Session #: ___________

INNOVATION DIFFERENTIATION: EXAMINING THE PROBLEM-SOLVING APPROACHES OF ENGINEERING AND TECHNOLOGIST STUDENTS

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1. ABSTRACT

Often it seems that engineers and technologists are lumped into the same model, since both areas of study employ design as their primary problem solving method. However, are they using the same design processes, and, if so, do they focus on different parts of the process? Very little work has been done to elucidate this question. Therefore, this pilot project aims to determine whether there are significant differences between the problem-solving strategies of individual engineering and technology students enrolled at a large Midwestern institution and to develop a technique to easily and accurately extract meaningful, relevant information from observations of students undertaking a short design project. Four subjects, two each from the Colleges of Engineering and Technology, were given a design problem to solve in thirty minutes while using a think-aloud protocol. Their verbal comments and activities (computer use and drawings) were audio and video recorded. Using the Halfin (1973) coding protocol as well as a custom information gathering coding protocol devised by the authors, we analyzed the amount of time spent in different design activities as well as what kind of information was gathered and for what purpose during those activities. Our results indicate that the engineering and technology students demonstrated different approaches to solving the design problem. The technologists appeared to be more 'problem and information focused', trying to clarify the problem to be solved and gathering information to propose solutions, whereas the engineers tended to be 'solution and knowledge focused,' relying on prior knowledge to generate solutions and spending less time on clarifying the nature and extent of the problem itself. Future research is needed to determine whether these initial findings hold up for other students, experts in the field, and/or full design projects.

2. INTRODUCTION

The differences between degrees in engineering and engineering technology are often described based on their workplace focus areas: "conceptual design or research and development" vs "construction, manufacturing, product design, testing, or technical services and sales," respectively, or their curricular focus "engineering programs often focus on theory and conceptual design, while engineering technology programs usually focus on application and implementation." (ABET, 2011) Despite these differences both degrees place an emphasis on design. While these differences and similarities are well accepted, there is limited research on what the design outcomes of the two are. The purpose of this study was to examine some of these aspects by gathering empirical data. More specifically, we aimed to study the cognitive processes of technologists and how they differ from those of engineers as they use a design process to solve a design problem. This pilot project utilized think-aloud protocols surrounding an authentic design-type problem, supplemented with follow up questions, to gather data from a small sample of senior-level college students in technology and engineering. The data were analyzed to determine how well the research method elicits meaningful, relevant information. Findings will inform future research, but also inform educators in both disciplines by providing information on students' approaches to design and skills in information literacy.

3. RESEARCH QUESTIONS

This research study examined the cognitive processes employed by participants as they approached solving a design problem. Undergraduate students were selected from Colleges of Technology and Engineering enrolled at a Midwestern university. The following research questions guided this study:

1. Are undergraduate students majoring in Technology or Engineering using similar cognitive processes as they solve design problems?

2. Will undergraduate students majoring in Technology and Engineering perform similarly when presented with the same ill-defined design problem to solve?

3. Are there important cognitive processes missing from students' performances in both groups?

4. Will students majoring in Technology or Engineering use gather and use information in similar ways when solving the same ill-defined design problem?

4. PARTICIPANTS

Four participants were recruited for this pilot study, two junior/senior level students each from disciplines within the College of Technology and College of Engineering. The researchers identified undergraduate students with high academic standing and strong technology or engineering skills. Each participant individually was given a contemporary design problem scenario that required an engineering/technology solution (see Appendix 1). Since this was a pilot study with a small sample size, to control for internal variation the researchers selected participants who best exemplified expert problem solving techniques for their discipline.

Recruitment of participants was accomplished by the researchers sending selected instructors within the Colleges of Technology and Engineering an email to be forwarded to undergraduate students who met the defined qualifications of high performance in the course. In order to maximize confidentiality and anonymity, the course instructor was unaware of who responded to the forwarded email, and the researchers were unaware of which students the emails were sent to; they could only identify the students who replied. The first eligible respondents were selected for the study.

5. METHODOLOGY

5.1 Think-aloud Protocol

The study used a concurrent think-aloud verbal protocol method, a research methodology that has been employed in other studies seeking to understand participants' design capabilities and approaches to problem solving within design (Ericsson & Simon, 1993; Kruger & Cross, 2001; van Someren, van de Velde, & Sandberg, 1994). A concurrent verbal protocol session requires participants to speak aloud his or her thoughts as the individual brainstorms strategies to solve an open-ended design problem. The researcher only prompts participants to keep speaking aloud their thoughts; the researcher does not provide any other input during the testing session (Ericsson & Simon, 1993).

5.2 Analysis Frame – Halfin Code

The analysis frame for the think aloud portion of this research was created by Halfin (1973) who used a Delphi process to identify universal cognitive processes used by well-known designers, professional engineers, and inventors including Charles Goodyear, Thomas Edison, Frank Lloyd Wright, and the Wright Brothers. Halfin studied physical design documents of these designers including notebooks, design drawings, and lab files and identified the common cognitive strategies that emerged in these works. He used an eight member panel to provide construct validity in order to accept, modify, or omit any of the operational or general cognitive strategies definitions. The final Delphi instrument including definitions of 14 cognitive strategies was sent out to a 28 member Delphi panel which included both practicing engineers and engineering faculty at academic institutions. Three additional cognitive strategies were added to the instrument by the Delphi panel for a total of 17 cognitive categories. Halfin's cognitive strategies list defines the essential categories for analysis of the data collected in the think-aloud verbal protocols as suggested by Merriam (1998). Since this study only tracked the initial design activities of the participant, a subset of the full Halfin code was used. The codes and definitions used are provided in Appendix 2.

5.3 Information Frame – Custom Code

Although the Halfin Code provides a framework for analyzing students' cognitive processes, it does not explicitly contain a facet related to information gathering activities (in particular, there is a code for 'interpreting data', but not for 'gathering data'). For this study, the authors wanted to explicitly gather data on two facets of the information gathering process: what sources do students use, and what is the content of the information they are trying to find? To that end, the authors constructed a coding system based on the prior work of Wertz et al (2011) and Bursic and Atman (1997). The coding scheme is summarized in Appendix 3. Wertz et al analyzed resources used by first-year engineering students in completing a memo assignment advocating for increasing the environmental sustainability of some facet of campus operations. Bursic and Atman compared the amount and type of information requested by first-year and senior engineering students in a think-aloud protocol involving the design of a children's playground. They tracked not only explicit requests for information from the moderator, but also assumptions students made about the constraints or objectives of the project. In the Bursic and Atman study, students were explicitly encouraged to make requests for more information, while in this study students were given no explicit directions about using information.

5.4 Data Collection

Participants carried out the think-aloud protocol in an existing observation lab that had been built for such studies. The students were given a SmartPen and tablet that captured their written notes synchronized with an audio file of their verbalizations. The students were also videotaped to capture non-verbal cues as well as capturing a duplicate audio file. Finally, the students were provided with a computer connected to the internet, which they could use during the protocol. The computer was running the Morae usability software, which records actions that occur on the computer screen, again with a synchronized audio file. After reading and signing the informed consent form, students read aloud the problem statement and were told they had about thirty minutes to work on the design solution and were free to use the materials (pen, paper, and computer) in the room to complete their task. A moderator remained in the observation room during the activity, prompting the participants if they stopped 'thinking-aloud' for more than a few seconds.

Once the participants indicated they had completed their design, the moderator asked a series of follow up questions to elicit the participants' feelings about how well they had done in their design process, if they had questions about the problem or the process, how they used modeling behavior in the design, and if they felt they had gathered enough information for their solution. They also filled out a short survey about their confidence in how well they carried out different design and information gathering activities and how important those activities are for design in general. Since one of the goals of the project was to determine how well the assessment tools worked, these questions provided feedback to the authors on how the students felt they performed and any limitations they found with the problem statements.

6. RESULTS

The video files were analyzed by two of the authors using the Halfin coding scheme. The authors identified the type of cognitive process used throughout the design activity and extracted the number of distinct actions that involved that cognitive process and the elapsed time carrying out each action. The results are summarized in Table 1.

Two of the authors analyzed the information gathering activities of the students according to the Information Frame coding scheme. The scheme enabled the authors to determine the total number of documents used, the kinds of sources, and the purpose for gathering that information. Additionally, instances when participants verbalized their assumptions about the problem were recorded. The results of the information frame analysis are summarized in Table 2.

Table 1: Analysis of cognitive processes utilized by participants, according to the Halfin coding scheme.

f = frequency, T = time, %T = percent of time on code

	Engineer 1			Engineer 2			Technologist 1			Technologist 2		
Halfin's Code	***F***	**T**	***%T***	***F***	**T**	**%T**	***F***	**T**	**%T**	***f***	**T**	**%T**
DF	6	01:28.7	5	24	07:28.9	25	4	01:27.5	13	13	02:19.0	8
AN	18	05:33.3	20	32	09:41.2	32	2	00:06.7	1	18	06:44.8	25
DE	20	05:46.9	21	6	00:43.1	2	13	04:12.7	38	1	00:13.0	1
MA	6	02:10.7	8	5	00:36.1	2	3	00:29.5	4	4	01:14.7	5
PR	10	03:39.9	13	9	02:19.1	8	1	00:55.3	8	3	00:23.1	1
QH	7	02:39.8	10	3	00:09.4	1	2	00:18.7	3	6	01:08.2	4
MO	8	02:01.9	7	1	00:23.5	1	9	03:01.2	27	0	0	0
CO	4	00:42.6	3	0	0	0	2	00:39.4	6	0	0	0
ID	3	03:27.4	13	17	08:50.4	29	0	0	0	24	15:23.6	56

Table 2: Analysis of information gathering activities and assumptions made by participants.

	Engineer 1	**Engineer 2**	**Technologist 1**	**Technologist 2**
Number of sources used	2	0	9	10
Types of sources used	Government News	N/A	Wikipedia (3) Images (2) .com (2) Maps	.org (3) Wikipedia (2) .com (2) .gov Trade magazine Blog
Information Requested	Health Concerns	N/A	Client Information Geography Science and Technology	Product Information Economic Context Geography Political Context
Assumptions Made	Availability of Resources Budget Technical Requirements Information about Clients	Availability of Resources Budget Technical Requirements Economic Context	Political Context	Availability of Resources Health Concerns

In order to convey a more complete picture of the case studies, each one will be discussed individually.

6.1 Case 1 (Engineer 1)

This participant (Engineer 1) first read the problem statement and then began breaking down constraints and criteria as defined in the problem statement, coded *analysis* or AN. The participant also identified any assumptions she imposed upon the design problem, coded *predicting* or PR. The participant then proceeded to develop consecutive multiple solutions, coded *design* or DE. Finally, the participant compared the pros and cons of certain materials she had chosen to use in the different solutions by rating these decisions based upon constraints such as cost, time, etc. In the course of the activity, the participant tackled several different problems, including transportation, storage, and purification of water, in contrast to the other participants, who focused primarily on purification.

The participant indicated that many of the design ideas while brainstorming came from past learning experiences while enrolled as an engineering major. Of the time spent in the protocol, 20% was spent analyzing criteria laid out in the problem statement and 21% was spent designing solutions. (see Figure 1). These codes, AN and DE respectively, make up the majority of the participant's design process.

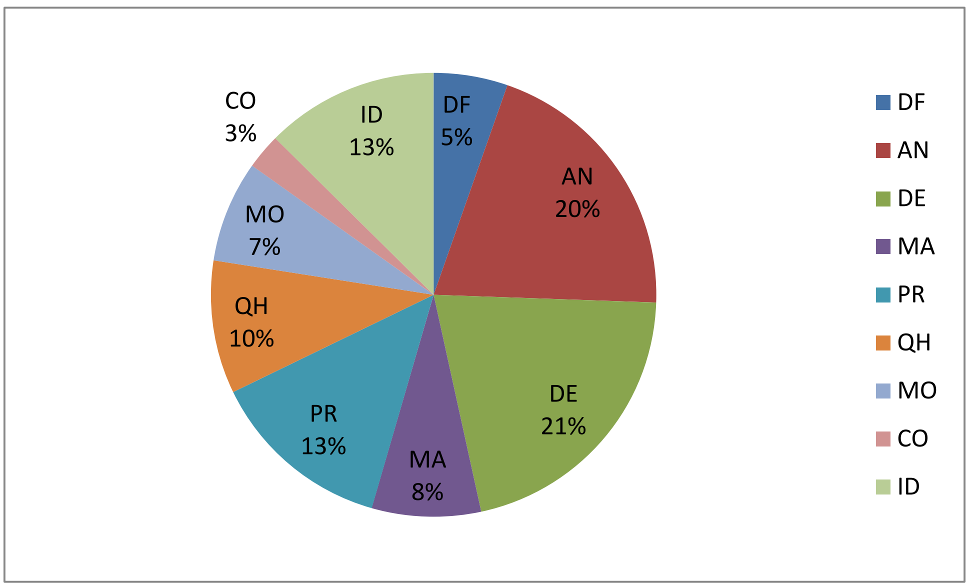

Figure 1: Cognitive processes used by 'Engineer 1.' See Appendix 1 for code abbreviations

With regard to information-related activities, the participant's only verbalized need for information concerned how cholera was transmitted. She conducted a Google search and selected a Council on Foreign Relations report, bypassing other lower quality resources. She also followed a link from the report to a *New York Times* article on the same topic. She articulated that the report was from the Council on Foreign Relations, the only participant to explicitly name the source of their information, other than those that referenced *Wikipedia*. During the activity and in the debriefing of the activity, the participant mentioned that she felt in the short time available, she would have wasted a lot of time searching for credible sources, but that she would go back to gather more hard facts about the problem if she were to continue working on it. The participant indicated in the debriefing that she would have liked to know more about the constraints, but did not ask during the activity for additional information about them.

6.2 Case 2 (Engineer 2)

Upon completion of reading the problem statement, this participant also began by breaking down the problem, identifying constraints and criteria, coded as *analysis* or AN. The participant also worked to define in the problem and describe the constraints he had identified. The self-imposed constraints included no rainfall and lack of proximity to water. After the defining constraints and criteria phase, the participant began to develop a solution involving a water tank made primarily of mud, leaves, sticks, and grass. The participant referred within his dialogue of his previous employment at a water treatment plant to develop a filter design using concrete and mud. This phase of the protocol represented idea generation and was coded DE. DE was the single largest activity this participant engaged in (see Figure 2).

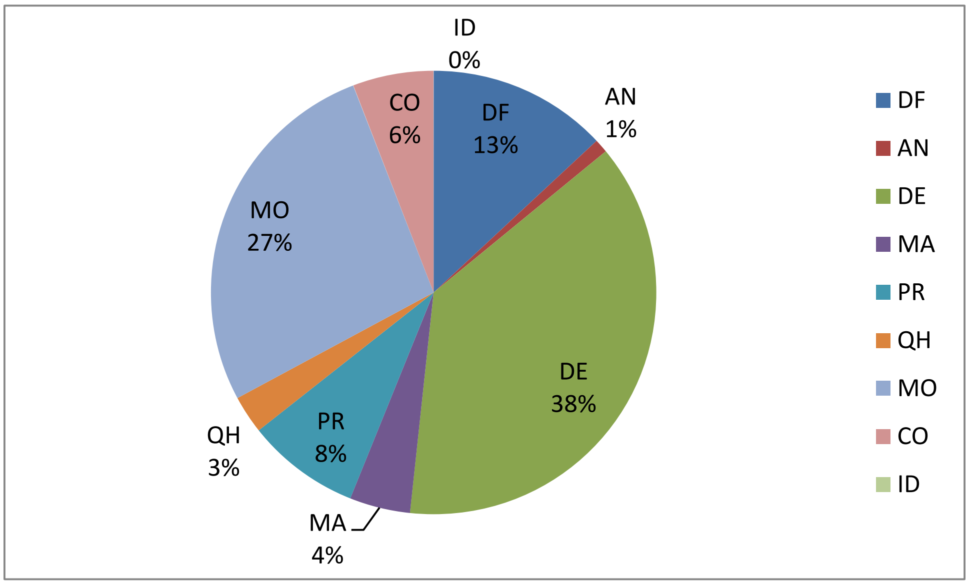

Figure 2: Cognitive processes used by 'Engineer 2.' See Appendix 1 for code abbreviations

Engineer 2 spent 65% of his time within the solution space of the process represented by modeling, coded MO at 27%, and designing, DE at 38%. The participant spent 0% (no time) researching information. This is unlike the other participants, who each spent a minimum of three minutes researching information. In the debriefing after the activity, the participant further indicated that he didn't need to gather any more information about the problem. When identifying constraints at the beginning of this design activity, he used phrases such as "assuming no nearby water source," without asking the moderator or attempting to independently determine whether there was a nearby water source.

6.3 Case 3 (Technologist 1)

This participant began the activity by defining in the problem statement in terms of the conditions the clients were experiencing with their drinking water. Next, the participant began to describe the desired new condition of the drinking water as a solution was developed. This portion of the protocol was coded *analysis* or AN. The participant also included self-imposed constraints such as the availability of unfiltered water not described in the problem statement. The first possible solution suggested by the participant was to use a physical filter and a cheap chemical to further cleanse the water. The participant generated the idea to chemically clean the water by using pre-existing knowledge, as he referred to a relative employed by a waste water treatment plant. The participant later rejects the solution on the grounds that the chemical used may endanger the health of children of the village. The other solutions that the participant mentioned were a plant-based filter and a mechanical, reverse osmosis filter. The final solution the participant identified was drawn from researching solar disinfection online.

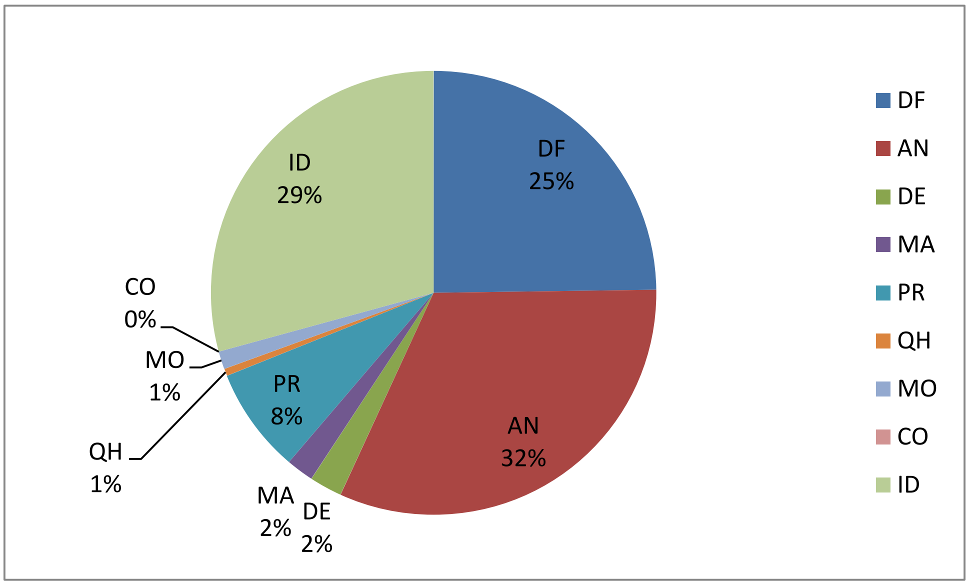

Figure 3: Cognitive processes used by 'Technologist 1.' See Appendix 1 for code abbreviations

Technologist 1 developed solutions using preexisting knowledge obtained from undergraduate mechanical engineering technology courses as well as anecdotal prior experience. The majority of the protocol was spent researching information, ID at 29%, and analyzing information, AN at 32%. The participant spent a total of 3% in the solution space with only 1% of time modeling a solution and 2% generating design ideas (see Figure 3).

The participant vetted his ideas by searching for information to help scope the problem and to provide a rationale for the constraints he articulated. For example, he attempted to find the amount of rainfall the region received to determine whether it could be harvested as a source of water. He also looked for maps to see what bodies of water might be nearby. He eventually found a *Wikipedia* article on "Water Purification" that provided an overview of several methods of purifying water. From that resource, he selected solar disinfection as a preferred solution. In the debriefing after the activity, the participant felt that he would be more confident if he had more time to research the technologies and find more details about the problem.

6.4 Case 4 (Technologist 2)

Immediately after reading the problem statement through twice, the participant identified the criteria and constraints defined in the problem statement, as well as verbalizing his own assumptions. Next within the participant dialogue, he admits that he has no prior knowledge about the problem and begins to research possible solutions, coded *interpreting data* or ID. This phase of the protocol takes up the majority of time at 56%. This is the largest percentage of time spent among all four participants. The second largest phase the Tech 2 participant utilized was analysis, coded AN, at 25% (see Figure 4).

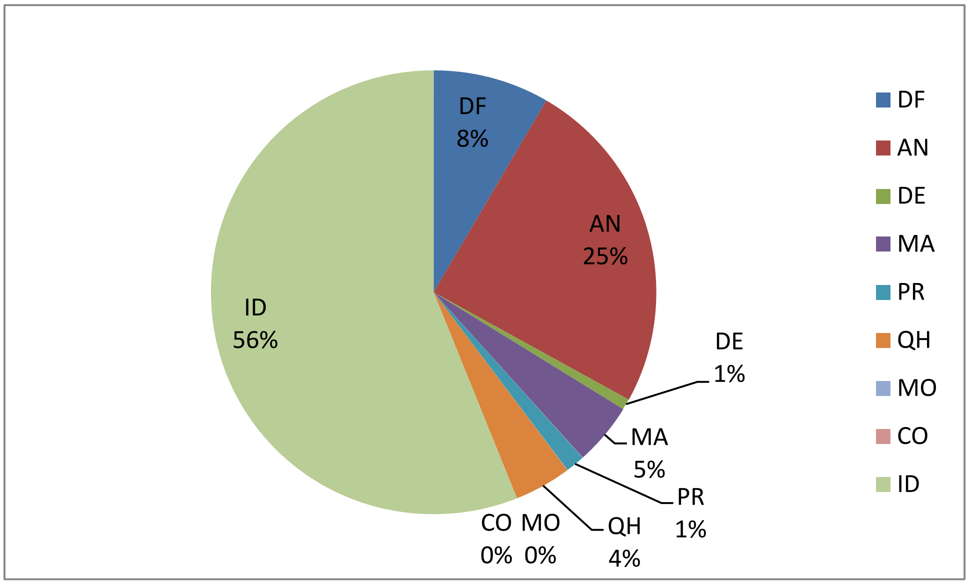

Figure 4: Cognitive processes used by 'Technologist 2.' See Appendix 1 for code abbreviations

Several times during the protocol, the participant dialogued that he had learned, through undergraduate engineering and technology courses, to research possible solutions that may have already been designed, tested, and utilized successfully. The participant's final solution, UV disinfection, a solution already implemented by a non-profit group in a similar geographic area, was garnered through the participant's online research. Unlike the others, this participant indicated that he had no previous experience or knowledge related to water purification, which perhaps influenced the amount of time he spent searching for ideas.

This participant spent the majority of his time locating and reading information gathered from Google searches. According to his verbalizations during the activity, he based his determination of what to read by the short annotations that are retrieved in the Google results. He did not appear to pay attention to the source of information, but rather just the content he was reading. As a result, the information he retrieved was of mixed quality, including '.com' sites, a Johns Hopkins alumni news magazine article and a news blog. His final solution, interestingly, did come from the news blog, which posted a release of a cooperative venture between a non-profit organization and the government of Ghana. He did eventually click through to the web site of the non-profit responsible for the solution at the end of the activity time, but only to try and locate a contact person, not to further analyze the technology.

Although he found the UV disinfection solution near the beginning of the design activity, he continued to search for alternative solutions and did look at a map of the area as well. He was also concerned with the economic capacity of the region to implement the solution he found, and attempted to locate information on the products the region might produce and the overall economic situation of the community. He also looked at the geography of the area to help scope the problem.

7. ANALYSIS

The participants from engineering spent the most time engaging in Analysis, Designing, and Defining Problems. This portion of the Halfin Code is referred to as the "Solution Driven" section. The participants dialogued about the problem statement itself, the criteria and constraints contained within the problem statement, as well as self-imposed constraints and the materials, processes, and overall design that would make up their solution. Engineer 1 spent nearly the same amount of time Analyzing and Designing, 20% and 21%, respectively, but spent only 5% of time Defining Problems. Engineer 2 spent more time Designing and Defining Problems, 38% and 13%, respectively, than Engineer 1, but only spent 1% of time Analyzing.

Technologist 1 spent the most time Analyzing at 32%, while Technologist 2 spent the most time Interpreting Data at 56%. Both participants developed a final solution through the use of the internet and dialogued that a solution that had already been implemented successfully was the best course of action in regards to the problem statement.

Although all four participants spent some time in the Solution Driven phase (Engineer 1: 46%, Engineer 2: 52%, Technologist 1: 59%, Technologist 2: 34%), the biggest difference between the engineering participants and the technology participants was the use of internet resources, which made up a large portion of the activities coded as Interpreting Data. The engineering participants developed solutions that they had designed themselves, and between the two participants only Engineer 1 used the internet and for only three minutes, or 13% of time on code. Comparatively, the technology participants selected from the internet solutions that had already been designed. Technologist 2 had the highest percentage of time utilizing the internet; 15 minutes or 56% time on code.

Kruger and Cross (2006) characterize problem solving strategies as Problem Driven (focus on defining problem and finding solution as quickly as possible), Solution Driven (focus on generating solutions without identifying either problem or information needed), Information Driven (focus on gathering information and developing solution from that information), and Knowledge Driven (focuses on using prior personal knowledge). According to those criteria, the technology students both clearly demonstrate information driven problem solving strategies, while the engineering students align most closely with Knowledge Driven (Engineer 2) or Solution Driven (Engineer 1).

The information gathering activities in support of the design process were quite different between the engineering and engineering technology students. The engineers made substantially more assumptions about the constraints of the project, while the technology students searched for information to validate potential constraints. Perhaps as a result, the engineering students' solutions assumed a great deal about the resources available to the proposed clients and thus focused on extremely low-tech solutions using primarily primitive materials such as mud, grass, and twigs, while the technologists' solutions involved using more sophisticated technologies that nevertheless would not necessarily be beyond the reach of impoverished communities.

It was difficult to generalize any differences between how the participants evaluated their information resources. The one engineering student who did search for information identified credible sources, but the other one did not show any interest in gathering information. On the other hand, the technology students did not seem to make much distinction about the source of the information, rather the content and presentation of the information was their primary focus. Indeed, one of the technology students did find substantive information, but shied away from using it, appearing to be overwhelmed by the detail, although this might have been an artifact of the time constraints of the activity.

In terms of the effectiveness or limitations of the protocol itself, the authors considered whether the task was too artificial. The participants typically didn't ask the moderator for more information about the problem to refine constraints and objectives. This might be an artifact of how the problem was set up, or because they considered this to be like a textbook problem, where all the information is given in the problem statement. In future investigations, the authors would consider using a protocol where the moderator has a packet of information and lets the participants know that they can ask for further information or use the computer to gather more information, better simulating a real client interaction, a methodology closer to the one used by Bursic and Atman (1997).

The authors also discovered that the participants attempted to extract a lot of information about the constraints from a stock picture that accompanied the problem statement (see Appendix 1). The picture showed animals, trees, and individuals in a pond or lake using plastic containers. Although three of the participants explicitly referenced the picture, including one technology student who questioned whether the picture was misleading, all of the participants seemed to harvest information about available resources (trees, water, and in one case animals) from that picture (although, interestingly, no one mentioned the availability of plastic containers for transporting or storing water). Smith et al (1993) found that including a generic photograph can lead to design fixation on that example. To avoid this design fixation, the authors would remove the picture from the problem statement in future studies.

Also, overall, the information gathered focused on superficial resources, which might be a constraint of the 30 minute time limit of the activity. Three of the students said they would look for more information (information gathering also received the lowest self-rating of design activities performed in the follow-up survey), and they shied away from the more substantive information resources they found (government and non-profit technical reports), probably thinking they wouldn't be able to process that information in the time allotted. It might be valuable to allow more time for students to work on the design activity, to see if the time pressure could be alleviated. On the other hand, anecdotally, the authors have seen a great deal of superficial information usage on students' final projects, so it is possible that the challenges students faced in finding credible information continue throughout the entire design process and are accurately reflected in this exercise. When asked in the follow-up survey how confident they were about their ability to locate different kinds of resources, "library resources," government web sites, and technical books supplied the greatest challenge, and they indicated the least confidence in their ability to find information about local conditions, legal codes and standards, and procedures/management of a project. The only 'about' information they expressed confidence in finding was information about materials and costs.

8. CONCLUSIONS/FUTURE WORK

Although this was a pilot project with very few participants, and none of the results are generalizable, they are nonetheless tantalizing and are not in conflict with the distinction made by ABET between engineers and engineering technologists, that one focuses on conceptual design while the other concentrates on applying existing solutions and technologies. The authors were surprised by the stark difference in information gathering that results from this difference in focus and, in particular, of the implication of the importance of information literacy skills for both engineering and engineering technology students. In particular, the classification of both technology students as being Information Driven in their problem solving method is something that should be pursued further to see if it is generalizable. The implications for the need for technology students to gain information literacy skills would be enormous.

For the engineering students studied, the most important information literacy skill required appears to be the first ACRL information literacy standard 'ability to recognize the need for information' (ACRL 2000). Although the engineering student who gathered information appeared to be able to make quality assessments of the information gathered, without the ability to recognize the need for information, no progress can be made in actually gathering information to help solve a problem. It is difficult to assess the other information literacy skills of the engineering students studied, since their overall information usage was so small.

The technology students gathered a lot of information, showing good instincts for gathering information, but the information did not appear to be adequately vetted for quality and credibility. These students would benefit from instruction that emphasizes using appropriate resources and evaluating the quality of those sources. Both groups of students expressed a high level of discomfort using 'library resources' although recognizing the importance of those resources. This indicates an unmet need for instruction on effectively and efficiently using the resources available to those students.

Future work is needed to determine whether these preliminary results are generalizable, to compare novice and expert students' behaviors, and the effect of instructional interventions on the quality and quantity of information gathered. In addition, gender and domestic/international differences could be probed. The one female participant, for example, used a wide variety cognitive process (five different codes used at least 10% of the time), while the male participants used at most three different cognitive processes at least 10% of the total time on task. This study, as any pilot project, raises more questions than it answers, but the results so far indicate a potentially rich source for learning more about how our engineering and engineering technology students view the design process.

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Appendix 1: Problem statement provided to Participants

This is a copy of the task students carried out as part of the protocol.

The Problem:

The lack of access to clean water is a silent crisis affecting more than a third of the world's population. Clean drinking water shortages cause outbreak of serious epidemic illnesses such as cholera and killing more than 5 million people each year. Children are the most affected and about 60% of all infant mortality worldwide is linked to diseases that are water-related.

Your Task:

Your task is to develop a solution that will provide clean drinking water to about 100 people living in a village called Domeabra in Ghana. Describe how you would proceed from this problem statement in order to improve the current condition in this village. Please list all constraints that you impose on this problem and assumptions you make. Your solution should be feasible and cost-effective and have the capacity to provide clean water for at least 30 days. As you work through this problem, 'think aloud' your strategies for deriving a solution.

Appendix 2: Cognitive processes used in this study as defined by Halfin (1973)

Cognitive Process	**Code**	**Definition: Defined by Halfin**
Defining the Problem	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.
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.
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.
Managing	MA	The process of planning, organizing, directing, coordinating, and controlling the inputs and outputs of the system.
Predicting	PR	The process of prophesying or foretelling something in advance, anticipating the future on the basis of special knowledge.
Questioning	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.
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
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.

Appendix 3: Information Gathering Coding Protocol

	Code	Definition	Description/Examples
SECTION 1 – Source of Information	**HNBK**	Handbooks, Guides	Provides quick facts, formulas, equations and/or procedures
	STND	Standards	Provides standards and/or codes
	TXBK	Textbooks	Provides in-depth details of specific topic or related group of topics
	CATA	Product Catalogs	Web sites or catalogs containing information about products, including prices or specifications
	ENCL	Encyclopedias	Provides overview of wide range of topics
	TECH	Technical Reports	Official reports published by government or public agencies
	PATN	Patents	Existing and/or pending U.S. or foreign patents
	STAT	Statistical Compilations	Published data sets
	NWSP	Newspapers	*New York Times, Wall Street Journal, Journal Gazette*
	PMAG	Popular Magazines	*Good Housekeeping, People, Parents*
	TMAG	Trade Magazines	*Engineering News Record, Contracting Business*
	NMAG	News Magazines	*Newsweek, Time*
	JRNS	Journal Articles	*Journal of Solar Energy Engineering*
	CWEB	Commercial	Websites published by commercial enterprises (i.e. ".com") *www.ge.com, www.lightingexpert.com*
	NWEB	News Organizations	Websites published by news organizations *www.cnn.com, www.bbc.com, www.businessweek.com*
	GWEB	Government Agencies	Websites or reports published by federal, state, local or foreign government entities
	OWEB	Non-Profit Organizations	Websites published by non-profit organizations *www.greenpeace.org*
	EWEB	Scholarly Organizations	Websites published by educational entities *www.purdue.edu*
	PWEB	Personal	Websites authored by amateurs and non-experts (i.e. blogs, personal webpages, etc.)
	EXPT	Experts	Consulting with someone who has more expertise/knowledge than the participant (not someone involved with the project, i.e., a stakeholder)
	STAK	Stakeholders	Requests from stakeholders themselves (e.g., the moderator)
	SURV	Surveys	Formal or informal surveys developed by teams
	MAPS	Maps	Maps, charts, or other geographic visualizations

	Code	Definition	Description/Examples
	IMAG	Images	Photographs or other drawings
	Code	Definition	Description/Examples
SECTION 2 – Content of Information Request	**CULT**	Local culture	Division of labor;
	GEOG	Local Geography	Topography, natural resources, weather
	ECON	Local Conditions	Economic data about society under study. Median income, occupations, etc.
	POLI	Legal/Political	Local laws, regulations that would impact design.
	BUDG	Project Budget	How much can I spend on the solution?
	TECH	Technical Requirements	How far does the water have to be transported? How durable does the solution need to be?
	COST	Costs of Materials, Labor and/or, Maintenance	How much does a ¼ inch pipe cost?
	CLIE	Information about the Clients	Who is the group sponsoring this project?
	PROP	Material or Mechanical Properties	How much does water weigh? How much water will a clay pot hold before it breaks?
	SAFT	Safety	Will the design require hazardous materials or procedures?
	HEAL	Health/Physiology	What are the health risks of impure water? How do you treat cholera?
	AVAL	Availability of Materials, Expertise, etc.	Can you buy a 2x4 in the local community?
	STEC	Information about underpinning Science or Technology	How does chlorination of water work?
	PROD	Products	What water filtration devices already exist?
	PROC	Specific Procedures	How do you test whether water is clean?