, standard deviations, and standard error for each component of the instrument and the grand total were calculated and are reported by gender in Table 18. Student participants included 16 males and 6 females. The means and standard deviations were relatively similar for males and females. Females scored slightly higher on problem clarification, while males scored higher on developing a design, modeling/prototyping, and evaluating the design solution. On average, males performed better than females overall. For the SIP grand total, scores ranged from 1.38 to 35.5. However, for the SIP grand total scores, independent t-test results indicated no significant differences in overall performance between males and females, t (33) = 1.615, p = .05 (two-tailed), significance = .116. As previously noted, higher SIP scores indicate higher levels of performance.

Table 18. ***Number of Items, Range, and Standard Error of Measurement for FLL Study SIP Scores***

Scale	*N* Items	Score Range	Males (*n* = 16) *M*	*SD*	*SE*	Females (*n* = 6) *M*	*SD*	*SE*
Problem Clarification	6	0-30	19.61	9.44	2.36	21.67	1.86	.76
Developing a Design	6	0-30	9.45	7.51	1.88	7.58	3.80	1.55
Modeling/Prototyping	5	0-25	24.78	13.25	3.31	19.33	10.63	4.34
Evaluating the Design Solution	6	0-30	13.83	10.70	2.68	10.46	6.41	2.62
			(*n* = 22)			(*n* = 13)		
SIP Grand Total	23		17.51	11.10	2.37	11.90	7.45	2.07

Note. Higher scores indicate higher levels of observed problem solving performance.

Pearson correlation coefficients were computed on the SIP subscales for each of the four direct observations. For SIP 1, $N = 32$ (Table 19), four of the six correlations were statistically significant and were greater than or equal to .47 ($p = .01$). The correlations between problem clarifications and evaluating the design, $r = .215$ ($p \geq .05$), and between developing a design and evaluating the design solution, $r = .281$ ($p \geq .05$) were not significant. For SIP 2, $N = 27$ (Table 20), six of the six correlations were statistically significant and were greater than or equal to .63 ($p = .01$). For SIP 3, $N = 28$ (Table 21), six of the six correlations were statistically significant and were greater than or equal to .76 ($p = .01$). All six correlations for SIP 4, $N = 33$ (Table 22) were also statistically significant and were greater than or equal to .72 ($p = .01$).

Table 19. ***SIP 1 Sub-scale Correlations***

		Observation 1			
		Problem Clarification	Developing a Design	Modeling/ Prototyping	Evaluating the Design Solution
Problem Clarification	Pearson Correlation	--	.762**	.650**	.215
	Sig. (2-tailed)		.000	.000	.238
Developing a Design	Pearson Correlation		--	.738**	.281
	Sig. (2-tailed)			.000	.120
Modeling/ Prototyping	Pearson Correlation			--	.466**
	Sig. (2-tailed)				.007

** Correlation is significant at the .01 level (2-tailed).

Table 20. ***SIP 2 Sub-scale Correlations***

		Observation 2			
		Problem Clarification	Developing a Design	Modeling/ Prototyping	Evaluating the Design Solution
Problem Clarification	Pearson Correlation	--	.819**	.814**	.783**
	Sig. (2-tailed)		.000	.000	.000
Developing a Design	Pearson Correlation		--	.626**	.786**
	Sig. (2-tailed)			.000	.000
Modeling/ Prototyping	Pearson Correlation			--	.627**
	Sig. (2-tailed)				.000

** Correlation is significant at the .01 level (2-tailed).

Table 21. ***SIP 3 Sub-scale Correlations***

		Observation 3			
		Problem Clarification	Developing a Design	Modeling/ Prototyping	Evaluating the Design Solution
Problem Clarification	Pearson Correlation	--	.799**	.761**	.761**
	Sig. (2-tailed)		.000	.000	.000
Developing a Design	Pearson Correlation		--	.904**	.904**
	Sig. (2-tailed)			.000	.000
Modeling/ Prototyping	Pearson Correlation			--	1.00**
	Sig. (2-tailed)				.000

** Correlation is significant at the .01 level (2-tailed).

Table 22. ***SIP 4 Sub-scale Correlations***

		Observation 4			
		Problem Clarification	Developing a Design	Modeling/ Prototyping	Evaluating the Design Solution
Problem Clarification	Pearson Correlation	--	.887**	.756**	.724**
	Sig. (2-tailed)		.000	.000	.000
Developing a Design	Pearson Correlation		--	.856**	.747**
	Sig. (2-tailed)			.000	.000
Modeling/ Prototyping	Pearson Correlation			--	.875**
	Sig. (2-tailed)				.000

** Correlation is significant at the .01 level (2-tailed).

Over time, SIP observation correlations increased. Since the correlations were high and significant at the .01 level, the four dimensions of technological problem solving in the final revision of the SIP rating sheet could represent more of a generalized score of technological problem solving, rather than four separate dimensions.

Research Question 1

Is there a relationship between student participants' FLL experience levels and their technological problem solving styles and performances?

A simple one-way analysis of variance was conducted to determine the relationship between student participants' FLL experience levels and their technological problem solving styles and performances. The independent variable, FLL experience in years, included three levels: zero, one, and two years of experience. The dependent variables were PSI-TECH grand total scores and SIP grand total scores (Table 23). The ANOVA for PSI-TECH grand total scores was not significant, $F\ (2, 33) = .022$, $p = .05$. The ANOVA for SIP grand total scores was not significant, $F\ (2, 32) = 1.05$, $p = .05$. The effect size between FLL experience levels and PSI-TECH grand total scores, as assessed by η^2, was relatively small, with FLL experience levels accounting for about 4% of the variance in the dependent variable. The effect size between FLL experience levels and SIP grand total scores, as assessed by η^2, was medium, with FLL experience levels accounting for about 6% of the variance of the dependent variable. Since there was not enough variance in the FLL experience construct, it was dropped from subsequent analyses.

Table 23. ***ANOVA for FLL Experience Levels***

		SS	*df*	*MS*	*F*	Sig.
PSI-TECH Grand Total	Between Groups	13.39	2	6.69	.022	.978
	Within Groups	9838.57	33	298.14		
	Total	9851.96	35			
Sip Grand Total	Between Groups	216.27	2	108.14	1.05	.361
	Within Groups	3292.93	32	102.90		
	Total	3509.20	34			

Post hoc tests could not be performed for FLL experience levels for student participants because the group with 2 years of experience had fewer than two cases (Table 23). The variances among FLL experience levels were extremely low: $\text{Variance}_{\text{PSI.0years}} = 378.38$, $\text{Variance}_{\text{PSI.1year}} = 24.50$ and $\text{Variance}_{\text{PSI.2years}} = 0.00$.

Research Question 2

Is there a relationship between FLL student participants' age and gender with their technological problem solving styles and performances?

PSI-TECH

A one-way multivariate analysis of variance was conducted to determine the effect of age and gender on technological problem solving styles and performances. Means and standard error for PSI-TECH are reported in Table 24. There were no significant differences among ages and gender on problem solving styles. There were no significant between-subjects effects on technological problem solving styles of the constructs age, gender, or the age*gender difference interaction (Table 25).

Table 24. ***Means and Standard Error on PSI-TECH Total 1, Total 2, Total 3, and Grand Total Scores According to Age and Gender***

		PSI Total 1		PSI Total 2		PSI Total 3		PSI Grand Total	
Age	Gender	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
9	M	96.20	9.11	88.20	9.17	87.60	10.45	90.67	8.90
10	M	87.50	14.41	87.00	14.49	92.50	16.52	89.00	14.07
11	M	77.00	20.38	113.00	20.50	85.00	23.36	91.67	19.90
	F	83.67	11.77	79.00	11.83	79.33	13.49	80.67	11.49
12	M	101.33	8.32	97.33	8.37	92.17	9.54	96.94	8.12
	F	87.00	11.77	86.67	11.83	86.33	13.49	86.67	11.49
13	M	90.00	11.77	83.33	11.83	67.00	13.49	80.11	11.49
	F	101.4	9.11	100.20	9.17	90.00	10.45	97.20	8.90
14	M	94.00	20.38	71.00	20.50	91.00	23.36	85.33	19.90

Table 25. ***Between-Subjects Effects PSI-TECH Grand Total***

Source	Type III *SS*	*df*	*F*	Sig.	Partial η^2	Observed $1 - \beta$
Corrected Model	1162.97	8	.367	.926	.128	.136
Intercept	149689.96	1	378.05	.000	.950	1.00
Age	116.20	5	.059	.997	.014	.060
Gender	7.41	1	.019	.893	.001	.052
Age*Gender	847.31	2	1.07	.362	.097	.211

SIP

Means and standard error for SIP scores are reported in Table 26. Significant differences were found among age groups and on the age*gender interaction, Wilks' $\Lambda = .041$, $F\ (25, 35) = 1.90$, $p < .05$, and Wilks' $\Lambda = .125$, $F\ (10, 18) = .013$, $p < .05$, respectively. There were no significant between subjects effects on student individualized performance scores for the constructs age, gender, or the age*gender interaction (Table 27).

Table 26. ***Means and Standard Error on SIP Total 1, Total 2, Total 3, Total 4, and Grand Total Scores According to Age and Gender***

		SIP Total 1		SIP Total 2		SIP Total 3		SIP Total 4		SIP Grand Total	
Age	Gender	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
9	M	9.5	4.9	12.3	7.8	37.0	15.1	27.7	9.4	20.3	5.5
10	M	2.5	7.0	10.0	11.0	35.0	21.3	21.0	13.3	16.8	7.7
11	M	33.0	9.9	16.0	15.5	64.0	30.2	28.0	18.8	35.5	10.9
	F	44.0	9.9	34.0	15.5	6.0	30.2	57.0	18.8	31.1	10.9
12	M	17.2	4.4	29.4	6.9	22.4	13.5	14.8	8.4	18.0	4.9
	F	9.0	5.7	3.3	9.0	33.0	17.4	-3.1 E-15	10.8	9.5	6.3
13	M	8.3	5.7	16.7	9.0	41.7	17.4	1.3	10.8	15.4	6.3
	F	7.5	7.0	17.0	11.0	35.5	21.3	1.5 E-15	13.3	14.8	7.7
14	M	9.0	9.9	21.0	15.5	2.7 E-14	30.2	1.5 E-14	18.8	6.7	10.9

Note. Novice 0-22, Beginner 23-45, Competent 46-68, Proficient 69-91, and Expert 92-115.

Table 27. ***Between-Subjects Effects SIP Grand Total***

Source	Type III *SS*	*df*	*F*	Sig.	Partial η^2	Observed $1 - \beta$
Corrected Model	875.48	8	.915	.534	.360	.264
Intercept	4170.74	1	34.88	.000	.729	1.00
Age	782.11	5	1.31	.320	.335	.323
Gender	53.30	1	.446	.516	.033	.095
Age*Gender	46.05	2	.193	.827	.029	.074

SIP scores for each of the four observations were quite different. This could be due to the *Challenge* progression over the eight-week period and the cyclic nature of the problem solving process. During observation one, 11 and 12 year old student participants performed significantly better than did 9, 10, 13, and 14-year-old student participants (Figure 9). Eleven year old females performed significantly better than did 11-year-old males. Twelve year old males performed significantly better than did 12-year-old females. Males aged 9, 10, 12, 13, and 14 performed at the novice level (score = 0-22), as did females age 12, and 13. Eleven-year-old males and females scored in the beginner range (score = 23-45).

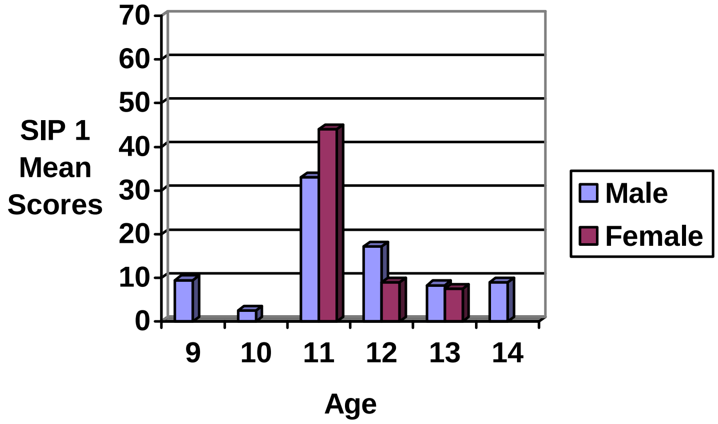

Figure 9. **SIP 1 mean comparisons for age and gender.**

During observation two, 9, 10, 13, and 14-year-old student participants' performance scores generally increased (Figure 10). However, only the 14-year-old scores were closer to the performance scores of the 11 and 12 year olds, which remained relatively consistent for 11-year-old females, decreased significantly for 11-year-old males, and increased significantly for 12-year-old males. Males aged 9, 10, 11, 13, and 14 performed at the novice level (scores = 0-22), as did 12 and 13 year old females. Eleven-year-old females remained at the beginner level (scores = 23-45).

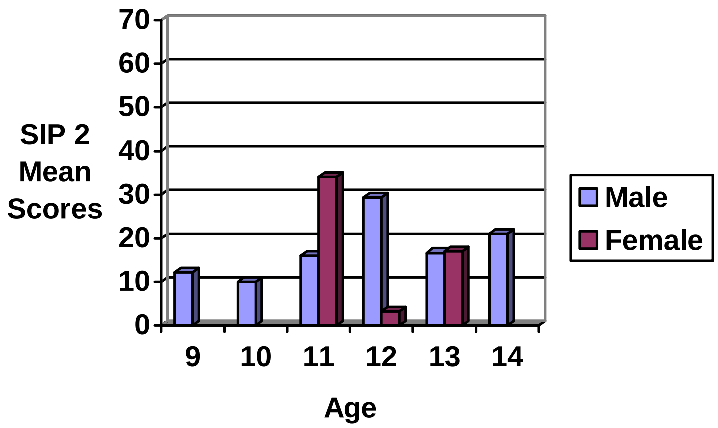

Figure 10. **SIP 2 mean comparisons for age and gender.**

Observation three performance scores peaked for males aged 9, 10, 11, and 13, as did 13-year-old females (Figure 11). Eleven-year-old females' performance scores decreased significantly from observation two, as did 14-year-old males. Twelve-year-old males' performance scores decreased slightly from observation two, but remained higher than observation one scores. Student participants scoring at the novice level included 11 year old females, and 12 and 14 year old males. Beginner level performances included 9, 10, and 13-year-old males, and 12 and 13 year old females. Eleven-year-old males improved their scores to the competent level (scores = 46-68).

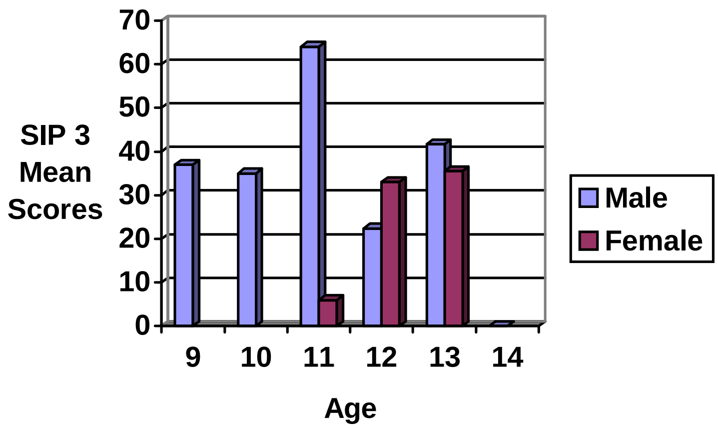

***Figure 11.* SIP 3 mean comparisons for age and gender.**

SIP four observation scores decreased for all student participants except 11-year-old females who reached their peak at the competent level (Figure 12). Nine-year-old males remained consistent at the beginner level, 10-year-old males dropped from beginner to novice, and 11-year-old males dropped from competent to beginner. This significant drop in performance scores could be due to observation four taking place during week eight of the *Challenge* season. This is the final week to complete the design, construction, programming, and research components of the competition. It seems that construction and programming take place during the majority of the eight weeks, and then during the last week most student participants stop working on the robot to complete the research project. The decline in performance scores in 13 and 14-year-old participants could also represent issues with the instrument itself. Since it appears that most of the research project is carried out during the last two weeks of the *Challenge* season, the SIP rating sheet should be revised even further to reflect all aspects of the technological problem solving activity.

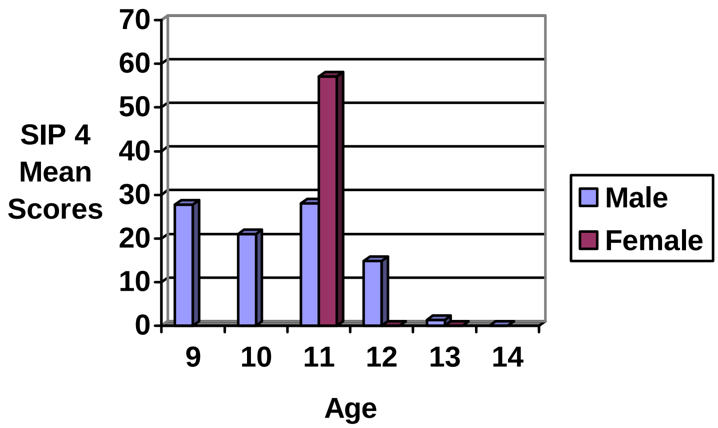

Figure 12. **SIP 4 mean comparisons for age and gender.**

Research Question 3

How well do student participants' technological problem solving styles predict their technological problem solving performances?

A multiple regression analysis was conducted to determine how well student participants' technological problem solving styles predicted technological problem solving performances (Table 28). The predictor was PSI-TECH grand total scores, while the criterion variable was SIP grand total scores. PSI-TECH grand total scores were not significantly related to SIP grand total scores, F (1, 33) = .798, p = .05. The sample multiple correlation coefficient (.15) was not significant, indicating only 2% of the variance of performance scores can be accounted for by technological problem solving styles. Therefore, in this study, student participants' technological problem solving styles are not good predictors of technological problem solving performances. It is important to note that FLL student participants' PSI-TECH scores were self-reported, while trained raters observed and reported SIP scores.

Table 28. ***Summary of Regression Analysis for PSI-TECH Grand Total Predicting SIP Grand Total (N = 29)***

Model 1[a]	*B*	*SE B*	β
PSI-TECH Grand Total	9.23E-02	.103	.154
R^2		.024	
F for change in R^2		.798	

[a]Dependent variable: SIP Grand Total

Research Question 4

What effect does participation in a technological problem solving activity such as FLL have on student participants' technological problem solving styles and performances before, during, and after the technological problem solving activity?

PSI-TECH

A one-way repeated measures ANOVA was conducted with the factor being the time of PSI-TECH administrations before, during, and after the FLL 2004 No Limits *Challenge* season. The dependent variables were PSI-TECH subscale scores and the PSI-TECH total score. Means and standard deviations are reported in Table 29 for each measure of the PSI-TECH subscales. Figure 9 shows the change in means of the subscales over the eight-week period. Figure 10 shows the change in PSI-TECH total scores for each administration and the grand total.

Thirty-eight percent of student participants completing all three PSI-TECH administrations (N = 29) improved their technological problem solving styles at each mark. Overall, 53% (N = 36) improved from week one to week nine. Those who did not improve systematically did however remain relatively consistent in their problem solving styles. For various reasons, several student participants did not complete all three administrations. For example, several students were absent from school and consequently missed practice on the day of the PSI-TECH administration.

Table 29. *Repeated Measures ANOVA PSI-TECH*

	Measure	*M*	*SD*
Confidence	1	29.14	7.64
	2	25.24	6.02
	3	24.03	6.99
Approach/Avoidance	1	48.83	10.50
	2	49.28	13.32
	3	46.41	13.29
Personal Control	1	15.97	5.05
	2	16.21	5.22
	3	15.76	5.28
PSI-TECH Total	1	93.93	18.72
	2	90.72	19.53
	3	86.21	21.18

Note. Lower scores indicate higher levels of self-perceived problem solving style (confidence, approach/avoidance, and personal control).

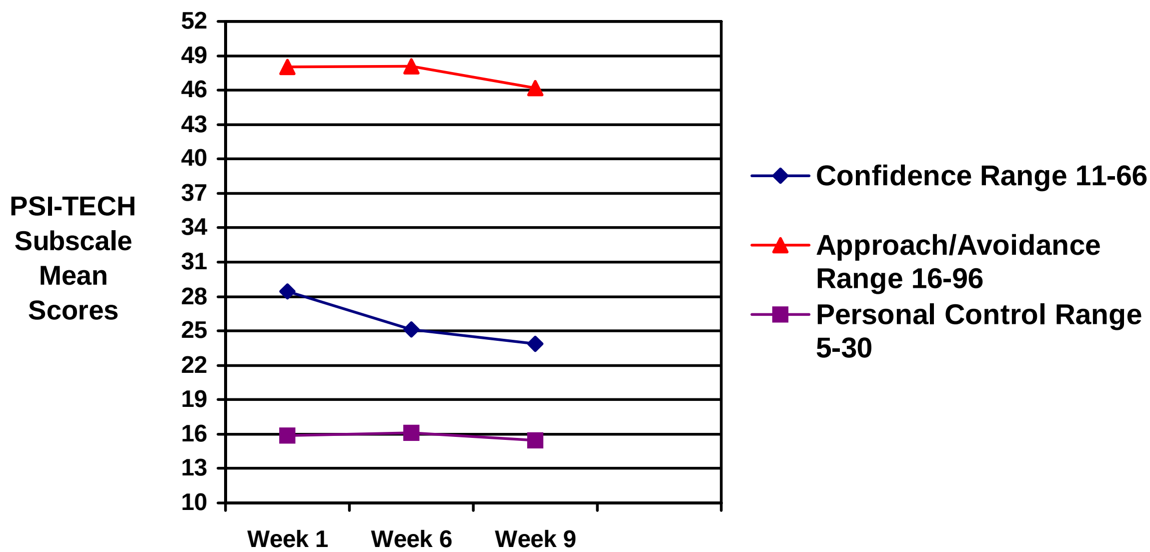

Figure 13. **PSI Sub-scale means over time (Decreases in scores represent improvement).**

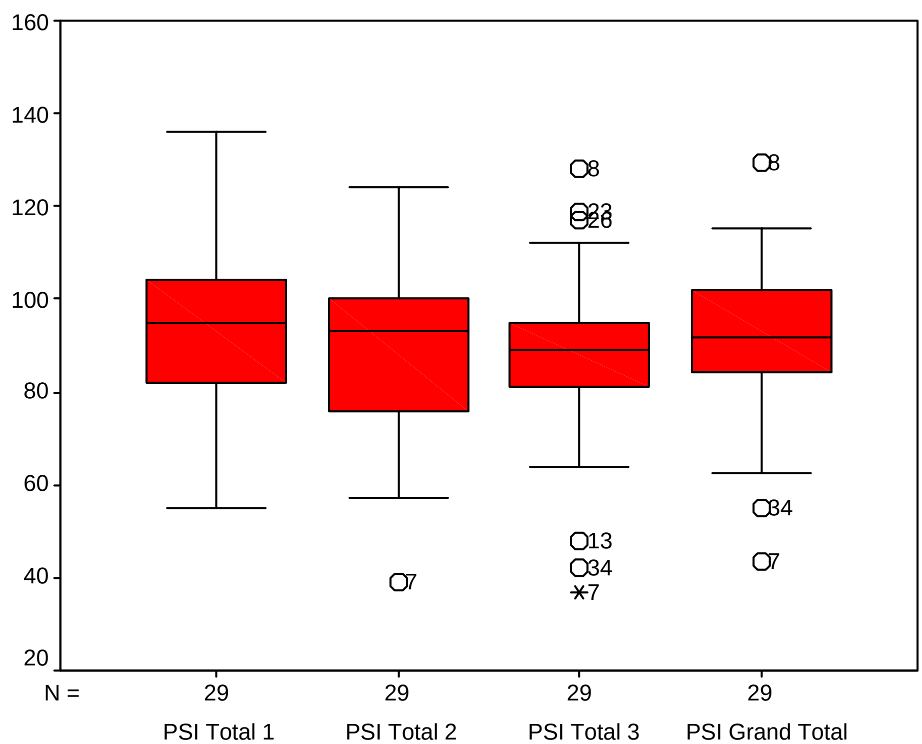

Figure 14. **PSI-TECH Total Mean Scores over Time and the Grand Total.**

The results for the ANOVA indicated a significant time effect in confidence scores, Wilks' Λ = .622, F (2, 27) = 8.21, $p < .05$, multivariate $\eta^2 = .38$, and in PSI-TECH total scores, Wilks' Λ = .763, F (2, 27) = 4.19, $p = .05$, multivariate $\eta^2 = .24$ (Table 30). There was no significant time effect for approach/avoidance or personal control. Significant within subjects effects occurred in confidence scores and the PSI-TECH total score (Table 31). There were no significant within subjects effects for approach/avoidance or personal control.

Table 30. ***Wilks' Lambda***

Effect	*F*	Hypothesis *df*	Error *df*	Sig.	Partial η^2	Observed $1 - \beta$
Confidence	8.21	2	27	.002	.378	.939
Approach/ Avoidance	1.77	2	27	.189	.116	.338
Personal Control	.193	2	27	.826	.014	.077
PSI-TECH Total	4.19	2	27	.026	.237	.687

Table 31. ***Within Subjects Effects (Greenhouse-Geisser)***

	Type III *SS*	*df*	*F*	Sig.	Partial η^2	Observed $1 - \beta$
Confidence	412.62	1.7	11.52	.000	.292	.980
Approach/ Avoidance	137.45	1.9	1.57	.217	.053	.312
Personal Control	2.92	1.7	.124	.857	.004	.067
PSI-TECH Total	873.40	1.9	4.21	.022	.131	.694

SIP

A one-way repeated measures ANOVA was conducted with the factor being the four SIP observation points throughout the FLL *Challenge* season. The dependent variable was SIP scores. Means and standard deviations are reported in Table 32 for all observations of SIP subscales. Figure 11 shows the change in means of the subscales over the eight-week period. Figure 12 shows the change in SIP total scores for each administration. It is important to note that the majority of performance measures increased over the first three observation points (weeks 3, 4, and 7), but then dropped during week eight. This could be due to student participants putting off the research component of the competition until the last week. Therefore, if an action described on the SIP rating sheet was not observed, then a score of zero was marked, causing the performance level of the participant to drop.

Table 32. *Repeated Measures ANOVA SIP*

	Observation	*M*	*SD*
Problem Clarification	1	3.50	5.01
	2	7.50	6.08
	3	8.91	7.51
	4	1.04	2.01
Developing a Design	1	1.36	2.36
	2	1.64	2.19
	3	5.41	5.32
	4	2.14	3.62
Modeling/Prototyping	1	7.14	4.87
	2	5.86	4.41
	3	8.64	7.54
	4	6.64	9.31
Evaluating the Design Solution	1	.82	2.26
	2	2.31	4.76
	3	8.64	7.54
	4	4.55	7.21
SIP Total	1	12.82	12.30
	2	17.32	15.37
	3	31.59	27.11
	4	14.36	20.85

Note. Higher scores indicate higher levels of observed problem solving performance.

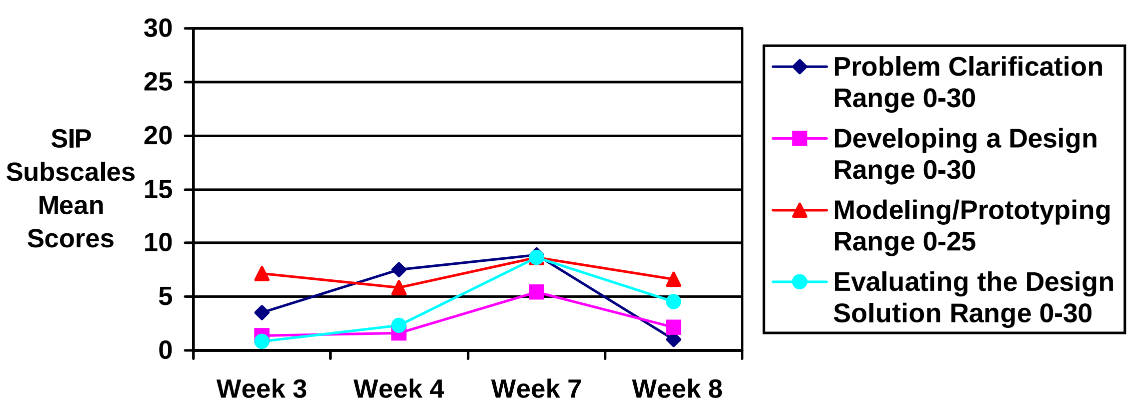

Figure 15. **SIP Subscale Scores over Time (Increases in scores represent improvement).**

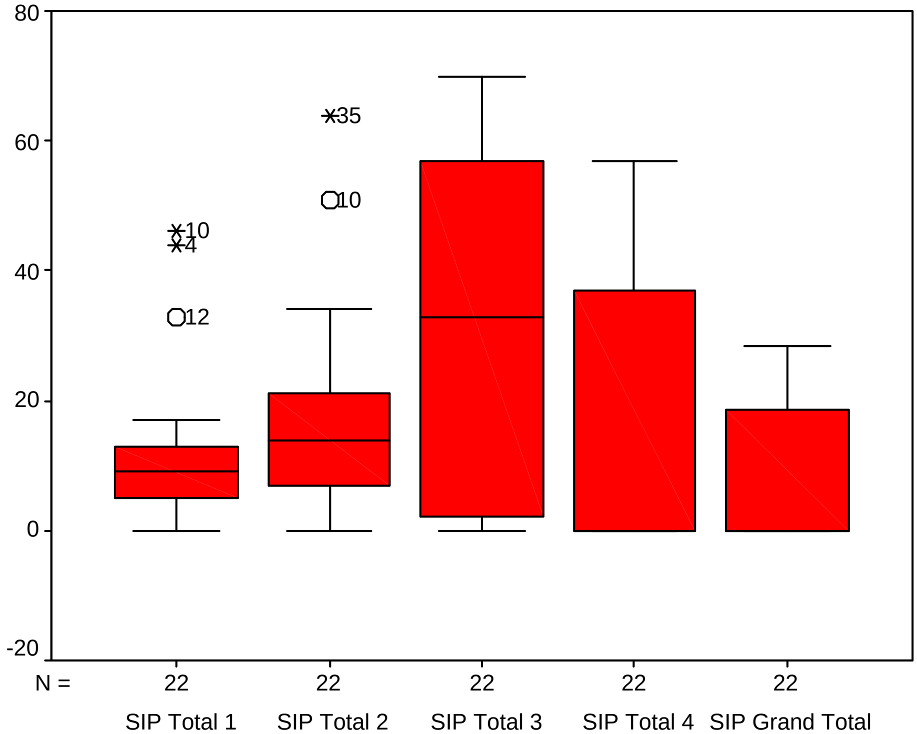

Figure 16. **SIP Total Mean Scores over Time and the Grand Total.**

The results for the ANOVA indicated a significant time effect in problem clarification scores, Wilks' Λ = .216, F (3, 19) = 23.01, p < .05, multivariate η^2 = .78, in developing a design scores, Wilks' Λ = .651, F (3, 19) = 3.39, p = .05, multivariate η^2 = .35, in evaluating a design solution scores, Wilks' Λ = .404, F (3, 19) = 9.32, p = .05, multivariate η^2 = .60, and in SIP total scores, Wilks' Λ = .578, F (3, 19) = 4.62, p = .05, multivariate η^2 = .42 (Table 33). There was no significant time effect for modeling/prototyping. Significant within subjects effects are indicated in problem clarification, developing a design, evaluating a design solution, and the SIP total scores (Table 34). There were no within subjects effects for modeling/prototyping scores. Progress was noted through the first three observations, and then dropped at week eight. Of those student participants present for all four SIP observations (n = 22), one performed optimally during week three, six during week four, thirteen during week seven, and two during week eight.

Table 33. ***Wilks' Lambda***

Effect	*F*	Hypothesis *df*	Error *df*	Sig.	Partial η^2	Observed 1 - β
Problem Clarification	23.01	3	19	.000	.784	1.00
Developing a Design	3.39	3	19	.039	.349	.671
Modeling/Prototyping	.867	3	19	.428	.133	.223
Evaluating a Design Solution	9.32	3	19	.001	.596	.987
SIP Total	4.62	3	19	.014	.422	.814

Table 34. ***Within Subjects Effects (Greenhouse-Geisser)***

	Type III *SS*	*df*	*F*	Sig.	Partial η^2	Observed 1 - β
Problem Clarification	862.22	1.76	8.22	.002	.281	.926
Developing a Design	232.27	1.92	6.83	.003	.245	.891
Modeling/Prototyping	90.23	2.18	.861	.438	.039	.195
Evaluating a Design Solution	763.85	2.09	8.79	.001	.295	.966
SIP Total	4863.50	1.86	4.67	.017	.182	.731

Exit Interviews

An eight-question exit interview was conducted with 30 FLL student participants to support SIP observations and to discern student participants' ideas about technological problem solving. The following codes are used when quoting from the interviews. For example, H3.13.M.0 would represent Team 2, student participant 3 a 13-year-old male with zero years of experience (Team 1 = B, Team 2 = H, Team 3 = W, Team 4 = C). This coding system is also used in the case summaries appendix.

Interview questions were designed to ascertain how student participants first begin to think about the problem solving process, how they know when they have been successful in solving a problem, the form of the solution versus the function of the solution, and whether they believe participating in FLL will help them perform better in school.

The Problem Solving Process

The revised SIP measured four categories of technological problem solving: problem clarification, developing a design, modeling/prototyping, and evaluating the design solution. The original SIP rubric was consulted to specify categories of student participants' responses on the exit interview.

When asked the first thing a student participant would do when confronted with a new problem, 16 responses were coded problem clarification, 12 developing a design, and 2 other. Several responses were:

> *I try to figure out the problem* (problem clarification). [B3.10.M.0]

> *Everything I could do* (other). [H2.11.M.1]

> *I think about it and talk it over to think of a different answer* (problem clarification). [H5.13.F.0]

> *I think about what to do to solve it* (developing a design). [W11.11.F.0]

When asked the second thing a student participant would do when confronted with a new problem, 5 responses were coded problem clarification, 10 developing a design, 3 modeling/prototyping, 9 evaluating the design solution, and 2 other. These responses support the problem solving process as a cyclic endeavor. Selected student participants said:

> *I find a way to fix it. Sometimes other solutions work better* (developing a design). [B10.12.M.1]

> *You have to test it and make sure everything is supported* (evaluating the design solution). [H2.11.M.1]

> *Rebuild it* (modeling/prototyping). [H7.13.M.0]

> *Find the best solution. You have to figure out the steps to get to the solution* (developing a design). [H8.13.F.0]

> *See how long I have to do it and plan out steps to get there* (problem clarification). [W3.12.F.0]

> *If the first plan doesn't work try to figure out the problem* (problem clarification). [W8.12.M.0]

> *Think about the outcomes* (developing a design). [C2.14.M.2]

Drawing and sketching is an important aspect of the problem solving process. It helps student participants to visualize what their solution will look like. It also aids in communicating their ideas with team members. When asked if it helps to draw ideas for their robot, six student participants responded yes, three said no, three said sometimes, one was not sure, one had tried but it did not work out, four said they imagined it in their heads and thoughts, and nine said they had never tried it before.

> *Diagrams help to show the team*. [B3.10.M.0]

Well, yeah. We did it a lot on the board. [B6.10.M.0]

Not really. I'm not a real big drawer. [B9.13.M.0]

Normally keep it in my head. I'd rather have notes because I'm a terrible drawer. [W3.12.F.0]

Yes, when designing our differential and to calculate gear ratios. [C2.14.M.2]

Evaluating and testing the design solution help student participants determine if their solution is successful. Student participants were asked, "How do you know when you have successfully solved a problem?" Eighteen responded, "When it works." This response indicates that most student participants may not fully comprehend the meaning of testing and evaluating even though many responded that testing and evaluating would be the second thing they do in order to solve a problem. Some responses were:

I change focus or take a break. [B1.12.M.1]

When it doesn't come up any more. [B8.9.M.0]

Check research. [H1.13.F.1]

If I feel good about it. [W3.12.F.0]

I like it to work about 95% five times. [C2.14.M.2]

Form vs. Function

For some 9 through 14-year-old children, it is very important for things to look good. They might want their MP3 player to look good, but at the same time function well. FLL student participants must design and build an autonomous robot to perform specific tasks in a competitive environment. When asked, "What matters most to you, the way your robot looks or the way your robot works?" all respondents save one replied, "Works." The one remaining respondent said, "Both."

Works, as long as it is moderately easy to change the wires. [B12.12.M.1]

Works. It's got to do what it's supposed to do. [H1.13.F.1]

Works. It has to have a certain movement. [H2.11.M.1]

Definitely works. They don't look pretty, so it might help for it to be intimidating. [C2.14.M.2]

Both even. Works should be high, but looks are important so people won't laugh at you. [C5.12.M.0]

Increasing Performance in School

The majority of student participants believe that participating in an activity like FLL will help them do better in school (26 affirmative responses, 6 negative responses). Eleven respondents specifically mentioned that they felt more confident about solving different types of problems. Three thought it would help them in a technology class, nine in math, four in science, two in engineering, and two in English. From the responses below, it would seem that FLL student participants are beginning to recognize the interrelatedness of problem solving in many different aspects of their lives.

> *Not in most areas, but it might help in science that uses technological parts.* [B5.9.M.0]
>
> *Yes, it expands the way you think. Think of different ways to solve problems.* [B6.10.M.0]
>
> *Not really, but you get experience in competing and teamwork.* [B7.9.M.1]
>
> *I think it will help with teamwork, especially when I go to college in engineering. It's about presentations, innovation and imagination. Maybe not one particular subject, but aspects of all subjects.* [B10.12.M.1]
>
> *Yes, problem solving can be related to other things and other people.* [H3.13.M.0]
>
> *Yes, how you can work with other people. I didn't like working with people but now I do.* [H7.13.M.0]
>
> *Yeah, it could help with science. You know, how things work and how they are made.* [W8.12.M.0]
>
> *Probably not because I've had to miss several classes, but I could put it on my college resume.* [C2.14.M.2]
>
> *Yes, teach better problem solving skills and group work.* [C4.12.M.0]
>
> *Yeah, makes me concentrate more.* [C5.12.M.0]

Chapter 5
Conclusions

Using a correlational research approach, this FLL study was conducted with self-selected 9-14 year old FLL student participants. Four teams were randomly selected from VDOE Regions 6 & 7 (Appendix A) and asked to share their 2004 No Limits *Challenge* experience. The purposes of this study were: 1) to determine the relationships among age, gender, and FLL experience levels with student participants' problem solving styles and problem solving performances; 2) to assess how well student participants' problem solving styles would predict their individualized problem solving performances, and 3) to determine the effect a technological problem solving activity has on student participants' problem solving styles and performances over time.

FLL student participants reported self-perceptions of their technological problem solving styles by responding to 35 items related to confidence, approach/avoidance styles, and personal control on the PSI-TECH. This was done three times over the eight week *Challenge* season in order to determine the changes in their technological problem solving styles over time. Student participants' technological problem solving behaviors were observed at four points during this eight-week period. Two trained raters used the revised SIP rubric to score those behaviors in four categories of a technological problem solving process: Problem and Design Clarification, Developing a Design, Modeling/Prototyping, and Evaluating a Design Solution.

Research Question One

Is there a relationship between student participants' FLL experience levels and their technological problem solving styles and performances?

Research indicates more experienced problem solvers reach greater levels of problem solving performance than do those who are inexperienced with problem clarification procedures (Bjorklund et al., 1990). Years of experience have also been found to be effectual predictors of near transfer problem solving skills (MacPherson, 1998). It was expected in this study that more experienced FLL student participants would have higher technological problem solving styles and performances. Because there was virtually no variance in the experience levels of student participants in this study, no significant differences were found for PSI-TECH or SIP scores. Because there was virtually no variance in the FLL experience levels of student participants in this study, these findings are sample specific. Further research with greater FLL experience level variance is needed.

Research Question Two

Is there a relationship between FLL student participants' age and gender and their technological problem solving styles and performances? As previously mentioned FLL student participants' ages range from 9 to 14 years.

Wu et al. (1996) suggested that changes in problem solving styles would occur in children who are in the process of developing cognitively. When students are faced with relevant, real world problem solving experiences (Berkermer, 1989; Davis et al. 1997; and Thornton 1995), and they possess the problem solving strategies to solve specific problems; Thornton theorizes that eight year olds will perform just as easily as seventeen year olds. While the researcher expected to find older rather than younger FLL student participants to have higher problem solving styles and performances, no significant differences were found among age groups or gender on technological problem solving styles. This means that 9-14 year old females participating in FLL are no different from 9-14 year old males participating in FLL in the way they perceive their overall technological problem solving style.

However, significant differences were found among age groups and the interaction between age and gender on technological problem solving performances. Generally, it was determined that 11 and 12 years old student participants performed significantly better than did 9, 10, 13, and 14 year old student participants. This analysis supports de Bono's (1972) finding that 10-12 year olds more readily adopted to the conditions of problem solving through instructions than did other ages. This also supports Bame and Gatewood's (1983) theory that experiential and exploratory learning could prove beneficial to student participants who indicate plateaus in brain growth, meaning that teaching technological problem solving skills beginning in elementary school would provide all ages with the tools and strategies necessary to solve problems successfully. Specific research is needed to support Custer's (1999) theory that developing problem clarification abilities and using this ability to make sound decisions builds technological problem solving confidence.

Gender alone did not show any significant differences for SIP scores. Overall, females scored no differently than did males in technological problem solving performance, meaning that during this particular technological problem solving activity girls were as equally engaged as boys. Research designed to compare teams of females with teams of males and with teams of male and females would provide greater insight on this relationship. Also, the data collected in this study should be reanalyzed to reflect the lack of gender variation in the 9, 10, and 14-year-old age groups.

Research Question Three

How well do student participants' technological problem solving styles predict their technological problem-solving performances?

Technological problem solving style accounted for only two percent of the variance in performance scores for this FLL study. This finding supports MacPherson's (1998) indication that problem solving styles were the least important indicators of problem solving skills. More research is needed to better determine the relationship between styles and performances. Revisions in how technological problem solving style is measured should be evaluated. Since the PSI-TECH is a self-reporting instrument and SIP scores are observed, gaps in the relationship exist.

Research Question Four

What effect does participation in a technological problem solving activity such as FLL have on student participants' technological problem solving styles and performances over time?

Throughout the cognitive science literature, there is a recurring theme: progressions of hierarchical domains of knowledge lead to higher order thinking. Many theorists believe problem solving to be the pinnacle. Jonassen (2004) specifies design problem solving to be the most difficult to learn. The results of research question four indicate that while design problem solving may be complex, it is reasonable to suggest that technological problem solving activities such as the FLL Robotics *Challenge* facilitate children's implementation of the cyclic problem solving process. Without any formal training or coursework, 9-14 year old FLL student participants showed significant increases in confidence, PSI-TECH total scores, problem clarification, developing a design, evaluating a design solution, and SIP total scores in only eight weeks. There was no significant time effect for approach/avoidance styles, personal control, and modeling/prototyping. This may indicate that in order for children to fully comprehend and transfer technological problem solving skills and processes, formal training or coursework is needed. Though student participants' self-perceptions of their problem solving styles were high, as seen in the performance case summaries (Appendix Q), no student participants excelled beyond the beginner level. This may indicate that even though FLL claims to be a technological problem solving activity, how much problem solving is really being taught during this activity is unknown.

Exit Interviews

The results of the exit interviews support the idea that technological problem solving is a non-linear process. Student participants recognized that there are steps to solving problems; however, the order in which they actually solved their problems was not sequential throughout the eight-week activity. Tangible results helped them realize the success of a problem solution, or if troubleshooting and redesign might be necessary. Since LEGOs™ are modeling tools, the need for sketching design ideas in this type of technological activity were reduced; however, several student participants found that using drawings was an effective method of communicating and sharing ideas with teammates.

Many student participants spoke of the value of teamwork in problem solving, which supports the idea that there is a social component to learning. They seemed to think that this type of technological problem solving activity helps them develop different perspectives on learning; however, no one discussed developing a respect for the perspectives and ideas of others. Few student participants realized that this type of technological problem solving activity would help them in school. This indicates the lack of transfer of knowledge in this type of after school activity, which suggests a more formal approach be taken.

Implications

In theory, the technological design process represents a linear progression, as do the stages of development and the hierarchy of learning. However, the results of this FLL study challenge the assumption of linearity in problem solving. While there are definite stages of development and progressions in the learning process, all children of a particular age group do not develop at the same rate or in the same manner. Cognitively developing females perceive their problem solving styles to be the same as their male counterparts. Why then do their performances differ as their ages and experiences change and develop? What sociological issues come in to play?

According to the cognitive theorists mentioned in the review of literature, knowledge leads to cognition, which can be critical, creative, and/or productive. Productive thinking, as required in technological problem solving is developed through real world experience. Factual, conceptual, procedural, and metacognitive knowledge is gained and is transferable through the cognitive process. In Anderson and Krathwohl's (2001) revised taxonomy, the *understanding* dimension relates directly to the *problem clarification* dimension of technological problem solving. Likewise, the *apply* dimension relates to the *developing a design* and *modeling/prototyping* dimensions; the *analyze* and *evaluate* dimensions relate to *evaluating a design solution*, which includes troubleshooting and redesigning; and the *create* dimension of the revised taxonomy corresponds with the *implementation* dimension of technological problem solving.

Basic thinking skills, as those developed through the technological problem solving process support the knowledge dimension. The hierarchy involved in this process leads to transformation. Relevancy in the thinking process leads to transfer of knowledge. This is how technology education as general education enhances interdisciplinary study. Factual knowledge is supported through the study of humanities, conceptual knowledge through the sciences, and procedural knowledge through mathematics, specifically heuristic processes. Technological problem solving activities involve all the aforementioned knowledge dimensions, and through relevant experiential learning, provide students with the opportunity to reach the metacognitive dimension. It enables them to develop and improve reasoning skills that are necessary to make sound decisions and enables success in a high-tech world that will become increasingly complicated.

The results of this research study indicate the importance of teaching technological problem solving during the elementary school years. During the eight-week FLL Robotics *Challenge*, student participants informally build problem-solving confidence, and learn problem clarification strategies, design development, and evaluation techniques. Introducing the technological problem solving process into 21st century elementary school curricula would afford each child the opportunity to improve and develop cognitively, not just those students who choose to participate in an after school technological problem solving activity like FLL. To do this the FIRST™ Organization and the Educational Division of LEGO™ could actively join a coalition of educational organizations such as the International Technology Education Association, National Science Teachers Association, National Council of Teachers of Mathematics, Association for Supervision and Curriculum Development, the K-12 Division of the American Society of Engineering Education, and many others, to propose a mandate for teaching technological problem solving in elementary school curricula.

Recommendations for Further Research

Recommendations for further research on the teaching of technological problem solving in elementary schools are based on the results and conclusions of this study.

1. Research replication on a larger scale is recommended to verify the findings of this study. Larger sampling should occur to ensure satisfactory variance in the experience construct. This would require formal training of testing administrators and observation raters.

2. Research replication on a much smaller scale is recommended to investigate the ethnographic and sociological impacts indicated by participation in a technological problem solving activity such as FLL for more specific age groups: 9-10 years olds, 11-12 year olds, and 13-14 year olds.

3. Further research is needed to evaluate the percentage of all FLL student participants by age to investigate how social constructs may impact the experience levels of student participants in said technological problem solving activity.

4. Conduct research designed to specifically determine the relationships between technological problem solving styles and student individualized performances and the bearing each has on children learning to solve problems.

5. The development and implementation of technological problem solving coursework for cognitively developing children is germane to building knowledge and experience that is transferable to all aspects of learning.

6. The development and implementation of technological problem solving training for pre-service and in-service teachers to study the effects said training would have on teaching and learning.

7. It is recommended that this study be revised to investigate the effects of technological problem solving styles and performances on student participants of the many other educational robotics platforms, and to scopes beyond such as student achievement in STEM related content areas.

8. A longitudinal research study should be conducted to determine the evolution of technological problem solving styles and performances and how they affect student participants' course taking patterns and career choices.

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Appendices

Appendix A: Original Student Individualized Performance Rubric (Custer et al. 2001)

PROBLEM & DESIGN CLARIFICATION					
	Expert	Proficient	Competent	Beginner	Novice
Examine context & define problem	**Poses pertinent questions** for clarification. **Identifies and prioritizes sub-problems** (within the larger problem). **Explores context**.	**Poses questions**. **Identifies sub-problems** but does not prioritize. **Ignores context**.	**Asks some pertinent questions.** **Identifies key content**. **Defines problem adequately**. **Ignores context**.	**Expresses limited** knowledge of context or problem; problem is defined but needs clarification. **Asks questions** but not pertinent and too few. **Ignores context**. **Exhibits some indifference or frustration**.	**Tends to hone in on wrong problem**, isolated subset, or easiest part to solve. **Begins to solve without clarification or questions**. **Doesn't see context**. **Exhibits considerable indifference or frustration**.
Develop, clarify, & negotiate constraints and criteria	**Explains key constraints** in detail. **Tries to negotiate or circumvent constraints**. **Clarifies criteria** prior to solving problem or posing solutions.	**Clarifies constraints** in detail; expresses their relationship to the problem solution. **Engages in limited negotiation** of the constraints.	**Clarifies constraints and accepts them** as presented and understood.	**Recognizes constraints** but seeks minimal clarification. Accepts constraints as is. **Clarifies constraints late in design process** as failures occur.	**Does not identify constraints or criteria**; does not grasp the significance of constraints. **Sees constraints as insignificant**.
Conduct research/gather pertinent information	**Consults several key sources**. **Evaluates information**; relates information back to problem and constraints. **Uses refined search strategies**. **Researches sub-problems**	**Consults several key sources**. **Uses observational techniques**. **Cites references.** **Ignores sub-problems.**	**Uses search guides and locates at least 2 sources**. **Consults sources** with some direction and/or organization.	**Conducts very limited research**. **Search restricted to easy-to- find and readily available resources**.	**Does not conduct research nor consult sources**. **Starts solving problem without information**.

DEVELOP A DESIGN					
	Expert	Proficient	Competent	Beginner	Novice
Generate and visualize possible solutions	**Generates creative and efficient solutions**. **All solutions meet constraints and address the original problem**. **Able to generate a number of different solutions**. **Is innovative**	**Generates feasible solutions,** but many are similar. **Meets constraints**. **Uses resources efficiently**. **Proposes creative solutions**. Thinks "inside of the box".	**Generates solutions** that meet **most** of constraints. **Establishes resources needed to implement solution**. **Generates several possible solutions within constraints**. Thinks "inside the box."	**Identifies solutions** that meet **some** of the constraints. **Some solutions are adequate to solve the problem**. **Solutions may/may not be feasible**. **Identifies single solution that meets constraints**.	**Cannot identify solutions *or* solutions are inappropriate** to framed problem. **Does not appear to have an idea of where to begin**. **Solutions are disconnected from, or totally ignore, constraints**.
Select a design solution	**Provides detailed reasons for selecting solution**. **Provides backup or alternate** solution in case the first solution fails. **Attempts to be innovative and wants best possible solution**. **Self-assured.**	**Selects solution on basis of efficiency and effectiveness**. **Checks against constraints**. **Provides basic rationale for selection**. **Tends not to have an alternative solution** in case the initial choice does not work.	**Selects a reasonable solution based on criteria**. **Solution meets constraints**.	**Selects solution with limited attention to criteria**. **Can select solution**. **Solution may or may not be feasible**. **Is tentative and insecure in the selection process**.	**Selects solution according to personal preferences**. **Unable to decide solution.** **Solution may be unrealistic or impractical**. **Uses few if any criteria to evaluate solutions**. **Solution represents an easy way out.**
Plan & communicate design	**Develops detailed design plan, drawings, and sketches**. **Devotes careful attention to constraints**. **Continuously revisits and refines the solution.** **Knows when to stop the refinement process.**	**Creates a plan** with supporting technical drawings. **Maintains journal or log of daily activities**. **Meets constraints**.	**Creates an organized plan with sufficient detail**. **Identifies basic tools, resources**. **Visualizes using technical drawings**. **Ignores some constraints**.	**Explains design plan**, citing procedures, resources, and other requirements. **Visualizes using technical sketches** without regard for scale. **Ignores key constraints**.	**Explains design** in general terms and with little detail. **Sketches are rough** and without sufficient detail. May attempt to move forward without drawings. **Ignores constraints**.

MODEL/PROTOTYPE					
	Expert	Proficient	Competent	Beginner	Novice
Select and use resources	Uses appropriate resources (i.e. tools, materials, and information) for developing and producing the solution. Accesses a variety of information sources (websites, manuals, technicians, electronic catalogs, etc.). Selects and adeptly uses resources.	Accesses and uses appropriate resources to solve the problem. Exhibits refined knowledge of tools, materials, and technological processes. Uses resources confidently.	Selects and uses appropriate resources related to most aspects of the problem. Displays some difficulty in accessing information. Selects appropriate tools for developing and producing the solution. Search for resources is limited to few sources.	Selects a limited range of resources. Some difficulty in choosing appropriate technological resources. Needs guidance in safe use of resources.	Limited ability to select and use basic resources. Selection of tools, materials, processes, and information may be inappropriate. Selected resources may not be feasible due to lack of availability, need for expertise, or cost.
Develop a plan for producing a model/prototype	Develops a well detailed plan with references to design constraints and criteria. Includes testing and modification steps. Incorporates quality control measures.	Develops a detailed and systematic plan. Communicates information and processes needed to produce the model or prototype. Incorporates testing as a procedural step.	Develops a plan with logical and sufficient steps to develop and produce a solution. Plan needs quality control checkpoints.	Develops a plan with some gaps and insufficient steps to solve the problem. Connection with design criteria and constraints is marginal.	Develops a plan that lacks coherence and departs from design constraints and criteria. Plan contains gaps and does not flow logically. Procedures lack necessary detail.
Produce model/prototype	Is adept with tools and resources, making continual adjustments to "tweak" the model/prototype. Demonstrates persistence with minor problems. Enjoys the challenge of refinements.	Uses tools and resources without guidance. Refines model to enhance appearance and capabilities.	Uses tools and resources with little or no guidance. May redo model/prototype parts to improve quality.	Uses tools and resources with some guidance. May have difficulty selecting appropriate resources. Refines work, but may prefer to leave model as first produced.	Needs guidance in order to use resources safely and appropriately. Crudely constructs model/prototype, with little or no refinement.

EVALUATE THE DESIGN SOLUTION					
	Expert	Proficient	Competent	Beginner	Novice
Test and critique solution	**The solution fully meets the design constraints and criteria**. **Specific improvement ideas are generated and documented**.	**The solution meets most of the design constraints and criteria**. **Some general improvement ideas are generated and documented**.	**The solution addresses some design criteria completely but ignores others**. **Recognizes the need for improvement.** Some ideas are generated, however only in concept. **Documentation is sketchy**.	**The solution is only marginally connected with the design criteria**. **Shows little interest in improving the solution**.	**The solution fails to meet selected design criteria**. In spite of problems detected during testing, **no effort is made to refine the solution**.
Refine solution	**Solution is refined in a manner consistent with constraints and criteria**. **Solution is in constant refinement**, based on continuous data gathering.	**Solution is refined in a manner consistent with constraints.** **Changes represent some improvement to the quality and functionality of the solution.**	**Solution is refined to be consistent with design constraints and criteria**. **Refinements may be cosmetic and may not be significant**.	**Some minor refinement of the original solution**. **Refinements are primarily cosmetic** in nature and contribute only marginally to the quality or effectiveness of the solution.	**Solution is accepted "as is".** **Criteria and constraints are not referenced**. **No data is collected to evaluate the solution**.
Documentation/Technical Reporting	**All aspects of the design process are well documented**, including the processes used, design details, and resources. **Documentation package is well organized**, highly reflective, technically accurate, and communicates effectively to others.	**The design process is documented** including the processes used, design details, and resources. **Drawings are technical and provide essential information** **Documentation is fairly organized. Some insights** concerning design changes and refinements are detailed.	**Documentation of design processes are factual** and includes all components. **Drawings are technical and provide essential information**. **Reflections are limited to facts**, with limited depth.	**Some attention to documentation** with a preference for graphically depicting the design. **Little evidence of a clear organizational scheme**. **Some design stages may not be documented**.	**Little documentation** is done of either the product design or of the design process. **Documentation is limited to hand-drawn sketches and sketchy, handwritten notes**.

Appendix B: 2004 Virginia Department of Education Regions 6 & 7

VDOE Region 6	VDOE Region 7
Alleghany Highlands	Bland
Botetourt	Bristol City
Covington City	Buchanan
Craig	Carroll
Danville City	Dickenson
Floyd	Galax City
Franklin	Giles
Henry	Grayson
Martinsville City	Lee
Montgomery	Norton City
Patrick	Pulaski
Pittsylvania	Radford City
Roanoke	Russell
Roanoke City	Scott
Salem City	Smyth
	Tazewell
	Washington
	Wise
	Wythe

Source: http://www.pen.k12.va.us/VDOE/dbpubs/doedir/ July 13, 2004

Appendix C: Selected Problem Solving Approaches

Berkemer, 1989
Analyze the problem
Ask questions
Brainstorm and generate ideas
Construct solution
Test the solution
Final Test (p. 75)

Chrisof, 1939
Formulate the problem
Elaborate on the problem
Progress toward a solution (complete or partial solution or defeat) (p. 170)

Davis, M., Hawley, P. McMullan, B. Spilka, G., 1997
Identify and define the problem
Gather and analyze information
Determine performance criteria for successful solutions
Generate alternative solutions and build prototypes
Evaluate and select appropriate solutions
Implement choices
Evaluate outcomes

Dewey, 1910
Presentation of the problem
Define the problem
Formulate hypotheses
Verification

Hatch, 1988
Recognize the problem
Analyze contributing factors
Consider possible solutions
Choose optimal solutions
Evaluate results (p. 90)

Hutchinson and Karsnitz, 1994
Identifying problems and opportunities
Framing a design brief
Investigation and research
Generating alternative solutions
Choosing a solution
Developmental work
Modeling and prototyping
Testing and evaluating
Redesigning and improving (p. 19)

ITEA, 2000
Identify and define the problem
Investigate and research the problem
Generate ideas for a solution
Chose the best solution
Model and test the solution
Reevaluate the solution
Final solution (pp. 5-6)

Merrifield, Guilford, Christensen, and Frick, 1962
Preparation,
Analysis,
Production,
Verification,
Reapplication

Polya, 1957
Understand the problem
Devise a plan
Carry out the plan
Look back

Pucel, 1992 (Paraphrased in Lewis, Petrina, and Hill, 1998)
Identify an unmet human need
Clarify the specific technical problem
Identify relevant existing technical methods and knowledge
Invent a probable solution
Determine the social and economic feasibility of the solution
Modify the solution
Implement the solution

Savage and Sterry, 1990
Define the problem
Develop alternate solutions
Select a solution
Implement and evaluate the solution
Redesign the solution
Interpret the solution (p. 14)

Wallas, 1926 Stages of Control
Preparation
Incubation
Illumination
Verification (p.80)

Appendix D: FLL Challenge History

1998 Pilot Implementation

1999 First Contact

"Teams went to the International Space Station (ISS) responding to chaos caused by an unidentified flying object damaging the space station while researching the prevention of future mishaps" (U.S. FIRST, 2004e). "Includes, Mission Objectives, and 3-D drawings of this years [sic] Playing Field, plus hear special messages from FIRST Founder, Dean Kamen and Astronaut, Dan Barry" (U.S. FIRST, f).

2000 Volcanic Panic

"Takes on a whole new meaning. We wake a sleeping giant like you've never seen before! Start running because the lava is coming and it's coming fast!" (U.S. FIRST, 2004e). "Teams visit Hawaii to use robotics technologies in dangerous search and rescue operations during volcanic eruptions" (U.S. FIRST, e).

2001 Artic Impact

"Forget the shouts and suntan oil--we're going North--way North! Get ready for the dangerous world of icebergs, frostbite, carnivorous animals and mile-high slushies! Grab your mittens and stay cool with FLL in the Biggest snow squall of the century!" (U.S. FIRST, 2004f). "Teams visit the Artic and learn how to use robotics technology to study global climate change" (U.S. FIRST, e).

2002 City Sights

"Explore the challenges that urban planners face everyday in order to provide basic services such as clean water, a safe environment, education, sustainable energy, and venues to the inhabitants of the city" (U.S. FIRST, 2004f). "Teams learn how to use robotics technology to explore solutions for their own cities. In New England teams design a fish shaped robot that cleans Boston Harbor without disrupting the natural habitat. In the Midwest teams design robots that sort and recycle trash at a record pace. In Europe teams design robots that park cars at rail station to encourage railway use and reduce pollution" (U.S. FIRST, e). "City Sights explores the obstacles, restrictions and challenges that urban planners face everyday in order to provide basic services such as housing, clean water, safe environment, education and medical assistance, sustainable energy, mass transportation and communication venues to the inhabitants of the city. Factors like population, finite land and water resources, and unique geographical situations, are just a few of the variable to consider as effective solutions are explored" (U.S. FIRST, f).

2003 Mission Mars

"Have you ever looked into the night sky and wondered what it would be like to live in another part of our galaxy? Have you ever wanted to travel the solar system? Well, in 2003, hop on board and blast off with FIRST LEGO League's Justin Case on his exploration of the universe. The playing field is the planet Mars. The Challenge is to visit the Red Planet and explore the Martian landscape with visions of colonization. Unlock the fascinating world that lives in MISSION MARS, and experience similar challenges encountered by the scientist and space engineers" (U.S. FIRST, 2004f).

2004 No Limits

"Just as some people struggle in extreme settings, people with varying levels of abilities encounter barriers in everyday settings. This year First [sic] LEGO League teams will look at everyday settings in a whole new way with an eye on how technology and fresh thinking can make a difference in creating equal access for all" (U.S. FIRST, 2004f). "Each FLL team will build and program a robot that addresses the specific needs of people who face physical challenges in today's society. Teams will research and present robotics technology solutions to help individuals in their community perform the everyday actions that many people today take for granted" (U.S. FIRST, g).

2005 Ocean Odyssey Challenge (to be revealed September 12, 2005)

"FIRST LEGO League travels into the depths of the ocean to explore the mysteries that lie below. The oceans are of vital importance to the health of the Earth and to everyone that lives on this planet; yet only 1% of these magnificent bodies of water have been studied. Oceans provide inspiration, fun, and food. They absorb carbon and generate oxygen, profoundly affecting the global environmental system. A distress call has been issued to FIRST LEGO League teams around the world to find solutions that will sustain the health, biodiversity, and productivity of the world's oceans for present and future generations" (U.S.FIRST, 2005a)

Appendix E: FLL Challenge Schedules

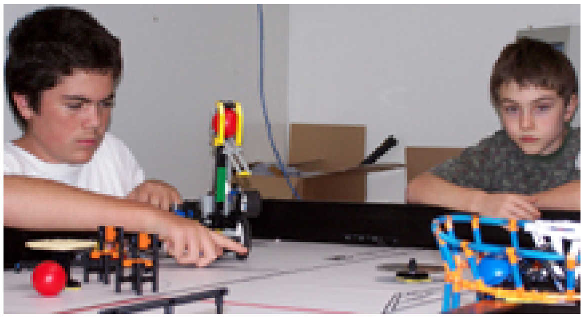
FLL 2004 No Limits

May 1	Team registration opens
May 10	Robot kits and team manuals begin to ship
August 16	Field set up kits begin to ship
September 1	State tournament details posted
September 1	International team forum opens
September 15	*Challenge* announced
September 30	Team registration closes
October 1-15	State tournament applications accepted
November-January	Local events and state tournaments (U.S. FIRST, 2004h)

FLL 2005 Ocean Odyssey

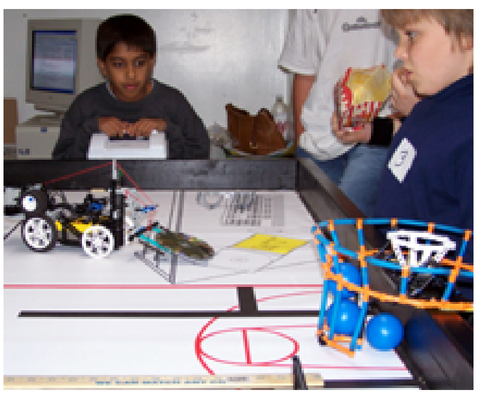
May 2	Team registration opens
June	Robot kits and team manuals begin to ship
Mid August	Field set-up kits begin to ship
September 1	State tournament details posted
September 1	International team forum opens
September 12	*Challenge* announced
September 30	Team registration and product sales close
October 3-15	State tournament applications accepted
November-January	Local events and state tournaments (U.S. FIRST, 2005b)

Appendix F: 2004 FLL Challenge At a Glance

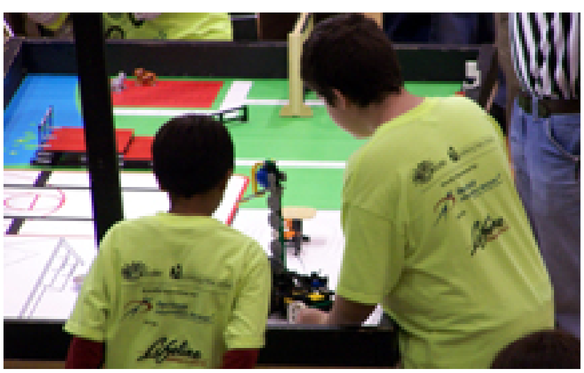


Team One at practice.

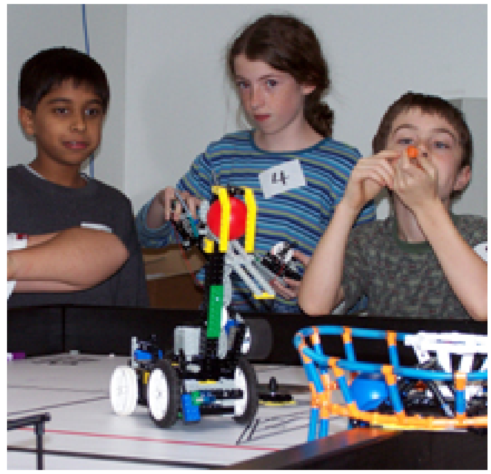
The CD mission.



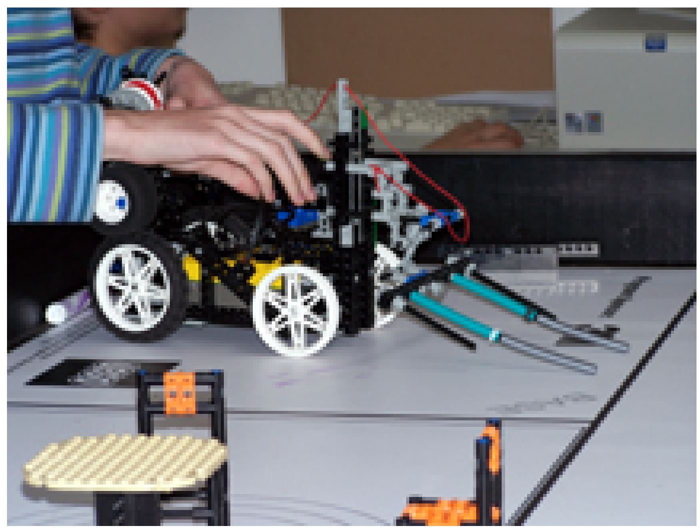
Score!!



Regional Tournament…



The ball in the basket mission.



First, we have to pick it up!

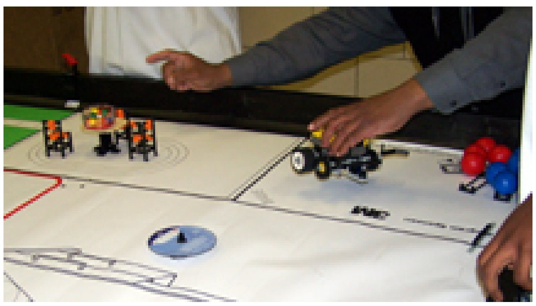
The real deal!

Team Two at practice.

The computer communicates with the robot via the IR tower.

Hey, watch this.

Cool!!



The robot has to put the food on the table.

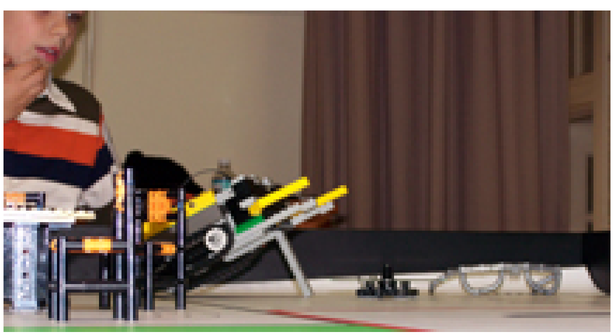
We've got to get this right. We're next at the competition table!

Mentoring… A little help please?

Team Three at practice.

The chairs have to go under the table.

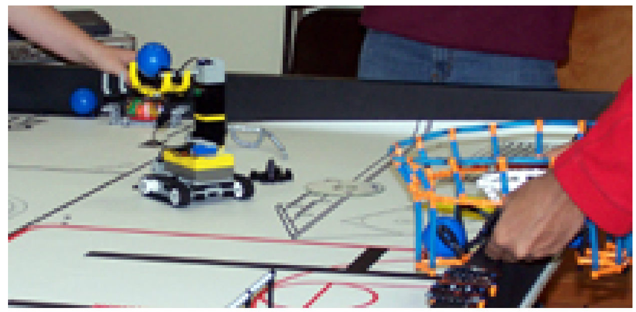
Two chairs under, one to go!



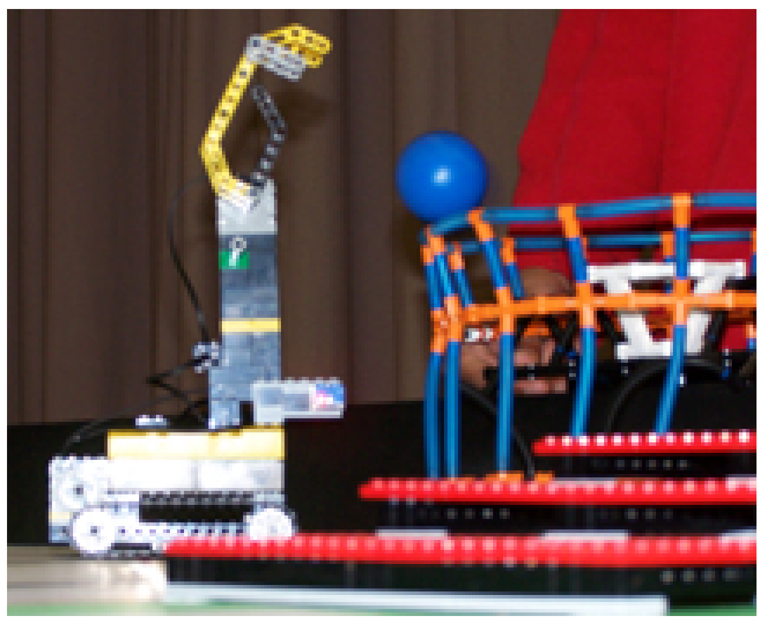
Hmmm… It was a good idea.

Technical presentation for the engineers.

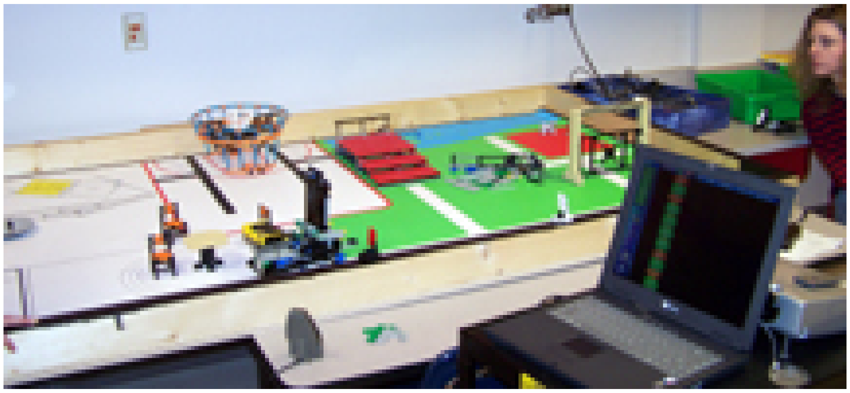
And for my next trick.



Okay, it’s on track for the basket.



Five points! Do it again.

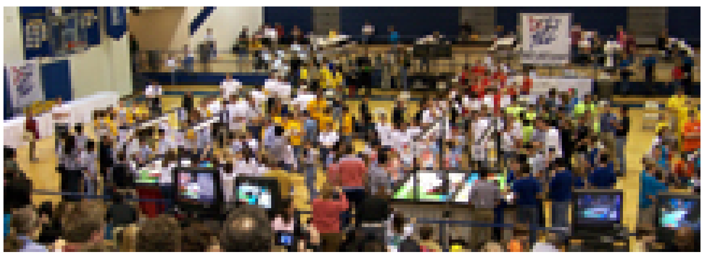


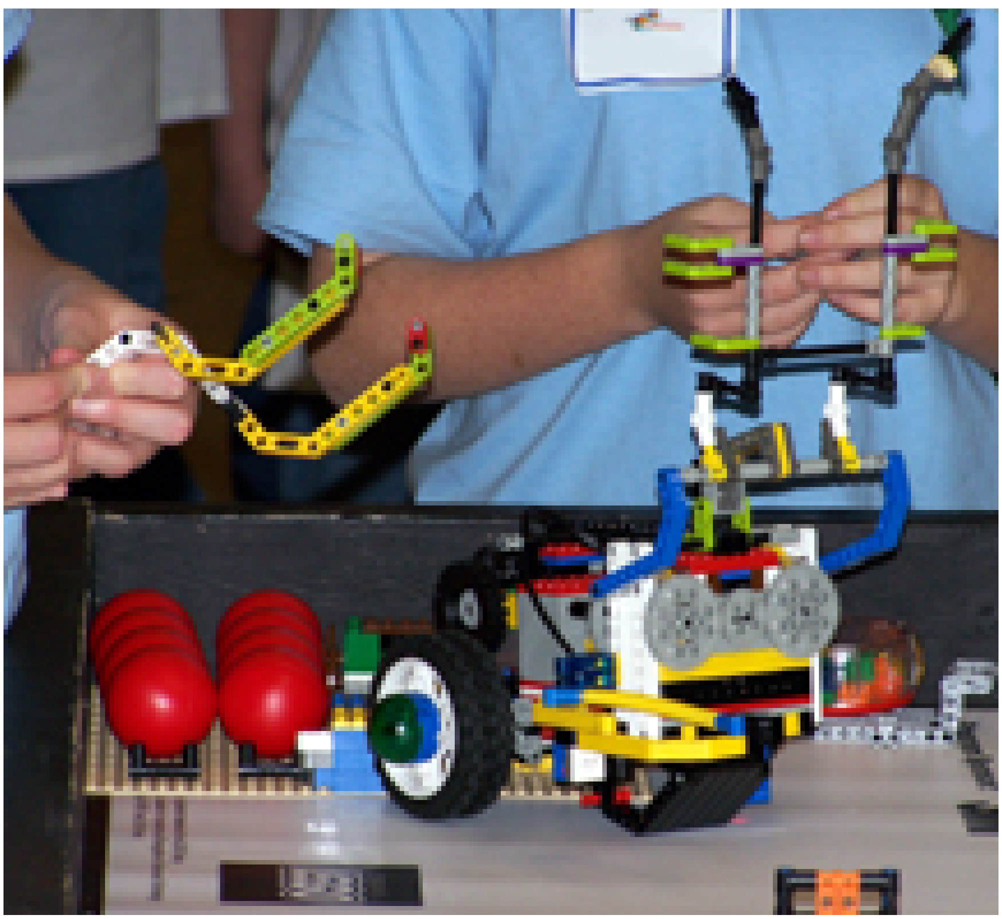
Team Four… the practice field.

Preventative maintenance…
checking the treads.

We're ready when you are, judge.

2004 No Limits Virginia FLL State Tournament





STATE CHAMPS!!

Appendix G: The Technological Problem Solving Inventory

The Technological Problem Solving Inventory

FORM B Technological Problem Solving Version
P. Paul Heppner, Ph.D. Modified and Reproduced by Wu, Custer, and Dyrenfurth, 1993

Name: ____ Date ________________________

Instructions: The items below ask you how you deal with technological problems. Some examples of problems might be lights that will not light, automobiles that will not start, doors that stick and make noise, a problem with a computer, etc. There are no right or wrong answers. Please answer the items as honestly as you can. *Your answers should be how you really deal with problems. Don't answer how you think you should deal with them.* **Please answer each item.** All responses will remain completely confidential.

Read each item. Answer if you agree or disagree, using the numbers below. Circle the number that matches your answer at the end of each item.

1	2	3	4	5	6
Really agree	**Mostly agree**	**Agree, a little**	**Disagree, a little**	**Mostly disagree**	**Really disagree**

1.	When I can't solve a problem, I don't try to find out why.	**1**	**2**	**3**	**4**	**5**	**6**
2.	When I have a big problem, I don't get information to help me understand the problem.	**1**	**2**	**3**	**4**	**5**	**6**
3.	When I can't solve a problem, I question if I can solve it at all.	**1**	**2**	**3**	**4**	**5**	**6**
4.	After I solve a problem, I don't think about what went right or what went wrong.	**1**	**2**	**3**	**4**	**5**	**6**
5.	Usually, I can think up new and useful ways to solve a problem.	**1**	**2**	**3**	**4**	**5**	**6**
6.	Sometimes, I solve a problem in one way. Then I compare what really happened to what I thought should have happened.	**1**	**2**	**3**	**4**	**5**	**6**
7.	I think of as many possible ways to handle a problem until I can't come up with any more ideas.	**1**	**2**	**3**	**4**	**5**	**6**
8.	When I have a problem, I always look at my feelings. That helps me to learn what's going on.	**1**	**2**	**3**	**4**	**5**	**6**
9.	When I feel mixed-up about a problem, I don't try to understand my ideas or feelings.	**1**	**2**	**3**	**4**	**5**	**6**
10.	I can solve most problems even if I don't have a solution at first.	**1**	**2**	**3**	**4**	**5**	**6**

1 Really agree	2 Mostly agree	3 Agree, a little	4 Disagree, a little	5 Mostly disagree	6 Really disagree

11.	Many of my problems are too big and hard for me to solve.	**1**	**2**	**3**	**4**	**5**	**6**
12.	When solving a problem, I make decisions that I am happy with later.	**1**	**2**	**3**	**4**	**5**	**6**
13.	When I have a problem, I usually do the first thing I think of to solve it.	**1**	**2**	**3**	**4**	**5**	**6**
14.	Sometimes, I don't take enough time to solve my problems carefully.	**1**	**2**	**3**	**4**	**5**	**6**
15.	I don't take time to think if other solutions to a problem will work.	**1**	**2**	**3**	**4**	**5**	**6**
16.	When I have a problem, I stop and think about it before deciding on a next step.	**1**	**2**	**3**	**4**	**5**	**6**
17.	When solving problems, I usually use the first good idea that I think of.	**1**	**2**	**3**	**4**	**5**	**6**
18.	When solving a problem, I think about the effects of all possible solutions. Then I compare the solutions to each other.	**1**	**2**	**3**	**4**	**5**	**6**
19.	I'm almost sure that my plans to solve a problem will work.	**1**	**2**	**3**	**4**	**5**	**6**
20.	Sometimes before I carry out a certain plan, I try to guess what might happen.	**1**	**2**	**3**	**4**	**5**	**6**
21.	When I try to think of possible ways to solve a problem, I don't come up with very many answers.	**1**	**2**	**3**	**4**	**5**	**6**
22.	Circle the number 2 for this item.	**1**	**2**	**3**	**4**	**5**	**6**
23.	If I spend enough time and effort, I can solve most of my problems.	**1**	**2**	**3**	**4**	**5**	**6**
24.	When faced with a new situation, I can handle any possible problems.	**1**	**2**	**3**	**4**	**5**	**6**
25.	While working on a problem, I sometimes get confused. Then I don't concentrate on the real problem.	**1**	**2**	**3**	**4**	**5**	**6**
26.	I often make quick decisions and regret them later.	**1**	**2**	**3**	**4**	**5**	**6**
27.	I trust my ability to solve new and different problems.	**1**	**2**	**3**	**4**	**5**	**6**
28.	I carefully compare different solutions to solve problems.	**1**	**2**	**3**	**4**	**5**	**6**
29.	When I think of ways of handling a problem, I don't put different ideas together.	**1**	**2**	**3**	**4**	**5**	**6**

1 Really agree	2 Mostly agree	3 Agree, a little	4 Disagree, a little	5 Mostly disagree	6 Really disagree

30.	When faced with a problem, I don't usually see the things around me that may make my problem worse.	**1**	**2**	**3**	**4**	**5**	**6**
31.	When faced with a problem, I first look at the situation to get all the important pieces of information.	**1**	**2**	**3**	**4**	**5**	**6**
32.	Sometimes I get so upset, I can't think of ways to solve my problem.	**1**	**2**	**3**	**4**	**5**	**6**
33.	After choosing a solution to a problem, the results usually match what I expect.	**1**	**2**	**3**	**4**	**5**	**6**
34.	When faced with a problem, I am not sure I can handle the situation.	**1**	**2**	**3**	**4**	**5**	**6**
35.	When I have a problem, one of the first things I do is try to learn exactly what the problem is.	**1**	**2**	**3**	**4**	**5**	**6**

Appendix H. Final Revision of the SIP Rating Sheet for FLL Study and SIP Subscale Classifications

Student Individualized Performance (SIP) Rating Sheet

Observation: Team:

Date: Location:

	Team Member									
	1	2	3	4	5	6	7	8	9	10
1. Identifies and defines the problem										
2. Prioritizes sub-problems within the larger problem										
3. Identifies and negotiates key constraints										
4. Clarifies criteria prior to solving problem or posing solution										
5. Consults several key resources										
6. Evaluates information; relates information back to problem and constraints										
7. Generates creative and efficient solutions										
8. Solutions meet constraints and address the original problem										
9. Selects a design solution on basis of efficiency and effectiveness										
10. Provides backup or alternate solutions in case the chosen one fails										
11. Develops a detailed design plan with supporting technical drawings and sketches										
12. Maintains journal or log of daily activities										
13. Identifies and uses appropriate materials for producing the model/prototype										
14. Exhibits refined knowledge of materials involved in producing the solution										
15. Develops and executes a detailed and systematic plan, which includes testing and modification										
16. Revisits and refines the problem solution										
17. Demonstrates persistence with minor problems										
18. Tests and critiques the solution										
19. Generates and executes ideas for modifications and improvements										
20. Refines solution based on continuous data gathering										
21. Changes represent some improvement to the quality, functionality, and effectiveness of the solution										
22. Documents ideas for modifications and improvements										
23. Documentation appears to be well organized										

Revised SIP Subscales

I. Problem Clarification

A. Examines context and defines problems
- Item 1
- Item 2

B. Develops, clarifies, and negotiates constraints and criteria
- Item 3
- Item 4

C. Conducts research/gathers pertinent information
- Item 5
- Item 6

II. Develop a Design

A. Generates and visualizes possible solutions
- Item 7
- Item 8

B. Selects a design solution
- Item 9
- Item 10

C. Plans and communicates design
- Item 11
- Item 12

III. Model/Prototype

A. Selects and uses resources
- Item 13
- Item 14

B. Develops a plan for producing a model/prototype
- Item 15

C. Produces model/prototype
- Item 16
- Item 17

IV. Evaluate the Design Solution

A. Tests and critiques solution
- Item 18
- Item 19

B. Evaluates and refines solution
- Item 20
- Item 21

C. Documentation/technical reporting
- Item 22
- Item 23

Appendix I: Pilot Study Letters and Forms

Administrative Information Letter and FIRST™ LEGO™ League Pilot Study Permission

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

To: Mrs. Julia Bussey, Technology Education Teacher, Blacksburg Middle School
Mr. Gary McCoy, Principal, Blacksburg Middle School
Re: Dissertation Research Pilot Study
Date: August 10, 2004

My name is Terri Varnado and I am a Ph.D. candidate in the Technology Education program at Virginia Tech. My proposal for dissertation research, *The Effects of FIRST™ LEGO™ League Participation on Problem Solving Style and Performance*, has been approved by my doctoral committee. The purposes of this study are 1) to determine the relationships among age, gender, and FLL experience levels with participants' problem solving styles and problem solving performance; and 2) to predict student individualized problem solving performance using statistical regression methods.

May I conduct a pilot study during the week of August 30-September 3, 2004? This pilot study will enable me to validate two instruments: *The Problem Solving Inventory* (PSI) and the *Student Individualized Performance* (SIP). I would like to have groups of students, 4-10 students per group, complete a design/problem solving activity using LEGO™ *Mindstorms* robotics kits (attached). On Monday, August 30, 2004, the PSI will be administered. This will take about 20 minutes, after which the robotics design problem will be introduced. The students will have the rest of the week to design and implement a solution. Direct observations will take place Tuesday through Friday. From this pilot study, I will be able to validate the aforementioned instruments and use them in the FLL study, which will take place from September 8, 2004 to November 23, 2004.

If I may answer any questions you have or provide any information you need, please do not hesitate to call on me. Please complete the pilot study permission form below. Thank you very much for your support and cooperation.

Sincerely,

Terri E. Varnado
PhD Candidate, Technology Education
Graduate Research Assistant, Center for Power Electronic Systems
Electrical and Computer Engineering, Virginia Tech
270 Whittemore Hall
Blacksburg, VA 24061-0111
Phone: Office (540) 231-6020
Home (540) 951-2951
Cell (225) 324-2416
E-mail: tvarnado@vt.edu

Pilot Study Permission Form

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

Terri Varnado has my permission to conduct the LEGO *Mindstorms* robotics design pilot study at Blacksburg Middle School, in the classroom of Mrs. Julia Bussey.

____
Julia Bussey, Technology Education Teacher, Blacksburg Middle School

____
Gary McCoy, Principal, Blacksburg Middle School

Problem Solving Pilot Study Information Letter to Parents

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

Dear Parent/Guardian,

It is important for educators to understand if technological problem solving has a positive impact on students' problem solving abilities. The purpose of this study is to determine the specific effects a technological problem solving activity, such as FIRST™ LEGO™ League, has on student participants' problem solving style and performance. Before the FLL study can be conducted during the 2004 FLL Challenge season, a pilot study to validate the assessment instruments is needed. Your permission to allow your child to participate in this pilot study is required.

Using a standardized instrument, students' problem solving confidence, approach/avoidance styles, and personal control will be measured. On Monday, August 30, 2004, student participants will be asked to complete a 35-item questionnaire. This usually takes about 20 minutes. When this assessment is complete, student participants will be asked to answer a 10 question inventory, which will help to identify your child's prior experience with technological problem solving activities. The remaining four days of the week, student participants will be observed directly by the researchers, while they work in groups to solve a problem using LEGOs™ This observation will take place during the student participant's technology education class time. Participation in this pilot study will in no way affect the students' grade or participation in his or her class.

A digital video camera will be set up to take pictures of student participants during the entire problem solving process. This is to help the researchers provide clear and accurate measurements of your child's problem solving performance. These videos will be used for the purposes of clarifying inconsistencies among the observers' observations, and to demonstrate different levels of problem solving performance among the participants during the FLL Challenge season. Digital video footage will be secured in a locked file cabinet in the Electrical and Computer Engineering Office of Undergraduate Student Affairs and will be retained for a period of up to 10 years.

Identification of children and their data will be known only to the researchers while conducting the study. At no time, will any other groups or individuals be able to connect a participant with his or her data. Your child's name will not be used in any publication or video footage. Participation in this research study is strictly voluntary and students may withdraw at any time.

Please fill out the parental permission form and the photo release form attached to this letter and return it to Mrs. Julia Bussey as soon as possible. If you have any questions, please do not hesitate to call me (Terri Varnado) at 540-951-2951 (Home) or 225-324-2416 (Cell). You may also correspond via email (tvarnado@vt.edu). Thank you for your support of and cooperation in this important research study.

Sincerely,

Terri E. Varnado
PhD Candidate, Technology Education
Graduate Research Assistant, Center for Power Electronic Systems
Electrical and Computer Engineering, Virginia Tech
270 Whittemore Hall
Blacksburg, VA 24061-0111
Office Phone: (540) 231-6020

Parental Permission Form

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

My child, ____ (print name), has my permission to participate fully in the *Problem Solving Style and Performance* research study, as outlined in the enclosed letter. I understand that there will be minimal risk to my child and that participation is voluntary. My child's name will not be used in the research publications and videos.

____________________________________ ________________________
Parent/Guardian (print name) Date

____________________________________ ________________________
Parent/Guardian Signature Date

____________________________________ ________________________
FLL Student Participant (print name) Date

____________________________________ ________________________
FLL Student Participant Signature Date

Photo Release Form

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

For the publicity and recognition I may receive,

I ____, (Print Name)
hereby grant permission to Terri Varnado and Virginia Tech (VT) to be photographed, without further compensation, understanding that the same is intended for Terri Varnado's research and/or VT publication, promotional, or instructional purposes in print media, newspaper, television, video, motion picture, or Web site on the Internet.

I additionally consent to the use of my interview comments in connection with Terri Varnado's research and/or VT publication, promotional, or instructional purposes in print media, newspaper, television, video, motion picture, or Web site on the Internet.

Any other use of these images, and/or interview comments needs my permission in advance.

_____________________________________ __________________________

FLL Student Participant Date

_____________________________________ __________________________

Parent/guardian signature (if participant is a minor) Date

Appendix J: Revised SIP for Pilot Study

Student Individualized Performance (SIP) Rating Sheet - I

Observation 1: Team:
Date: Location:

Rating Scale

1 = Novice **2 = Beginner** **3 = Competent** **4 = Proficient** **5 = Expert**

I. Problem Clarification	Team Member									
	1	2	3	4	5	6	7	8	9	10
A. Examines context and defines problem										
1. Identifies and defines the problem										
2. Asks pertinent questions										
3. Prioritizes sub-problems within the larger problem										
4. Explores context										
B. Develops, clarifies, and negotiates constraints & criteria										
1. Identifies key constraints										
2. Negotiates constraints										
3. Clarifies criteria prior to solving problem or posing solutions										
C. Conducts research/gathers pertinent information										
1. Consults several key sources										
2. Uses refined search strategies & observational techniques										
3. Researches sub-problems										
4. Evaluates information; relates information back to problem and constraints										

Notes:

Student Individualized Performance (SIP) Rating Sheet - II

Observation 2 Team:
Date: Location:

Rating Scale

1 = Novice **2 = Beginner** **3 = Competent** **4 = Proficient** **5 = Expert**

II. Develop a Design	Team Member									
	1	2	3	4	5	6	7	8	9	10
A. Generates and visualizes possible solutions										
1. Generates creative & efficient solutions										
2. Solutions meet constraints and address the original problem										
3. Ideas are innovative										
B. Selects a design solution										
1. Selects solution on basis of efficiency and effectiveness										
2. Provides basic rationale for selection										
3. Provides backup or alternate solutions in case the chosen one fails										
C. Plans and communicates design										
1. Develops a detailed design plan with supporting technical drawings and sketches										
2. Explains design plan, citing procedures, resources, and other requirement										
3. Maintains journal or log of daily activities										

Notes:

Student Individualized Performance (SIP) Rating Sheet - III

Observation 3 Team:
Date: Location:

Rating Scale

1 = Novice **2 = Beginner** **3 = Competent** **4 = Proficient** **5 = Expert**

III. Model/Prototype	Team Member									
	1	2	3	4	5	6	7	8	9	10
A. Selects and uses resources										
1. Identifies appropriate resources for producing the model/prototype										
2. Uses appropriate resources for producing the model/prototype										
3. Exhibits refined knowledge of tools, materials, and technological processes involved in producing the solution										
4. Selected resources may not be feasible due to lack of availability, need for expertise, or cost										
B. Develops a plan for producing a model/prototype										
1. Develops a detailed and systematic plan, which includes testing, and modification										
2. Executes a detailed and systematic plan, which includes testing and modification										
3. Incorporates quality control measures										
C. Produces model/prototype										
1. Revisits and refines the problem solution										
2. Demonstrates persistence with minor problems										
3. Uses tools and resources adeptly and confidently										
4. Enjoys the challenge of refinements										

Notes:

Student Individualized Performance (SIP) Rating Sheet - IV

Observation 4 Team:
Date: Location:

Rating Scale

1 = Novice **2 = Beginner** **3 = Competent** **4 = Proficient** **5 = Expert**

IV. Evaluate the Design Solution	Team Member									
	1	2	3	4	5	6	7	8	9	10
A. Tests and critiques solution										
1. Designs effective testing strategies										
2. Tests and critiques the solution										
3. Generates ideas for modifications and improvements										
4. Executes ideas for modifications and improvements										
B. Evaluates and refines solution										
1. Refines solution based on continuous data gathering										
2. Changes represent some improvement to the quality, functionality, and effectiveness of the solution										
C. Documentation/technical reporting										
1. Documents ideas for modifications and improvements										
2. Documentation includes the processes used, design details, and resources										
3. Documentation is well organized										
4. Documentation is highly reflective and contains insight concerning changes and refinements										
5. Drawings are technical and provide essential information										

Notes:

Appendix K: FLL Study Information Letter and Parental Permission Forms

FIRST™ LEGO™ League Information Letter to Parents

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

Dear Parent/Guardian,

During the 2004 FIRST™ LEGO™ League (FLL) Challenge season, I will be conducting a research study involving technological problem solving. It is important for educators to understand if FLL has a positive impact on students' problem solving abilities. The purpose of this study is to determine the effects FLL has on student participants' problem solving style and performance. Your permission to allow your child to participate in this study is required.

Identification of children and their data will be known only to the researchers while conducting the study. At no time, will any other groups or individuals be able to connect a participant with his or her data. Your child's name will not be used in any publication or video footage. Participation in this research study is strictly voluntary and students may withdraw at any time.

Using a standardized instrument, I will be assessing students' problem solving confidence, approach/avoidance styles, and personal control. At three points during the FLL Challenge season, student participants will be asked to complete a 35-item questionnaire. This usually takes about 20 minutes for each administration. Additionally, four times throughout the season, participants will be observed directly by the researchers. This observation will take place during the team's practice sessions. Your child will also be asked to participate in a brief exit interview at the end of the FLL experience.

A digital video camera will be set up to take pictures of student participants during the entire practice sessions in which your child's team will be observed. Exit interviews will also be recorded. This is to help the researchers provide clear and accurate measurements of your child's problem solving performance. These videos will be used for the purposes of clarifying inconsistencies among the observers' observations, and to demonstrate different levels of problem solving performance among the participants during the FLL Challenge season. Digital video footage will be secured in a locked file cabinet in the Electrical and Computer Engineering Office of Undergraduate Student Affairs and will be retained for a period of up to 10 years.

Please fill out the parental permission form and the photo release form attached to this letter and return it to the FLL coach as soon as possible. If you have any questions, please do not hesitate to call me (Terri Varnado) at 540-951-2951 (Home) or 225-324-2416 (Cell). You may also correspond via email (tvarnado@vt.edu). Thank you for your support of and cooperation in this important research study.

Sincerely,

Terri E. Varnado
PhD Candidate, Technology Education
Graduate Research Assistant, Center for Power Electronic Systems
Electrical and Computer Engineering, Virginia Tech
270 Whittemore Hall
Blacksburg, VA 24061-0111
Office Phone: (540) 231-6020

Parental Permission Form

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

My child, ____ (print name), has my permission to participate fully in the *Problem Solving Style and Performance* research study, as outlined in the enclosed letter. I understand that there will be minimal risk to my child and that participation is voluntary. My child's name will not be used in the research publications and videos.

____________________________________ ________________________
Parent/Guardian (print name) Date

____________________________________ ________________________
Parent/Guardian Signature Date

____________________________________ ________________________
FLL Student Participant (print name) Date

____________________________________ ________________________
FLL Student Participant Signature Date

Photo Release Form
Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

For the publicity and recognition I may receive,

I ____, (Print Name)
hereby grant permission to Terri Varnado and Virginia Tech (VT) to be photographed, without further compensation, understanding that the same is intended for Terri Varnado's research and/or VT publication, promotional, or instructional purposes in print media, newspaper, television, video, motion picture, or Web site on the Internet.

I additionally consent to the use of my interview comments in connection with Terri Varnado's research and/or VT publication, promotional, or instructional purposes in print media, newspaper, television, video, motion picture, or Web site on the Internet.

Any other use of these images, and/or interview comments needs my permission in advance.

_____________________________________ _____________________________

FLL Student Participant Date

_____________________________________ _____________________________

Parent/guardian signature (if participant is a minor) Date

Appendix L: Possible FLL Experience Levels in Years According to Age

	1998	1999	2000	2001	2002	2003	2004
Age-Experience Levels	9-0	10-1	11-2	12-3	13-4	14-5	
		9-0	10-1	11-2	12-3	13-4	14-5
			9-0	10-1	11-2	12-3	13-4
				9-0	10-1	11-2	12-3
					9-0	10-1	11-2
						9-0	10-1
							9-0
	10-0	11-1	12-2	13-3	14-4		
		10-0	11-1	12-2	13-3	14-4	
			10-0	11-1	12-2	13-3	14-4
				10-0	11-1	12-2	13-3
					10-0	11-1	12-2
						10-0	11-1
	11-0	12-1	13-2	14-3			
		11-0	12-1	13-2	14-3		
			11-0	12-1	13-2	14-3	
				11-0	12-1	13-2	14-3
					11-0	12-1	13-2
						11-0	12-1
							11-0
	12-0	13-1	14-2				
		12-0	13-1	14-2			
			12-0	13-1	14-2		
				12-0	13-1	14-2	
					12-0	13-1	14-2
						12-0	13-1
							12-0
	13-0	14-1					
		13-0	14-1				
			13-0	14-1			
				13-0	14-1		
					13-0	14-1	
						13-0	14-1
							13-0
	14-0						
		14-0					
			14-0				
				14-0			
					14-0		
						14-0	
							14-0

Appendix M: Student Participant Inventory

FIRST™ LEGO™ League Student Participant Inventory

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

Team Name: ___________________________ Location: _________________________

Directions: Please read each of the questions and responses below fully before making the best selection. Your time and cooperation are greatly appreciated.

1. In which FIRST™ LEGO™ League (FLL) Challenges have you been a student participant? (Please check all that apply).
   - ❑ 2004 No Limits
   - ❑ 2003 Mission Mars
   - ❑ 2002 City Sights
   - ❑ 2001 Artic Impact
   - ❑ 2000 Volcanic Panic
   - ❑ 1999 First Contact
   - ❑ 1998 Pilot

2. Why did you want to join FLL? (Please check all that apply).
   - ❑ I played with LEGOs at home
   - ❑ To learn more about engineering and technology
   - ❑ I worked with LEGOs at school (Please indicate which class)
     - ❑ Math
     - ❑ Science
     - ❑ Social Studies
     - ❑ Technology Education
     - ❑ Other ____________________
   - ❑ My parents signed me up
   - ❑ My friend is on the team
   - ❑ Other _______________________

3. How do you learn about the FLL rules?
   - ❑ Read the manual
   - ❑ Look on the Internet
   - ❑ Coach tells me
   - ❑ Other ________________

4. What is your role on the team? (Check all that apply).
   - ❑ Design
   - ❑ Construction
   - ❑ Programming
   - ❑ Research
   - ❑ Other _______________________

5. Do you work out your own technical problems?
   - ❑ Yes
   - ❑ Sometimes an *adult* tells me what to do
   - ❑ No, an *adult* tells me what to do all the time
   - ❑ Sometimes a *teammate* tells me what to do
   - ❑ No, a *teammate* tells me what to do all the time
   - ❑ Other _______________________

6. With what other groups have you been involved?
   - ❑ None
   - ❑ 4H
   - ❑ B.E.S.T.
   - ❑ Odyssey of the Mind
   - ❑ FIRST™ Robotics Competition
   - ❑ Science Fair
   - ❑ Science Olympiad
   - ❑ Scouts
   - ❑ T.S.A.
   - ❑ V.I.C.A.
   - ❑ Young Astronauts
   - ❑ Other ________________

7. In the last year, which toys have you played with? (Check all that apply).
   - ❑ Capsela
   - ❑ Commando Bot
   - ❑ Digi-Draw
   - ❑ Erector Sets
   - ❑ Fischer Technik
   - ❑ Gameboy
   - ❑ GameCube
   - ❑ iQuest
   - ❑ K'Nex
   - ❑ Leap Pad/Quantum Pad
   - ❑ LEGOs
   - ❑ Math Shark
   - ❑ *Mindstorms*
   - ❑ Neopets
   - ❑ Nintendo
   - ❑ Playstation
   - ❑ RC cars, trucks, or airplanes
   - ❑ Sega
   - ❑ Snap Circuits
   - ❑ Tinker Toys
   - ❑ Virtual Reality 3-D Spiderman
   - ❑ Xbox
   - ❑ Zoids
   - ❑ None of these
   - ❑ Other ________________________

8. What is your favorite toy?

   ____

9. What is your birthday? (Please indicate the month, the day, and the year)

   ____

10. What is your gender?
    - ❑ Boy
    - ❑ Girl

Thanks for completing this survey!

Appendix N: Coach's and Mentor/Volunteer Inventories

FIRST™ LEGO™ League Coaches' Inventory

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

Team Name: ___________________________ Location: _________________________

Directions: Please read each of the questions and responses below fully before making the best selection for you and your team.

1. Which **one** of the following best describes your team's affiliation?
   - ❑ Part of the regular school day
   - ❑ An after school program
   - ❑ Home school
   - ❑ Neighborhood group
   - ❑ Community group (Scouts, YMCA, etc)
   - ❑ Religious group
   - ❑ Other __________________________

2. Which **one** of the following best describes your team's location?
   - ❑ Suburban
   - ❑ Urban
   - ❑ Rural
   - ❑ Other __________________________

3. How many members of your team are officially registered with FLL?
   - ❑ 4
   - ❑ 5
   - ❑ 6
   - ❑ 7
   - ❑ 8
   - ❑ 9
   - ❑ 10

4. How many registered team members are
   Boys? __________

   Girls? __________

5. What is the total number of registered coaches on your team?
   ____

6. How many of your officially registered coaches are
   Male? ___________

   Female? __________

7. How many parent volunteers does your team have?
   ____

8. Does your team have a "mentor"?
   - ❑ Yes
   - ❑ No

9. How did you select team members to participate in FLL? (Please check all that apply).
   - ❑ Recruited
   - ❑ Volunteered
   - ❑ Try-outs
   - ❑ Interviews
   - ❑ Essay writing
   - ❑ Other ________________________

10. If try-outs were required, what criteria were used to determine who would be selected as a FLL team member? (If additional space is needed, please write on the back of this page. If no try-outs were required, please skip to question 11).
    ____
    ____
    ____
    ____

11. How will your team members be assigned roles on the team?
    - ❑ No assignment; everyone participates in every aspect
    - ❑ Students choose what they like best
    - ❑ Random assignment
    - ❑ Coach decides which students are best for specific roles
    - ❑ Other ________________________

12. Which **one** programming platform will your team use most throughout the 2004 Challenge season?
    - ❑ RIS
    - ❑ RoboLab

13. What is your FLL coaching experience? (Please check all that apply).
    - ❑ 2004 No Limits
    - ❑ 2003 Mission Mars
    - ❑ 2002 City Sights
    - ❑ 2001 Artic Impact
    - ❑ 2000 Volcanic Panic
    - ❑ 1999 First Contact
    - ❑ 1998 Pilot

14. Have you ever attended a FLL coaches' workshop?
    - ❑ Yes (If yes, please answer questions 15)
    - ❑ No (If no, please skip to question 16)

15. If you have attended a FLL coaches' workshop, where and when did you attend?

    Location ______________________

    Date ________________________

16. Have you completed the FLL Online Coach Tutorials?

- ❑ Yes
- ❑ No
- ❑ I have completed other online tutorials (Please list).

____

____

17. With what other organizations have you "coached"? (Please check all that apply).
    - ❑ None
    - ❑ 4H
    - ❑ B.E.S.T.
    - ❑ Odyssey of the Mind
    - ❑ FIRST™ Robotics Competition
    - ❑ Science Fair
    - ❑ Science Olympiad
    - ❑ Scouts
    - ❑ T.S.A.
    - ❑ V.I.C.A.
    - ❑ Young Astronauts
    - ❑ Other ____________________

18. In what year were you born?

    ____

19. Which **one** of the following categories best describes your current occupation?
    - ❑ Administrative Support
    - ❑ Architecture, surveying, and cartography
    - ❑ Armed Forces
    - ❑ Art and design
    - ❑ Community and social services
    - ❑ Computer and mathematical occupations
    - ❑ Construction
    - ❑ Do not work outside the home
    - ❑ Drafting and engineering technology
    - ❑ Educator/Teacher (Please indicate the subject you teach: ______________________).
    - ❑ Engineering
    - ❑ Entertainment and performance, sports
    - ❑ Farming
    - ❑ Health diagnosing and treatment occupations
    - ❑ Health technologists and technicians
    - ❑ Installation
    - ❑ Legal
    - ❑ Life science
    - ❑ Management
    - ❑ Media and communications
    - ❑ Physical science
    - ❑ Production
    - ❑ Sales
    - ❑ Self-employed
    - ❑ Service
    - ❑ Student
        - o High School
        - o Undergraduate
        - o Graduate
    - ❑ Social science
    - ❑ Training, library, and museum occupations
    - ❑ Transportation
    - ❑ Other ____________________

Thanks! Thank you for taking the time to complete this inventory. Your input is greatly appreciated.

FIRST™ LEGO™ League Mentor/Volunteer Inventory

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

Team Name: ___________________________ Location:_________________________

Directions: Please read each of the questions and responses below fully before making the best selection. Your time and cooperation are greatly appreciated.

1. In what capacity have you been involved with FIRST™ LEGO™ League (FLL)? (Please check all that apply).

   Mentor
   - ❑ 2004 No Limits
   - ❑ 2003 Mission Mars
   - ❑ 2002 City Sights
   - ❑ 2001 Artic Impact
   - ❑ 2000 Volcanic Panic
   - ❑ 1999 First Contact
   - ❑ 1998 Pilot

   Coach
   - ❑ 2004 No Limits
   - ❑ 2003 Mission Mars
   - ❑ 2002 City Sights
   - ❑ 2001 Artic Impact
   - ❑ 2000 Volcanic Panic
   - ❑ 1999 First Contact
   - ❑ 1998 Pilot

   Student Participant
   - ❑ 2004 No Limits
   - ❑ 2003 Mission Mars
   - ❑ 2002 City Sights
   - ❑ 2001 Artic Impact
   - ❑ 2000 Volcanic Panic
   - ❑ 1999 First Contact
   - ❑ 1998 Pilot

   Volunteer
   - ❑ 2004 No Limits
   - ❑ 2003 Mission Mars
   - ❑ 2002 City Sights
   - ❑ 2001 Artic Impact
   - ❑ 2000 Volcanic Panic
   - ❑ 1999 First Contact
   - ❑ 1998 Pilot

   Sponsor
   - ❑ 2004 No Limits
   - ❑ 2003 Mission Mars
   - ❑ 2002 City Sights
   - ❑ 2001 Artic Impact
   - ❑ 2000 Volcanic Panic
   - ❑ 1999 First Contact
   - ❑ 1998 Pilot

2. With what other organizations have you been involved?
   - ❑ None
   - ❑ 4H
   - ❑ B.E.S.T.
   - ❑ Odyssey of the Mind
   - ❑ FIRST™ Robotics Competition
   - ❑ Science Fair
   - ❑ Science Olympiad
   - ❑ Scouts
   - ❑ T.S.A.
   - ❑ V.I.C.A.
   - ❑ Young Astronauts
   - ❑ Other _________________

3. Which **one** of the following categories best describes your current occupation?

- ❑ Administrative Support
- ❑ Architecture, surveying, and cartography
- ❑ Armed Forces
- ❑ Art and design
- ❑ Community and social services
- ❑ Computer and mathematical occupations
- ❑ Construction
- ❑ Do not work outside the home
- ❑ Drafting and engineering technology
- ❑ Educator/Teacher (Please indicate the subject you teach: ______________________________
- ❑ Engineering
- ❑ Entertainment and performance, sports
- ❑ Farming
- ❑ Health diagnosing and treatment occupations
- ❑ Health technologists and technicians
- ❑ Installation
- ❑ Legal
- ❑ Life science
- ❑ Management
- ❑ Media and communications
- ❑ Physical science
- ❑ Production
- ❑ Sales
- ❑ Self-employed
- ❑ Service

4. What is your highest level of education?
    - ❑ Less than high school
    - ❑ High school diploma
    - ❑ Some college
    - ❑ College degree
        - ❑ A.A.
        - ❑ A.A.S
        - ❑ B.A./B.S.
        - ❑ M.A./M.S.
        - ❑ Ed.D.
        - ❑ Ph.D.
        - ❑ Other ____________

5. What is your gender?
    - ❑ Male
    - ❑ Female

6. What is your date of birth? (Mo/year): _____________________________

Thank you for completing this survey!

Appendix O: Testing and Observation Schedule

Week	Date	Day	Team 1	Team 2	Team 3	Team 4
	September 15	Wednesday	2004 No Limits Challenge Released			
One	20	Monday	PSI-TECH 1			
	21	Tuesday		PSI-TECH 1		
	22	Wednesday			PSI-TECH 1	
	23	Thursday				PSI-TECH 1
Two	27	Monday				
	28	Tuesday				
	29	Wednesday				
	30	Thursday				
Three	October 4	Monday	SIP 1			
	5	Tuesday		SIP 1		
	6	Wednesday			SIP 1	
	7	Thursday				SIP 1
Four	11	Monday	SIP 2			
	12	Tuesday		SIP 2		
	13	Wednesday			SIP 2	
	14	Thursday				SIP 2
Five	18-22		International Engineering Education and Research Conference Gainesville, FL			
Six	25	Monday	PSI-TECH 2			
	26	Tuesday		PSI-TECH 2		
	27	Wednesday			PSI-TECH 2	
	28	Thursday				PSI-TECH 2
Seven	November 1	Monday	SIP 3			
	2	Tuesday		SIP 3		
	3	Wednesday			SIP 3	
	4	Thursday				SIP 3
Eight	8	Monday	SIP 4			
	9	Tuesday		SIP 4		
	10	Wednesday			SIP 4	
	11	Thursday				SIP 4
	13	Saturday	Danville Regional Tournament			
	14	Sunday	Christiansburg Regional Tournament			
	15	Monday	PSI-TECH 3			
	16	Tuesday		PSI-TECH 3		
	17	Wednesday			PSI-TECH 3	
	18	Thursday				PSI-TECH 3

Appendix P. Student Participant Exit Interview Questions

FIRST™ LEGO™ League Exit Interview

Terri E. Varnado, Ph.D. Candidate
Technology Education
Virginia Polytechnic Institute and State University
Fall 2004

This interview will be used to clarify any questions the researcher has about uncertainties in the direct observation. Student participants will be encouraged to speak freely about their experiences with the 2004 FLL Robotics *Challenge*. Questions to help student participants get started may look like the following:

1. When you are confronted with a new problem, what is the first thing you do? Why?

2. What is the second thing you do? Why?

3. How do you know when you have successfully solved a problem?

4. Once you have solved a problem, do you ever want to change it to make it better? Why?

5. What matters most to you, the way your robot looks or the way your robot works?

6. Does it help you to draw ideas for your robot? Why?

7. On the FLL student participant inventory you completed at the beginning of the season, you indicated your favorite toy to be ________________. Why do you like this toy?

8. Do you think because you are in FLL that it will help you to do better in school? Why?

Appendix Q: Case Summaries

Case Summaries PSI-TECH Ranked by Grand Total Scores (Best to Least)

Participant Code	September 20-23 PSI 1 (n=36)	October 25-28 PSI 2 (n=33)	November 15-18 PSI 3 (n=30)	Confidence Total (n=36)	Approach/ Avoidance Total (n=36)	Personal Control Total (n=36)	PSI Grand Total (n=36)
	Range 32-192	Range 32-192	Range 32-192	Range 11-66	Range 16-96	Range 5-30	Range 32-192
B7.9.M.1	55	39	37	14.33	19.67	9.67	43.67
C4.12.M.0	66	57	42	17.00	32.00	6.00	55.00
H3.13.M.0	64	75	48	14.67	33.67	14.00	62.33
W3.12.F.0	83	67	64	18.00	38.00	15.33	71.33
C3.11.M.0	72	..	..	21.00	36.00	15.00	72.00
W6.12.F.0	63	81	76	19.33	38.67	15.33	73.33
7.13.M.0	83	69	..	24.50	36.50	15.00	76.00
B2.11.F.0	91	72	65	27.00	38.00	11.0	76.00
W1.11.F.0	77	..	..	25.00	41.00	11.00	77.00
C6.14.M.0	78	81	..	21.50	44.00	14.00	79.50
W11.11.F.0	82	79	84	25.00	43.33	13.33	81.67
B3.10.M.0	101		64	20.00	50.50	12.00	82.50
B4.11.F.0	78	86	89	24.33	51.67	8.33	84.33
C2.14.M.2	94	71	91	32.00	40.00	13.33	85.33
H7.13.M.0	96	76	85	22.00	38.33	25.33	85.67
W2.10.M.0	95	74	95	27.67	45.33	15.00	88.00
C1.12.F.1	95	82	..	32.00	41.00	15.50	88.50
W10.12.F.0	93	84	..	26.50	44.00	18.00	88.50
W4.9.M.0	89	86	91	22.00	56.00	10.67	88.67
B5.9.M.0	92	93	84	23.67	47.67	18.33	89.67
B6.10.M.0	80	100	90	21.00	51.00	18.00	90.00
H2.11.M.1	77	113	85	28.33	49.67	13.67	91.67
H1.13.F.1	102	93	81	25.67	44.33	22.00	92.00
B9.13.M.0	110	99	68	26.00	51.33	15.00	92.33
H6.13.F.1	95	97	90	26.00	45.33	22.67	94.00
H8.13.F.0	104	97	87	25.00	52.00	19.00	96.00
H4.13.F.0	103	100	90	31.33	48.67	17.67	97.67
B10.12.M.1	112	93	91	33.00	49.33	16.33	98.67
W9.9.M.0	109	99	98	30.67	53.00	18.33	102.00
W7.12.M.0	127	96	88	29.67	59.33	14.67	103.67
H5.13.F.0	103	114	102	30.00	55.33	21.00	106.33
B1.12.M.1	98	118	103	30.67	56.00	19.67	106.33
C5.12.M.0	105	106	112	28.00	62.33	17.33	107.67
W8.12.M.0	100	114	117	31.00	62.33	17.00	110.33
W5.12.F.0	115	112	119	38.33	57.00	20.00	115.33
B8.9.M.0	136	124	128	36.33	77.67	15.33	129.33
Actual Range	55-136	39-124	37-128	14-38	19-77	6-25	43-129

Note: Assuming equal intervals and if PSI-TECH was a good predictor of SIP: Novice 160-192 (81-100%), Beginner 128-159 (61-80%), Competent 96-127 (41-60%), Proficient 64-95 (21-40%), and Expert 32-63 (0-20%). Showed an increase in problem solving style at each administration over the eight weeks; showed an increase in problem solving style from the first administration to the third administration with no improvement at the second administration.

Case Summaries SIP Ranked by Grand Total Scores (Best to Least)

Participant Code	October 4-7 SIP 1 (n=32)	October 11-14 SIP 2 (n=27)	Nov. 1-4 SIP 3 (n=28)	Nov. 8-11 SIP 4 (n=33)	Problem Clarification (n=35)	Developing a Design (n=35)	Modeling/ Prototyping (n=35)	Evaluating the Design Solution (n=35)	SIP Grand Total (n=35)
	Range 0-115	Range 0-115	Range 0-115	Range 0-115	Range 0-30	Range 0-30	Range 0-25	Range 0-30	Range 0-115
H2.11.M.1	33	16	64	28	7.50	4.50	12.50	10.75	35.50
W4.9.M.0	13	10	70	50	5.50	5.75	14.75	9.75	33.63
W9.9.M.0	13	10	70	50	5.50	5.75	14.75	9.75	33.63
W2.10.M.0	0	17	70	42	6.50	5.00	11.75	9.00	31.88
B4.11.F.0	44	34	6	57	7.75	5.00	13.25	9.25	31.13
C2.14.M.2	41	..	44	40	5.33	6.00	17.67	12.67	28.63
B10.12.M.1	46	51	18	0	10.00	4.25	9.25	5.25	23.88
B6.10.M.0	40	..	27	51	8.33	7.33	14.33	9.33	23.75
W8.12.M.0	17	7	46	37	5.25	4.75	11.50	5.25	23.63
W7.12.M.0	13	4	48	37	5.75	4.75	10.75	4.25	22.88
H3.13.M.0	9	14	68	4	7.75	3.75	7.75	4.50	21.13
H7.13.M.0	13	14	57	0	5.25	3.50	8.00	4.25	18.88
B1.12.M.1	19	..	..	57	8.00	5.00	15.50	9.50	17.38
B2.11.F.0	8	..	..	57	6.00	5.00	12.00	9.50	16.13
H4.13.F.0	8	14	41	0	5.00	3.00	5.25	2.50	16.00
H1.13.F.1	4	..	57	4	4.33	3.67	8.00	5.67	15.00
B7.9.M.1	28	..	8	21	3.33	3.00	8.00	4.67	14.63
H5.13.F.0	7	20	30	0	5.25	.75	5.75	2.50	13.63
C5.12.M.0	5	64	0	0	7.00	1.75	4.75	3.75	13.13
C1.12.F.1	5	64	..	..	16.50	3.50	9.50	5.00	12.50
W10.12.F.0	10	0	36	0	5.00	1.50	3.00	2.00	10.25
H8.13.F.0	..	4	34	0	5.67	0	3.67	3.33	10.25
W5.12.F.0	7	6	36	0	5.50	1.50	3.25	2.00	9.38
W6.12.F.0	10	4	27	0	5.50	1.50	2.25	1.00	9.00
W11.11.F.0	0	13	..	21	2.67	0	7.00	1.67	8.50
B5.9.M.0	4	20	2	0	3.25	.5	1.00	1.75	7.50
C6.14.M.0	9	21	0	0	2.75	0	4.75	0	6.75
B9.13.M.0	28	..	6	0	3.00	0	6.67	1.67	6.63
C4.12.M.0	5	21	0	0	3.25	0	3.25	0	6.50
B8.9.M.0	8	9	6	11	2.25	.5	3.50	2.25	6.25
C7.13.M.0	3	22	0	0	2.75	0	3.50	0	6.13
W3.12.F.0		9	..	0	2.50	0	2.00	0	2.25
B3.10.M.0	5	3	0	0	1.00	0	1.00	0	1.63
C3.11.M.0	5	..	..	..	5.00	0	0	0	1.38
W1.11.F.0	..	..	..	..	..	..	..	..	..
Actual Range	3-46	3-64	0-70	0-57	1-16.5	0-7.33	0-17.67	0-12.67	1.38-35.5

Note: Novice 0-22, Beginner 23-45, Competent 46-68, Proficient 69-91, and Expert 92-115. Peak performance

Appendix R: Gender Frequencies for Student Participant Inventory

Results of 2004 No Limits Student Participant Inventory

	Male		Female	
	n	%	*n*	%
SPI Q1.1 Did student participate in FLL 2004 No Limits?	22	100	14	100
SPI Q1.2 Did student participate in FLL 2003 Mission Mars?	4	18	3	14
SPI Q1.3 Did student participate in FLL 2002 City Sights?	1	5	0	0
SPI Q1.4 Did student participate in FLL 2001 Artic Impact?	0	0	0	0
SPI Q1.5 Did student participate in FLL 2000 Volcanic Panic?	1	5	0	0
SPI Q1.6 Did student participate in FLL 1999 First Contact?	0	0	0	0
SPI Q1.7 Did student participate in FLL 1998 Pilot Challenge?	0	0	0	0
SPI Q2.1 Joined FLL because student played with LEGOs at home	13	59	5	23
SPI Q2.2 Joined FLL because student wanted to learn more about engineering and technology.	12	55	9	41
SPI Q2.3 Joined FLL because student worked with LEGOs at school in Math.	1	5	0	0
SPI Q2.4 Joined FLL because student worked with LEGOs at school in Science.	1	5	0	0
SPI Q2.5 Joined FLL because student worked with LEGOs at school in Social Studies	0	0	0	0
SPI Q2.6 Joined FLL because student worked with LEGOs at school in Technology Education.	2	9	0	0
SPI Q2.7 Joined FLL because student worked with LEGOs at school in Other subject.	3	14	0	0
SPI Q2.8 Joined FLL because student's parents signed them up.	2	9	2	9
SPI Q2.9 Joined FLL because student's friend is on the team.	3	14	5	23
SPI Q2.10 Student joined FLL for some other reason.	3	14	4	18
SPI Q3.1 Student learns about the FLL rules by reading the manual.	8	36	4	18
SPI Q3.2 Student learns about the FLL rules by looking on the Internet.	3	14	4	18

SPI Q3.3 Student learns about the FLL rules because the coach tells them the rules.	14	64	11	50
SPI Q3.4 Student learns about the FLL rules by watching other people.	1	5	0	0
SPI Q4.1 Student's role on the team is Design.	8	36	3	14
SPI Q4.2 Student's role on the team is Construction.	11	50	3	14
SPI Q4.3 Student's role on the team is Programming.	10	45	4	64
SPI Q4.4 Student's role on the team is Research.	5	23	3	14
SPI Q4.5 Student's role on the team is something Other.	2	9	1	5
SPI Q5.1 Student works out his/her own technical problems.	7	32	5	23
SPI Q5.2 Sometimes an adult tells the student how to work out a technical problem.	11	50	7	32
SPI Q5.3 An adult always tells the student how to work out a technical problem.	0	0	0	0
SPI Q5.4 Sometimes a teammate tells the student how to work out a technical problem.	12	55	5	23
SPI Q5.5 A teammate always tells the student how to work out a technical problem.	0	0	0	0
SPI Q5.6 Student works out own technical problems: Other.	0	0	0	0
SPI Q6.1 Student has also been involved in 4H.	8	36	9	41
SPI Q6.2 Student has also been involved in B.E.S.T.	0	0	0	0
SPI Q6.3 Student has also been involved in Odyssey of the Mind.	1	5	0	0
SPI Q6.4 Student has also been involved in FIRST Robotics Competition.	1	5	0	0
SPI Q6.5 Student has also been involved in Science Fair.	5	23	5	23
SPI Q6.6 Student has also been involved in Science Olympiad.	0	0	0	0
SPI Q6.7 Student has also been involved in Scouts.	7	32	2	9
SPI Q6.8 Student has also been involved in T.S.A.	0	0	0	0
SPI Q6.9 Student has also been involved in V.I.C.A.	0	0	0	0
SPI Q6.10 Student has also been involved in Young Astronauts.	0	0	0	0
SPI Q6.11 Student has also been involved in other: Taekwondo.	4	18	3	14

SPI Q7.1 In the last year, student has also played with Capsela.	1	5	0	0
SPI Q7.2 In the last year, student has also played with Commando Bot.	1	5	0	0
SPI Q7.3 In the last year, student has also played with Digi-Draw	0	0	1	5
SPI Q7.4 In the last year, student has also played with Erector Sets	2	9	0	0
SPI Q7.5 In the last year, student has also played with Fischer Technik	0	0	0	0
SPI Q7.6 In the last year, student has also played with Gameboy	18	82	13	59
SPI Q7.7 In the last year, student has also played with GameCube	10	45	6	27
SPI Q7.8 In the last year, student has also played with iQuest.	0	0	2	9
SPI Q7.9 In the last year, student has also played with K'Nex.	9	41	2	9
SPI Q7.10 In the last year, student has also played with Leap Pad/Quantum Pad.	1	5	4	18
SPI Q7.11 In the last year, student has also played with LEGOs.	15	68	10	45
SPI Q7.12 In the last year, student has also played with Math Shark.	0	0	0	0
SPI Q7.13 In the last year, student has also played with Mindstorms.	5	23	0	0
SPI Q7.14 In the last year, student has also played with Neopets.	3	14	4	18
SPI Q7.15 In the last year, student has also played with Nintendo.	8	36	6	27
SPI Q7.16 In the last year, student has also played with Playstation.	16	73	9	41
SPI Q7.17 In the last year, student has also played with RC cars, trucks, or airplanes.	6	27	3	14
SPI Q7.18 In the last year, student has also played with Sega.	3	14	1	5
SPI Q7.19 In the last year, student has also played with Snap Circuits	0	0	0	0
SPI Q7.20 In the last year, student has also played with Tinker Toys.	3	14	2	9
SPI Q7.21 In the last year, student has also played with Virtual Reality 3-D Spiderman	0	0	0	0
SPI Q7.22 In the last year, student has also played with Xbox.	10	45	4	18
SPI Q7.23 In the last year, student has also played with Zoids.	1	5	0	0

VITA

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Academic Degrees and Credentials

		Specialization
Ph.D.	Virginia Polytechnic Institute and State University Blacksburg, VA (Expected May 13, 2005)	Technology Education; Curriculum and Instruction
M.S.	Louisiana State University Baton Rouge, LA 1999	Vocational Education with robotics emphasis
B.S.	Louisiana State University Baton Rouge, LA 1986	Industrial Arts Education with science emphasis

State of Idaho — Standard Secondary Technology Education 6-12; Advanced Occupational Specialist - Manufacturing Technology, Mechanical Drafting Technology

State of Washington — Professional Education 4-12 Technology Education: Credential #368144B

State of Louisiana — Lifetime Industrial Arts Type B: Credential #078896

Preparing the Future Professoriate Certification (Expected completion date: May 2005)

Honors and Awards

Council on Technology Teacher Education Research Incentive Grant: $1000. CTTE, 2005

Randall Welch Scholarship: $500. Presented by the Virginia Tech Technology Education Program, April 6, 2004

Donald Maley Spirit of Excellence Outstanding Graduate Student Citation, International Technology Education Association, 2004

Technology Education Division Outstanding Researcher Award, Robots on the Palouse: Association for Career and Technical Education, 2002

Outstanding Pathways Best Practices Methods: Kootenai Business Education Partnership and Coeur d'Alene Chamber of Commerce, 2001

Fulbright Memorial Fund Scholarship to Japan; Tokyo, Shizuoka, October 1998

Who's Who Among America's Teachers, 1996, 1998

Professional Experience

Summer 2004 — Temporary Faculty, Technology Education Program, Virginia Tech, Blacksburg, VA

2003-2005	Research Assistant, The Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, VA
2002-2003	Teaching Assistant, Technology Education, Virginia Tech, Blacksburg, VA
2002	Research Assistant, Co-Teach Grant Title II Teacher Quality Enhancement Project, Washington State University, Pullman, WA
2001-2002	Grant Assistant, The Department of Education's Preparing Tomorrow's Teachers to Use Technology (PT3), Washington State University, Pullman, WA
2000-2001	CAD Instructor, North Idaho College Workforce Training Center, Post Falls, ID
1999-2001	CAD/CAM/Robotics Instructor, Riverbend Professional Technical Academy, Post Falls, ID
1993-1999	Technology Teacher, Denham Springs High School, Denham Springs, LA
1991-1993	K-8 Physical Education Teacher, Lake Sherwood School, Baton Rouge, LA
1990-1991	Overnight Plant Manager, Hauser Chemical Research, Inc., Boulder, CO
1988-1990	Math/Science Resource Teacher, Eagle Valley High School, Gypsum, CO
1988-1990	Lost Wax Investment Foundry Supervisor, Rocky Mountain Castings, Eagle, CO
1986	Technology Teacher, Redemptorist High School, Baton Rouge, LA

Work Related Experience

Fall 2004-	Volunteer, Technology Education Lab, Blacksburg Middle School, Blacksburg, VA
February 2004	Co-founded the Technology Education Graduate Association
Summer 2003	Co-founded *reviving Women In Technology education (rWITe)*; an organization for the promotion of girls, women, and other underrepresented groups in technology education
October 2003	Founded *The Intellectual Networking Group (TING)*; a group of graduate students establishing connections with historical technology educators

August 2003	The University Corporation: California State University, Northridge. RoboEducators Summer CAD Institute, Boston, MA
Summer 2003	Recruiting Workshops for FIRST LEGO League Coaches, Virginia Tech
2002-2003	International Technology Education Association. Invention-Innovation-Inquiry: A Project to Develop Technological Literacy Units for Grades 5-6; A National Science Foundation Project.
November 2001	Mini-grant Writing Workshop, Washington State University PT3 Project
2001	Idaho State Mathematics Standards Evaluation Committee, Boise, ID
1999-2001	Established business/education partnerships with 16 companies for the Riverbend Professional Technical Academy
2000-2001	VICA (Vocational Industrial Clubs of America) Idaho State Board of Directors; Secretary
March 1999	Fulbright Memorial Fund Teacher Program Selection Committee; Houston, TX
March 1998	Established Louisiana Teacher In-Service: *Robotics in the Classroom*
1998-1999	Livingston Parish School-To-Careers Coordinator
Summer1997	Established K-12 *Robotics Summer Camp*
Spring 1997	Established elementary and middle level robotics workshops
1997-1998	LIGO (Laser Interferometer Gravitational Wave Observatory) curriculum development committee
1996-1999	Co-founder/sponsor Denham Springs High School Space Exploration Club
Spring 1994	Development and implementation of the *Introduction to Robotics* LDOE accredited high school course

Publications

Varnado, T.E. & Pendleton, L.K. (2004). Technology Education/Engineering Education: A Call for Collaboration. *Proceedings of the International Conference on Engineering Education, University of Florida,* October 17-21. Available online at http://www.succeednow.org/icee/

Varnado, Terri E. (March 2003). A bigger house (Books to Briefs). *Technology and Children, 7*(3), 19.

Varnado, Terri E. (January 2001). Teacher Training Guide: K-12; Integrating Robotics. (Currently distributed by OWI Robotics, Inc.).

Varnado, Terri E. (November 2000). Robotics Across the Curriculum. *Tech Directions*, *60*(4), 22-5.

Research Projects

Varnado, Terri (2002). *Robots on the Palouse*. Determine how experiences with robots influence at-risk 4th grade students' attitudes toward school, technology, and robots. Findings of the study will provide the researcher with information necessary to develop training opportunities for teacher educators, in-service teachers, and pre-service teachers for integrating technological literacy into curriculum development using robots as the motivating tool.

Akmal, T.T., Varnado, T.E., Krebill-Prather, R. (in progress). *Bringing Collaborative Partnership Stakeholders Together: A Catalyst for Change in Teaching and Learning*. Examine whether systematic gathering of stakeholders in collaborative school/university partnerships is beneficial to student achievement and teacher preparation. The specific impacts of converging stakeholders in one place as a catalyst for change will be explored.

International Conference Presentations

Varnado, T.E. *Problem Solving Style and Performance in FLL.* International Technology Education Association, 67th Annual Conference, Council on Technology Teacher Education Research Session, April 2005, Kansas City, MO.

Varnado, T.E. *A Latent Growth Curve Analysis of 9-14 Year Olds during a Problem Solving Activity.* Poster session presented at the International Technology Education Association, 67th Annual Conference, Council on Technology Teacher Education, April 2005, Kansas City, MO.

Bussey, J.M. & Varnado, T.E. *Oh My! She Ate a Fly!* International Technology Education Association, 67th Annual Conference, Technology Education Children's Council, April 2005, Kansas City, MO.

Varnado, T.E. *Technology Education/Engineering Education: A Call for Collaboration.* International Conference on Engineering Education, University of Florida, October 17-21, 2004, Gainesville, FL.

Bussey, J.M., Varnado, T.E., Pilson, S., Delany, L.. *Past, Present, and Future of Diversity in Technology Education*. International Technology Education Association, 66th Annual Conference, March 2004, Albuquerque, NM.

Varnado, Terri E. *Robots on the Palouse: Increasing Technology Awareness in At-Risk Fourth Grade Students.* International Technology Education Association, 65th Annual Conference, March 2003, Nashville, TN.

National Conference Presentations

Varnado, Terri E. *Robots on the Palouse: Increasing Technology Awareness in At-Risk Fourth Grade Students.* Association for Career and Technical Education, December 2002, Las Vegas, NV.

Varnado, Terri E. *Integrating Robotics.* Association of Science Museum Directors Convention, October 2000, Cleveland, OH.

Varnado, Terri E. *Using Robotics in the Classroom.* National Congress on Aviation and Space Education, April 1999, Orlando, FL.

Varnado, Terri E. *Robotics Technology.* American Vocational Association National Convention, December 1998, New Orleans, LA.

Regional & State Conference Presentations

Varnado, T.E. *Web-based Tutorials for LEGO Mindstorms Robotics.* Virginia Technology Education Association 9th Annual Children's Engineering Convention, February 2005, Glen Allen, VA.

Varnado, Terri E. *Robots on the Palouse: Increasing Technology Awareness in At-Risk Fourth Grade Students.* Virginia Technology Education Association Children's Engineering Convention, January 2003, Williamsburg, VA.

Varnado, Terri E. *Using Robotics in the High School Classroom.* Louisiana Science Teachers Association Convention, October 1998, Alexandria, LA.

Varnado, Terri E. *Robotics in the Classroom.* NASA Getting Comfortable Teaching With Space, November 1997, Livingston, LA (Invited Speaker).

Varnado, Terri E. *Robotics Technology.* Louisiana Vocational Association State Convention, August 1997, New Orleans, LA (Invited Speaker).

Grants Earned

Department of Teaching and Learning, Virginia Tech: Doctoral Graduate Student Research Mini-Grant. *Problem Solving Style and Performance in FIRST™ LEGO™ League.* December 2004. $2500

Schweitzer Engineering Laboratories, Inc. Gift to the Washington State University Foundation: *Robots on the Palouse*, April 2002. $6832.54

Learn and Serve America Service Learning Grant: *Robots in Action*, Denham Springs, LA 1998-1999. $4000

NASA's *Biomedical Research and Robotics*: LaSPACE grant; U.S. Air Force Academy, Peterson Air Force Base, June 1998. $4000

LA *LEARN for the 21st Century*, Denham Springs, LA, December 1997. $1000

NASA's *Remote Sensing*, University of Oklahoma, Norman, OK, June 1996. $4000

NASA's *Teaching With Space,* U.S. Space Foundation; Colorado Springs, CO, July 1996. $1500

Consulting Work

Contract: Mark Goddard, Teaching Assistant, Washington State University. Integrating Robotics Technology into Elementary/Middle School Science Methods, Spring 2002.

Established VTEC – Varnado Technologies Enterprises and Consulting (formerly Robotics Education Consultants, Inc.), June 1998, to work with K-12 students and teachers.

Professional and Academic Association Memberships

American Association of University Women
American Educational Research Association (2001-2002)
American Society for Engineering Education (2004)*
Association for Computing Machinery (2001-2002)
Association for Supervision and Curriculum Development (1999-2001)
International Technology Education Association*
    Council on Technology Teacher Education*
    Technology Education for Children Council*
Society of Manufacturing Engineers (1999-2001)
Kappa Delta Pi Education Honor Society*
Epsilon Pi Tau*

*Denotes current membership

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