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Research in Engineering and Technology Education

COGNITIVE PROCESSES OF STUDENTS SOLVING TECHNICAL PROBLEMS

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UNIVERSITY OF GEORGIA, 2007

This material is based on work supported by the National Science Foundation Under Grant No. ESI-0426421

Running head: COGNITIVE PROCESSES OF STUDENTS

Cognitive Processes of Students Participating in Two Approaches to Technology Education

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Abstract

The purpose of this study was to better understand cognitive strategies used by high school technology education students who have participated in technology education instruction with an engineering design focus. Specifically, this study evaluated the cognitive strategies of students participating in *Project Lead the Way* curriculum programs compared with students participating in technology education programs partnering with the National Center for Engineering and Technology Education (NCETE). High school students from these two groups were studied as they worked through an ill-defined problem: moving drinking water in developing countries. The data collected from these protocols was analyzed using a coding process and a list of universal technical mental processes (Halfin,1973) and OPTEMP software, (Hill, 1997) to record frequency and time of each mental process employed by the students. The study identified common cognitive strategies employed by students and identified where greatest emphasis was placed in the design process among the two groups. This study provides important insight for technology education as it seeks to implement engineering design.

Introduction

Since the publication of the Standards for Technological Literacy in 2000 (ITEA), there has been a number of new programs developed that are designed to teach technological literacy using engineering design as a curricular focus. *Project Lead the Way is* one such program, while another is a result of the work of the National Center for Engineering and Technology Education (NCETE). According to Douglas, Iversen, & Kalyandurg (2004), the engineering community has identified the need for teaching engineering in K-12, and this has been supported by the American Society of Engineering Education (ASEE). The ASEE research analyzed the current practices of K-12 engineering education. The study stated: “Clearly, there is a societal argument for the need for engineering education in our K-12 classrooms, as technical literacy promotes economic advancement. There is a statistical argument, as the number of students entering engineering schools declines, related to overall enrollment, and the number of women and underrepresented minorities in engineering remains well below the national average for higher education” (Douglas, Iversen, & Kalyandurg, 2004, p. 3). Clearly, the engineering education community has identified the important role K-12 education plays in the success of post-secondary engineering education. Teaching engineering content in technology education programs has become a recent popular trend with curriculum initiatives such as *Project Lead the Way*, but some states, like New York, have had a course called “Principles of Engineering” since the late 1980s (Lewis, 2005). Teaching engineering design in K-12 might possibly be good for post-secondary engineering education, but does it produce technological problem solvers who have the ability to properly manage an ill-defined problem and develop viable solutions?

Understanding the cognitive strategies of technical problem solvers is critical to developing curriculum that develops technologically literate individuals. The Standards for

Technological Literacy (ITEA, 2000) identified the important role of cognition in design by stating, “To become literate in the design process requires acquiring the cognitive and procedural knowledge needed to create a design, in addition to familiarity with the processes by which a design will be carried out to make a product or system” (ITEA, 2000, p. 90). Roberts (1994) emphasized “the purpose of teaching design is not to bring about change in the made world, but change in the student’s cognitive skills” (Roberts, 1994, p. 172). Furthermore, ill-defined problems are more difficult to solve since they require more cognitive operations than simpler, well-defined problems (Jonassen, 2000). Johnson (1992) suggested a framework for technology education curricula, which emphasizes intelligent processes. “Students should acquire a repertoire of cognitive and metacognitive skills and strategies that can be used when engaged in technological activity such as problem solving, decision making, and inquiry”(Johnson, 1992, p. 30). Cognitive and metacognitive skills are important thinking processes required for problem solving, and these skills should be taught to students in technology education courses. Careful examination of the cognitive processes employed by students as they work through an ill-defined technical problem provides a means of evaluating the effectiveness of a curriculum approach designed to develop effective problem solvers.

Research Questions

This research study examined the cognitive processes employed by students participating in two different curricular approaches to design and problem solving. The following research questions guided the study:

(1) Are students in selected programs using similar cognitive processes as they solve ill-defined problems?

(2) Will students in the selected programs perform similarly when presented with the same ill-defined problem to solve?

(3) What cognitive processes are missing from students participating in the two different programs, and how does each group differ?

(4) Are there important cognitive processes missing from students' performances in both groups?

It is critical to closely examine these important questions as the field of technology education considers engineering design as a focus alongside the need for developing technological literacy in K-12 learners. This research examined how a high school student who has learned engineering design solves an assigned ill-defined technical problem. This insight can be helpful to develop further curriculum in technology education that will develop technologically literate individuals. Another benefit of this study is to gain insight into how a high school student, who has learned engineering design methods, manages cognitive processes as he or she engages in problem solving when confronted with a limited time constraint. Finally, it is beneficial to identify where students fail to properly manage cognitive strategies and to identify what cognitive strategies are not utilized in the problem solving process.

Participants

This research study examined students participating in two different technology education curriculums: *Project Lead the Way*, and a technology education program with an engineering design focus. For the later group, three participants were drawn from programs of participating teachers in NCETE in-service workshops conducted at North Carolina A&T. Three subjects were selected from *Project Lead the Way* schools by recommendation from North Carolina A&T NCETE partners. The final total number of participants was seven due to the

NCETE partner group having had an alternate participant who agreed to participate in the study and returned proper consent forms. The participants selected from a *Project Lead the Way* program completed the course *Principles of Engineering* and were currently enrolled in the course *Engineering Design and Development* which is typically taught to seniors in high school. The participants selected from a technology education high school program not using *Project Lead the Way* curriculum were students who were taught by an instructor who has benefited from the NCETE in-service teacher workshops during the summer of 2006. It is important to note that the NCETE partnered school was currently generating new curriculum with a focus on engineering design which is why many course titles are not reflective of engineering design, see Appendix B. The researcher selected participants who are homogeneous in educational background, including the same criteria for the prerequisites of mathematics and science defined by the *Project Lead the Way* program. The researcher conducted the study near the end of the semester so the participants gained as much training on engineering design as possible. Demographic information for the participants can be found in Appendix B & C. General demographic information about the instructors, curriculum, class size, and course titles can be found in Appendix D & E.

Methodology

This study compared the cognitive processes used by the participants from the two curricular approaches to technology education as they used a design process to work through an ill-defined technical problem. The same ill-defined technical problem was presented to all the participants. Each participant was asked to carefully read the technical problem, identify all constraints he or she imposed on the problem, and then asked to begin to develop a solution. Each participant worked in isolation from other participants or classmates. The problem was selected because it was ill-defined by nature and it provided students the freedom to impose their own constraints and criteria as he or she saw fit. The study used a ‘think-aloud’ protocol method used in similar studies (Kruger and Cross, 1999; Ericsson and Simon, 1993; van Someren et al., 1994). Atman & Bursic (1998) suggests that using a verbal protocol analysis for assessing cognitive processes of engineering students is a powerful method to understand the process student take when developing a design solution. Atman and Bursic state: “analysis of a verbal protocol enables us to look at a subject’s process in detail rather than simply ‘grading’ a final solution. That is, we can now grade the ‘process’ as well as the final design” (Atman & Bursic, 1998, p. 130). Moreover, verbal protocol analysis has been endorsed as a sound method for capturing and assessing engineering student’s design processes (Atman & Bursic, 1998). Consequently, the participants were asked to verbalize their thoughts as they worked through the ill-defined problem. The researcher prompted participants to keep talking through the problem when he or she stopped verbalizing his or her thoughts; otherwise, the researcher did not interact with the participants. The participants were be given a total of 30 minutes to work through the early stages of engineering design process; however, several participants sessions did not use the entire 30 minutes. Although this time constraint limited engagement in the engineering design process, it was adequate to study how the student framed the problem and begin to develop an initial design plan. The data collection included frequency and duration of time of the various mental processes allowing the researcher to break coding data into units of time including, time on code, total time on each code, and total time of testing session. This method of organizing data by time has been used in similar problem solving studies (Welch, 1999). Frequency was also recorded tallying each time the participant used each cognitive strategy.

The open-ended problem that was given to the participants described typical conditions in underdeveloped areas of the world where the domestic water is often transported by women and girls. See figure 1. This activity often causes physical stress on these women and children resulting in acute medical conditions. The problem statement provided some general information about current constraints on this problem as well as solutions that are currently being employed. The statement asked the participants to provide details how they would proceed to develop strategies to improve the current conditions in these underdeveloped areas. The participants were asked to list all constraints that they imposed on the problem. Finally, the participants were asked to 'think aloud' their strategies for deriving a solution.

Framing the Problem

This study only examined the early stages of the design process. Certainly in the time constraint of thirty minutes, a student was unlikely to reach the final stages of the design process; therefore he or she was also unlikely to employ all of Halfin's mental processes. However, one of the most important stages of the engineering design process occurs at the onset of being presented with a technical problem: 'framing the problem' is this important stage. Experts in the field of design identify that framing the problem is a critical step to the design process and occurs as soon as the designer is presented with a technical problem (Dym, Agogino, Eris, Frey, and Leifer, 2005, Schön, 1983). This early stage of the engineering design process often finds engineers seeking to locate the problem space where the search for the solution begins, starting conditions are identified, and goals are stated. This problem space creates a partial structure from which a solution space can be formed. The solution space structure begins to be developed as ideas are generated; this structure is transferred back to problem space to again consider solution implications. This method seeks to generate cohesion of problem and solution (Cross, 2004).

This protocol study examined these cognitive strategies as the participants tackled the ill-defined problem.

Data Gathering and Analysis

The participants were videotaped for further analysis by the researcher. The tape was used to record each participant's voice as he or she thinks verbalized thoughts, as well as to record any actions such as sketching, measuring, or any other non-verbal cues. Cross (2004) indicated that one weakness of the 'think aloud' protocol method was that it was extremely weak at capturing non-verbal thought processes, using observation in combination with the 'think aloud' method was employed to help capture non-verbal cues. This technique of combining a think-aloud protocol with a video of the testing session is known as observational protocol and is a data collection method used to assess student design and problem solving strategies (Laeser, Moskal, Knecht, & Lasich, 2003). The data collection included frequency and duration of time of the various mental processes. A review of these frequencies and minutes spent on various cognitive processes adds insight into each participant's ability to properly manage time and use important cognitive processes that will lead to success or failure of the final design. The results of these observations showed if the participant became fixated on a specific cognitive strategy or steps of the engineering design process. Valuable information from this study revealed what cognitive strategies participants emphasized in addition to the cognitive strategies that the participants neglected.

This research study focused on cognitive processes from a list of 17 mental processes that were identified by Halfin (1973). Halfin used writings from ten high-level designers including Buckminster Fuller, Thomas Edision, and Frank Lloyd Wright. Halfin used a Delphi technique to identify 17 mental processes that were universal for these expert engineers and designs. Hill

(1997) developed a computer analysis tool called the *Observation Procedure for Technology Education Mental Processes* (OPTEMP) to assess problem-solving activities in technology education by employing Halfin's code of mental processes. Hill's study also included ten additional mental processes related to technology education, which were verified by Wicklein and Rowjewski (1997). This study used a revised and updated OPTEMP computer program to assist in coding and recording the frequency and duration of time of the cognitive processes employed by students as they worked through the selected ill-defined technical problem. The researcher coded the actions and cognitive processes used by each participant as he or she worked through the technical problem. The number of frequencies and the time spent on each strategy were compiled and a total was recorded in the OPTEMP output.

Microsoft Excel software was used to process the data files generated by the OPTEMP program. Careful analysis of the percentage of time and frequency spent on the various cognitive strategies provided insight into mental processes employed by the students as they worked to frame the ill-defined problem (Appendix A). Moreover, it was important to identify the cognitive processes that were missing in the problem solving processes employed by students from the two different technology education programs. The results from this study can assist in helping the NCETE partners to design and implement technology activities with an engineering design focus that can ensure that students are given the cognitive skills needed for high-level thinking and successful technical problem solving.

Findings

As mentioned earlier, this study sought to examine the early minutes in the design process as participants worked to frame or "set" an ill-defined problem. Although a thirty-minute or less examination appears to be inadequate in understanding the entire process taken by problem solvers, it can provide great insight into an individual's ability to organize the problem, constraints, and criteria in order to begin to develop a solution that adequately solves the problem. The research questions results are as follows:

(1) Are students in these different programs using similar cognitive processes as they solve ill-defined problems?

The research revealed that both groups used similar cognitive strategies as they worked though the ill-defined problem. Both groups employed at least six of the ten mental processes that were identified in the test sessions. The cognitive strategy analysis (AN) was the most common mental processes employed. This Halfin code (AN) was used when the researcher witnessed the participant breaking down the problem and identifying constraints and criteria. The participant's *analysis* percentage of time on that cognitive process ranged from 19 percent to 54 percent. However, the duration of time that the two groups spent on the various strategies varied considerably (See Table 1 & 2 and Figures 3 & 4).

(2) Will students in these programs perform similarly when presented with the same ill-defined problem to solve?

The results of this research revealed that the two groups did perform differently with respects to time spent developing solutions (DE). Often this mental process is considered the most critical determinate in how an individual designs a solution. Kruger and Cross (2001) identified that designers are either solution driven or problem driven. It is often found that novices get stuck in the problem definition stage and fail to generate solutions. Welch and Lim (2000) have made similar conclusions that novice designers becoming stuck in the problem space. The results of this study reveal that group one (NCETE partner group) spent more time on generating solutions than group two (PLTW). Group one spent from 18 percent to 32 percent designing and talking about solution ideas. Group two spent from 3 percent to 8 percent dialoging design solutions. Although creative designers are known for generating multiple solutions, there is a danger in generating solutions too quickly and not fully understanding the problems (Welch, 1999). It is important to consider that although group 1 spent more time generating solutions, an argument could be made that group 2 was careful to understand the problem they were asked to solve by spending a considerable amount of time defining and analyzing the problem. Comparatively, architects are problem solvers who generate multiple solutions to design problems, where engineers are often trained to locate a solution that works in a timely and cost effective manner (Akin, 2001). To surmise that group 1 contains more creative problem solvers than group 2 would not be a fair assessment.

Participant number six developed only one idea and was convinced that the one idea was the best solution possible based on his knowledge of similar cultures who have struggled with this problem. Ball, Ormerod, & Morley (2004) refer to this approach to solving problems as “case-driven” and is a novice designer approach. Case-driven approach is used to quickly move to a solution by recognizing the current problem with a problem similarly encountered and to apply a solution previously developed. Conversely, Cross (2004) suggests that expert problem solvers with experience in designing quickly move from the problem frame to proposing a solution conjecture. Considering that this participant spent a great deal of time identifying the constraints and criteria (Analysis) and very little time simply defining the problem, he may be demonstrating his ability to design quickly and efficiently as opposed to lacking creative idea generation (See Table 1 & 2 and Figure 1 - 4).

(3) What cognitive processes are missing from students representing the two different programs, and how does each group differ?

Of Halfin's 17 mental processes, seven processes were never employed by either group. A close examination of the seven missing processes presents a logical explanation for most of the missing mental processes. For example, models/prototypes codes (MP) were never employed, quite possibly due to the limited time constraints and lack of available model materials. This cognitive process was not expected to be employed in the problem framing stage of the design process so; it is logical and appropriate for this cognitive process was never employed. Interpreting data (ID) was also a mental process that was not often employed by participants in this study and is likely due to the fact that there was little data to interpret from the ill-defined problem statement. Only participant #1 employed the cognitive process of interpreting data and employed this cognitive process only 1% of his total time designing a solution.

Measuring (ME) was a mental process that could be applied to this ill-defined problem if a heuristic was applied to the constraints presented in the problem; however, this strategy was never was utilized by any participants.

The other missing cognitive processes from both groups included creating (CR), experimenting (EX), observing (OB), testing (TE) and visualizing (VI).

(4) Are there important cognitive processes missing from students' performances in both groups?

As mentioned above, measuring (ME) was never utilized by any participant in the study. This mental process seems to be one that could be applied to the ill-defined problem to quantify constraints and criteria for further analysis. Computing (CO) was used by two participants, one from each group used a number to estimate potential distances traveled or altitude of the mountain terrain; however no participants moved from estimations to using these figures to predict results of design solutions.

Table 1. Group #1 NCETE Partner								
Halfin's Code	Participant #1		Participant #2		Participant #3		Participant #4	
	Frequency	Time	Frequency	Time	Frequency	Time	Frequency	Time
DF	15	6.22	16	5.30	4	1.58	22	5.09
AN	33	5.23	34	11.37	22	5.01	63	8.05
DE	43	8.58	20	5.10	14	3.31	33	4.59
MA	16	2.27	0	0	1	0.39	11	1.55
PR	4	0.37	8	2.11	6	1.56	20	2.36
QH	0	0	12	2.56	2	0.41	1	0.04
CM	6	0.58	1	1.08	0	0	0	0
MO	12	4.13	0	0	0	0	20	3.01
CO	0	0	0	0	0	0	1	0.17
ID	1	0.40	0	0	0	0	0	0
Total	130	28.18	91	27.52	49	12.26	171	25.26

Table 2. Group #2 PLTW School						
Halfin's Code	Participant #5		Participant #6		Participant #7	
	Frequency	Time	Frequency	Time	Frequency	Time
DF	8	2.56	9	2.17	38	7.24
AN	168	13.39	55	4.53	91	14.18
DE	22	2.56	8	0.40	19	2.34
MA	2	0.16	12	1.57	11	1.46
PR	33	6.05	17	2.10	11	1.24
QH	0	0	1	0.13	1	0.13
CM	0	0	1	0.7	0	0
MO	13	3.11	0	0	0	0
CO	3	0.16	0	0	0	0
ID	0	0	0	0	0	0
Total	247	28.39	103	12.00	171	26.59

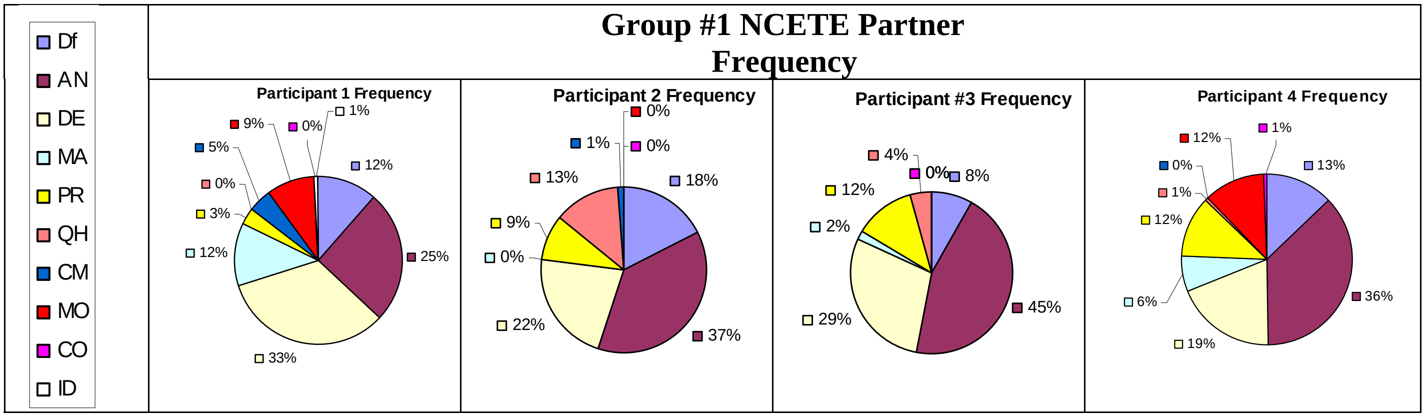


Figure 1.

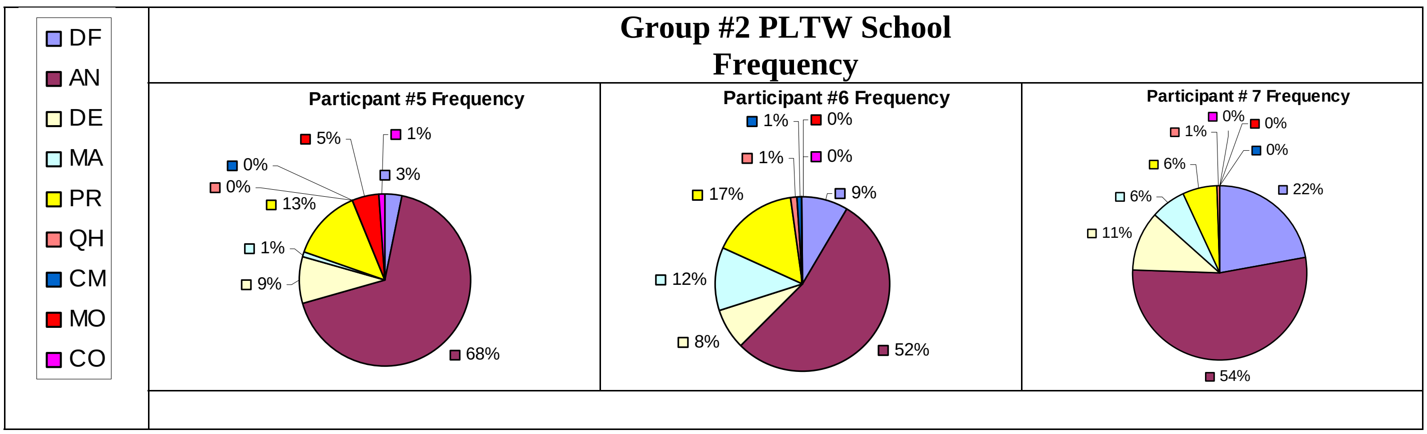


Figure2.

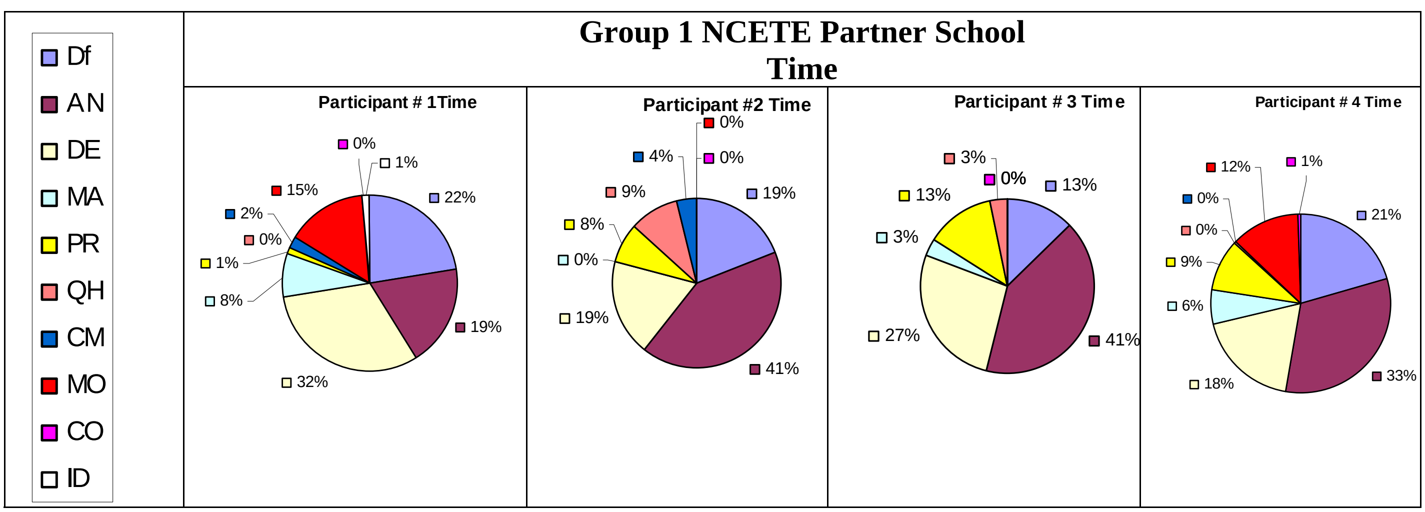


Figure 3.

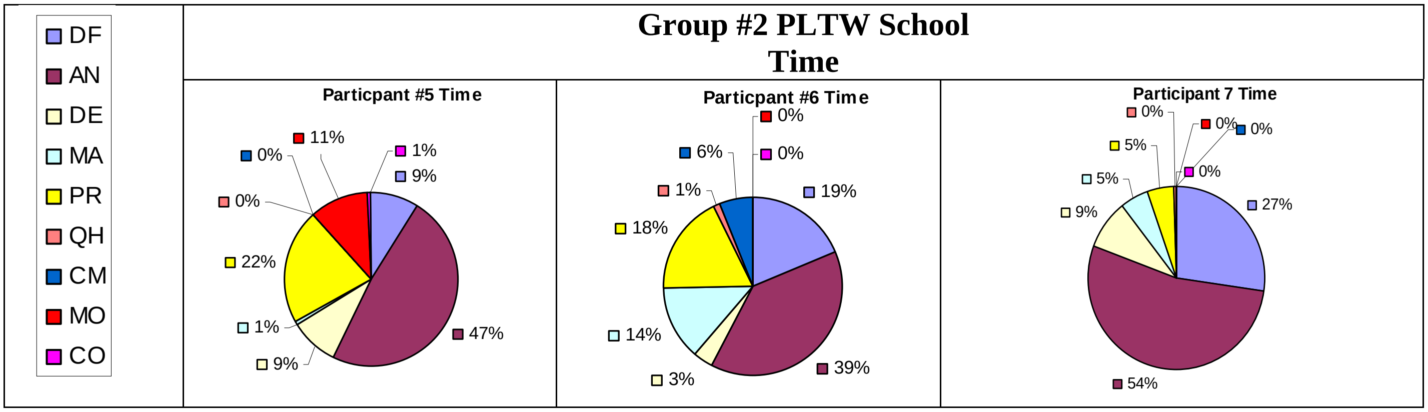


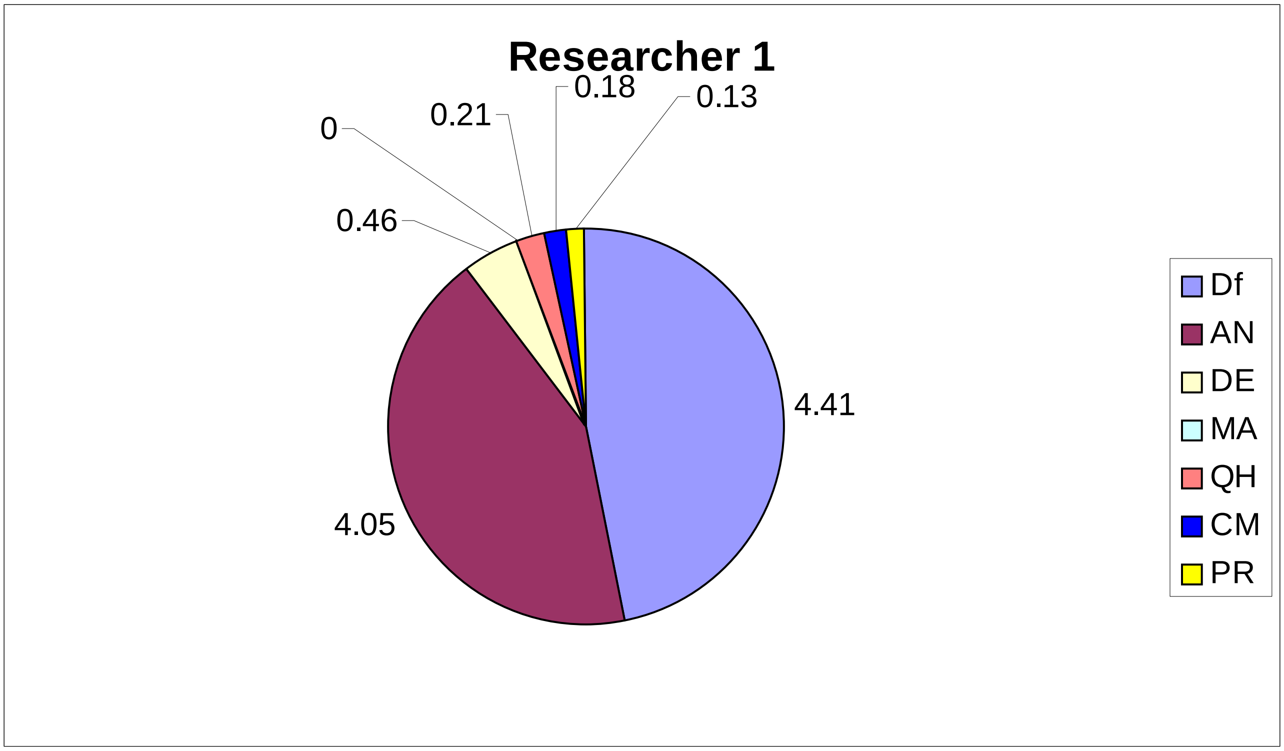
Figure 4.

Reliability

Measure inter-coder reliability revealed a high degree of consistency. Two researchers independently coded 10 percent of four of the seven protocols as outlined by Evans (1995). Segments were selected at the beginning, middle and at the end of the assessed protocols to ensure that the reliability check was tested at various stages of the testing session. The results were complied into total time on coded and is presented in table 3 below. Standard deviation was computed with ranges from .523 for analysis to .091 for managing and predicting. Figure 5 illustrates the inter-coder reliability results graphed by time on code.

Inter-coder Reliability Agreement Results			
Code	**Researcher # 1 Time**	**Researcher # 2 Time**	**Standard Deviation**
DF (Defining the Problem)	4.41	4.53	0.084853
AN (Analysis)	4.05	3.31	0.523259
DE (Designing)	0.46	1.01	0.388909
MA (Managing)	0	0.13	0.091924
QH (Questioning)	0.21	0.15	0.042426
CM (Communicating)	0.18	0.34	0.113137
PR (Predicting)	0.13	0	0.091924
Total Time	9.44	9.47	

Table 3.



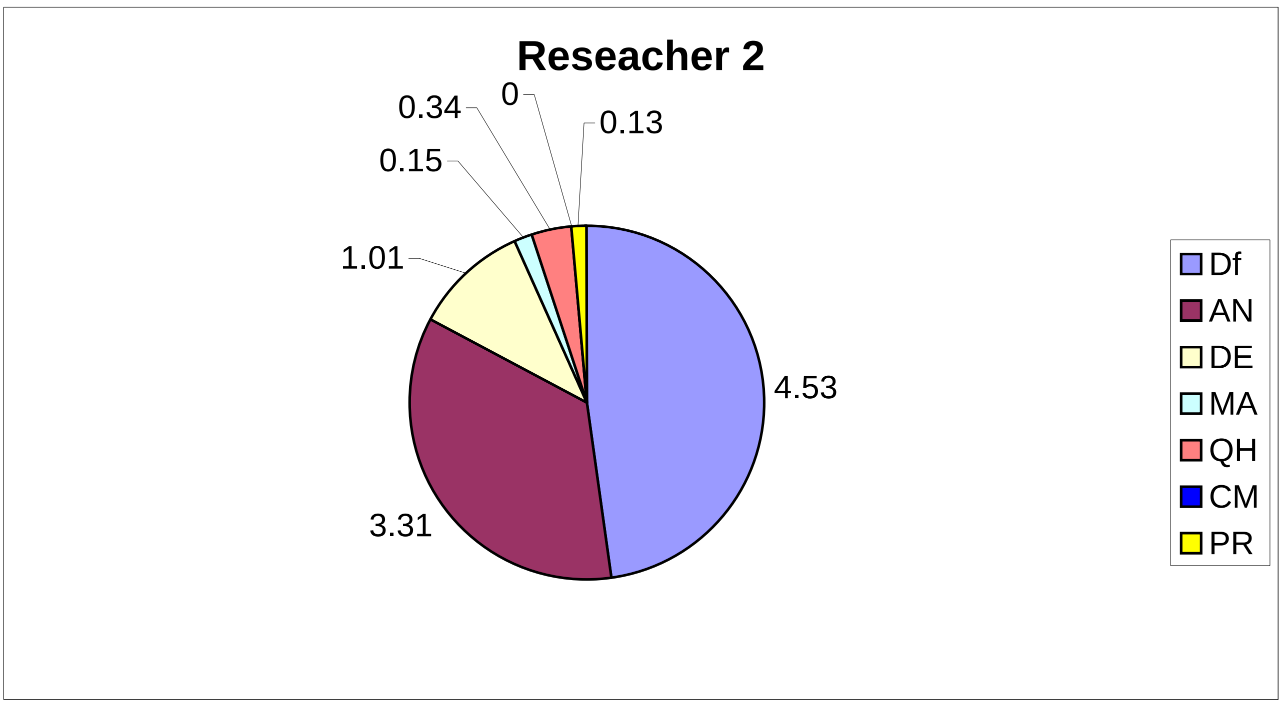


Figure 5.

Implication for Technology Education

As the field of technology education continues to move to engineering as a focus, a variety of the new curriculum projects have been created to infuse engineering design and engineering content into technology education. Some examples of curriculum projects include *Project Lead the Way*, *ProBase*, and ITEA's *Engineering by Design* to name a few. The implementation of new curriculum often requires a start-up cost that can include in-service teacher training, new supplies, new or upgraded computers, special computer software, and additional tools or materials necessary to implement such a program. To ensure that these funds are well spent and to ensure that these programs are effective, more empirical research needs to be conducted to measure the effectiveness of these engineering-focused curriculum programs. One way to do this is to examine students as they work to solve ill-defined problems. The method used in this study can provide a heightened awareness of what is really happening in the minds of the students as they work to solve a problem. Technology education programs have often emphasized the use of problem solving activities, but little research has been done to determine how effective these activities are in developing skills skilled problem solvers and excellent designers (Lewis, 1999). Clearly, more authentic assessment methods should be applied to future research projects in the field of technology education and more research needs to be done to probe at the effectiveness of these new curriculum projects focusing on engineering or engineering design at the high school levels. According to the results of this study, students do perform differently with resects to solving ill-defined problems when group by technology education programs. It is critical for the field of technology education to consider the type characteristics and outcomes it would like to develop in its students as problem solvers and designers, whether creative problem solvers: who can generate multiple solutions (or), problem solvers who can quickly locate the most efficient and cost effective solution. Certainly, a case can be made for both types of problem solvers, quite possibly a blend of experiences in problem solving would be appropriate for the field to consider as it makes a shift towards engineering design.

Recommendations

The results of this study indicate that students from these two technology education programs approach solving ill-defined problems differently. The best way to understand why they behave this way will require follow-up studies using a large sample size and more data collection of pedagogical approaches to design and problem solving of the participating programs in order to better understand this construct and thus would provide the researcher the ability to determine cause of behavior.

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Appendix A

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Problem

In certain underdeveloped areas of the world the majority, if not all, of domestic water is transported by women and young girls, causing considerable physical stress and resulting in medical conditions that are particularly acute during child-bearing and birth. Small villages are scattered throughout rural areas of the world where this has become a major issue, in part due to the steep mountainous terrain.

Currently, water is typically held in plastic or metal vessels and carried in the arms, balanced on the head, or attached to the ends of a rod and carried across the shoulders. Families who can afford beasts of burden (mules, camels, cattle, etc) employ them in this activity, although this is the exception.

Cultural and political constraints often hinder installation of modern water management systems; therefore temporary measures are needed to improve current conditions.

Your Task:

Describe how you would proceed from this problem statement in order to improve the current condition in these underdeveloped areas. Please list all constraints that you impose on this problem. As you work through this problem, ‘think aloud’ your strategies for deriving a solution.

Appendix B
Group 1 Student Demographic Information

Demographic Information for Group 1

	Participant 1	Participant 2	Participant 3	Participant 4
Grade Level	11	12	11	12
# Of technology classes Taken	4	4	3	2
Technology Courses	(2) Fundamentals of technology Communication Systems Manufacturing Systems	Fundamentals of technology Communication Systems Transportation Systems Advanced Studies	Fundamentals of technology Manufacturing Systems Transportation Systems	Fundamentals of technology Manufacturing Systems
Math Courses Taken	Algebra I Geometry Algebra II Pre-calculus	Algebra I Geometry Algebra II Pre-calculus	Algebra I Geometry Algebra II Pre-calculus	Algebra I Geometry Algebra II Pre-calculus AP Calculus BC
Science Courses Taken	Biology Chemistry Environmental Science	Physical Science Biology Chemistry AP Environmental Science	Biology Chemistry Environmental Science	Biology Chemistry Environmental Science Physics

Appendix C

Group 1 Student Demographic Information

Demographic Information for Group 2.

	Participant 5	Participant 6	Participant 7
Grade Level	12	12	12
# Of technology classes Taken	8	9	6
Technology Courses	Key Boarding Computer Applications Introduction to Engineering Design Principles of Engineering Engineering Design and Development Computer Integrated Manufacturing Systems Digital Electronics Civil Engineering Architecture Drafting engineering	Key Boarding Computer Applications Introduction to Engineering Design Principles of Engineering Engineering Design and Development Computer Integrated Manufacturing Systems Digital Electronics Civil Engineering Architecture Intro to engineering drafting Drafting engineering	Introduction to Engineering Design Principles of Engineering Engineering Design and Development Computer Integrated Manufacturing Systems Digital Electronics Civil Engineering Architecture
Math Courses Taken	Algebra I Algebra II Geometry Advanced Functions	Algebra II Geometry Pre-Calculus AP Calculus	Algebra I Geometry honors Algebra II honors Pre-Calculus honors
Science Courses Taken	Earth Science Biology Chemistry Physics Honors	Earth Science Biology Honors Chemistry Physics Honors	Earth Science Biology Chemistry Physics

Appendix D

Demographic Information for Group 1 Teacher

Group 1 Teacher Information	
Years of teaching experience	3
Educational Background	BS Industrial Relations (economics, history, business) UNC-CH teaching license in social studies(2003-4) Clear license 2004 with Technology Education endorsement
School size, students served	1850
Students enrolled in tech classes you teach	100-120
Technology course taught in last three years	Manufacturing Systems, Transportation Systems, Structural Systems, currently on team to write new entry level class—Technology, Engineering, and Design.
Do you follow a pre-design curriculum?	Yes—NC DPI provides curriculum guide. Available at www.ncpublicschools.org.
Textbook used	“Exploring Transportation” Johnson/Farrar-Hunter, Goodheart-Wilcox Company, 2000. “Manufacturing Systems” Wright, Goodheart-Wilcox, 2000
How is the Textbook used?	Occasionally
Have you taught your students to use a specific design model or engineering design model	I am incorporating the 10-step engineering design into my classes as an overall approach to the material. I learned this model at the NCETE professional development seminar I attended in 2006.
How much class time is dedicated to problem solving in a given week? Of this time, how much is dedicated to open-ended or ill-defined problems?	We have 47 minute classes 5 times a week—About 20% of the time is spent solving problems of one variety or another. about every 2 to 3 weeks we will work on a current event problem and attempt to come up with solutions. Much of the time is spent uncovering constraints—this seems to be a challenge for the largest number of students.
Do your students work in teams or individually on design challenges? If both what is the ratio?	About 90% teams. Most students are not willing to trust their individual answers and refuse to offer solutions unless the can be “safe” in a group. I am hopeful that working with a more structured problem solving process (engineering design) will give them the confidence to try some solutions on their own.

Appendix E

Demographic Information for Group 2 Teacher

Group 2 Teacher Information	
Years of teaching experience	7
Educational Background	Fay Technical College, Associates Degree A.S. in Architectural Technology North Carolina A&T B.S. Technology Education
School size, students served	1400-1500
Students enrolled in tech classes you teach	68
Technology course taught in last three years	Drafting I Drafting II (Engineering) Intro to Engineering Design Principles of Engineering Civil Engineering Architecture Computer Integrated Manufacturing Freshman Seminar
Do you follow a pre-design curriculum?	*Project Lead the Way*
Textbook used	N/A
How is the Textbook used?	N/A
Have you taught your students to use a specific design model or engineering design model	AutoCAD Land XML AutoCAD 2007 Autodesk Inventor II WPML 1000
How much class time is dedicated to problem solving in a given week? Of this time, how much is dedicated to open-ended or ill-defined problems?	2 hours, part b- ½ hour
Do your students work in teams or individually on design challenges? If both what is the ratio?	Yes, ratio=50/50

Appendix F

Table 5.
The Original Cognitive Processes identified by Halfin's 1973 Study of High-level Designers

Proposed mental methods	**Code**	**Definition**
Analyzing	AN	The process of identifying, isolating, taking apart, breaking down, or performing similar actions for the purpose of setting forth or clarifying the basic components of a phenomenon, problem, opportunity, object, system, or point of view.
Communicating	CM	The process of conveying information (or ideas) from one source (sender) to another (receiver) through a media using various modes. (The modes may be oral, written, picture, symbols, or any combination of these.)
Computing	CO	The process of selecting and applying mathematical symbols, operations, and processes to describe, estimate, calculate, quantity, relate, and/or evaluate in the real or abstract numerical sense.
Creating	CR	The process of combining the basic components or ideas of phenomena, objects, events, systems, or points of view in a unique manner which will better satisfy a need, either for the individual or for the outside world.
Defining problem(s)	DF	The process of stating or defining a problem which will enhance investigation leading to an optimal solution. It is transforming one state of affairs to another desired state.
Designing	DE	The process of conceiving, creating inventing, contriving, sketching, or planning by which some practical ends may be effected, or proposing a goal to meet the societal needs, desires, problems, or opportunities to do things better. Design is a cyclic or iterative process of continuous refinement or improvement.
Experimenting	EX	The process of determining the effects of something previously untried in order to test the validity of an hypothesis, to demonstrate a known (or unknown) truth or to try out various factors relating to a particular phenomenon problem, opportunity element, object,

Appendix F continued.

		event, system, or point of view.
Interpreting data	ID	The process of clarifying, evaluating, explaining, and translating to provide (or communicate) the meaning of particular data.
Managing	MA	The process of planning, organizing, directing, coordinating, and controlling the inputs and outputs of the system.
Measuring	ME	The process of describing characteristics (by the use of numbers) of a phenomenon problem, opportunity, element, object, event, system, or point of view in terms, which are transferable. Measurements are made by direct or indirect means, are on relative or absolute scales, and are continuous or discontinuous.
Modeling	MO	The process of producing or reducing an act, or condition to a generalized construct which may be presented graphically in the form of a sketch, diagram, or equation; presented physically in the form of a scale model or prototype; or described in the form of a written generalization.
Models/prototypes	MP	The process of forming, making, building, fabricating, creating, or combining parts to produce a scale model or prototype.
Observing	OB	The process of interacting with the environment through one or more of the senses (seeing, hearing, touching, smelling, tasting). The senses are utilized to determine the characteristics of a phenomenon, problem, opportunity, element, object, event, system, or point of view. The observer's experiences, values, and associations may influence the results.
Predicting	PR	The process of prophesying or foretelling something in advance, anticipating the future on the basis of special knowledge.
Questions/hypotheses	QH	Questioning is the process of asking, interrogating, challenging, or seeking answers related to a phenomenon, problem, opportunity element, object, event, system, or point of view.

Appendix, continued

Testing	TE	The process of determining the workability of a model, component, system, product, or point of view in a real or

		simulated environment to obtain information for clarifying or modifying design specifications.
Visualizing	VI	The process of perceiving a phenomenon, problem, opportunity, element, object, event, or system in the form of a mental image based on the experience of the perceiver. It includes an exercise of all the senses in establishing a valid mental analogy for the phenomena involved in a problem or opportunity.

Research related to this report was conducted in conjunction with the National Center for Engineering and Technology Education (NCETE). NCETE is a collaboration of nine partner universities: Brigham Young University; California State University, Los Angeles; the University of Georgia; the University of Illinois; Illinois State University; the University of Minnesota; North Carolina A&T State University, Utah State University; and the University of Wisconsin-Stout.

This material is based on work supported by the National Science Foundation Under Grant No. ESI-0426421. Any opinions, finding, and conclusions or recommendations expressed in these materials are those of the authors and do not necessarily reflect the view of the National Science Foundation.