AC 2011-2287: HIGH SCHOOL STUDENTS AS NOVICE DESIGNERS

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Abstract

Our vision is to improve the STEM learning and teaching environment for high school students through their understanding of engineering design. Engineering employs principles of mathematics and science to create technologies, thus serving as a STEM integrator. Design is recognized as the critical element of engineering thinking which differentiates engineering from other problem solving approaches. The purpose of this exploratory research is to clarify engineering design as a construct and perform empirical preparatory research on engineering design as a STEM learning experience for high school students. The pilot phase of this three year project tests the reasonableness of comparing high school student engineering design thinking with that of experts and investigate the feasibility of these research methods by addressing the following question: How does high school student engineering design thinking compare to that of experts in terms of engineering design performance and knowledge?

Pilot data has been collected from 16 students in four schools nationally. Methods including instrumentation and analysis will be reviewed by an advisory committee of experts before the main data collection (involving 60 students nationally) is conducted in the 2010-2011 school year. Data analysis and dissemination will be conducted in 2011-2012. Results from the pilot study will be presented and compared to results from previous work focused on experts at the 2011 ASEE conference. The area of focus for this paper is time allocation across essential elements of the design process. This research may help to uncover the elusive cognitive thought processes employed by students as they practice engineering design thinking and will inform curriculum developers and teachers planning classroom strategies to improve high school students' understanding of engineering.

Keywords: Engineering Design, High School, Engineering Education, Technological Literacy

Rationale

"The key to educating students to thrive in a competitive global economy is introducing them early to the engineering design skills and concepts that will engage them in applying their math and science knowledge to solve real problems" according to the National Center for Technological Literacy [1]. The engineering design process is a systematic problem solving method and is the key element of the field of engineering. Engineering design has the potential to integrate science, technology and mathematics concepts for students and is essential for developing technological literacy [2]. For over a decade now, experts have been calling for a push to increase technological literacy of our Nation's K-12 students [3-7].

While a demand for technological literacy is loud and clear, many young people are unprepared to make informed decisions in our democratic society regarding the development of new technologies and their applications. The National Center for Technological Literacy suggested, "While most people spend 95% of their time interacting with the technologies of the human-made world, few know these products are made through engineering, the missing link that connects science and math with innovation" [1]. The discrepancy between our society's reliance and dependence on technology and our ability to understand various technological issues has emerged as a serious concern for educators. "Technology is the outcome of engineering; it is rare that science translates directly into technology, just as it is not true that engineering is just applied science" [8]. Specifically, "Americans are poorly equipped to recognize, let alone ponder or address, the challenges technology poses or the problems it could solve" [7]. The relationship between understanding engineering and technological literacy is of special urgency during the high school years, since "technologically literate people should also know something about the engineering design process" [7].

This paper reports the pilot phase (year one) of an NSF funded three year exploratory project focused on understanding how high school students think through the engineering design process. The pilot phase of this study has been completed and results will be presented to address one of the two research questions: "How does high school student engineering design thinking compare to that of experts in terms of engineering design performance and knowledge?" Results and analysis for the second research question will not be available until the main study data collection is complete (years two and three) and will compare high school students entering the sequence of engineering design courses with those finishing the sequence.

Foundation

The University of Washington Center for Engineering Learning and Teaching has explored the cognitive processes of college engineering students extensively [9-13]. Findings in the past decade from this work rely on a variety of studies of freshman and seniors from multiple major universities and also practicing expert engineers in the field. One conceptual theme of this work is that performance can be positioned on a continuum from novice to expert. Expert performance represents a target for novice development. One goal of education is to improve novice performance such that it resembles expert performance more closely.

The Center for Engineering Learning and Teaching has provided substantial insight into the design thinking and performance of college students and experts, as well as, provided comparisons on a variety of constructs. Implications of this work provide guidance for collegiate learning and teaching environments. Our goal is to extend the continuum of novice to expert to include high school learners. By leveraging the Washington based Center's work on experts as a trajectory for high school student development, this research project will have implications for high school curriculum development, learning, and teaching methodologies.

Design problems in these previous studies are ill-structured and open-ended. These kinds of problems have many potential solution paths stemming from an ambiguous identification of a need. The Carnegie Foundation for the Advancement of Teaching has prepared a series of studies including a focus on educating engineers [14]. Sheppard's research identified *reflective judgment* as an appropriate framework for understanding the cognitive development of design thinking. "As individuals develop mature reflective judgment, their epistemological assumptions and their ability to evaluate knowledge claims and evidence and to justify their claims and beliefs change" [14].

King and Kitchener [15] have identified seven stages of reflective thinking organized into three clusters: pre- reflective thinking, quasi- reflective thinking, and reflective thinking. Results of a ten-year longitudinal study of reflective judgment [16-18] suggested that juniors in high school have a cognitive development that tended to approach stage 3 while college juniors tended to be nearing stage 4. This indicates that, on average, high school students are in the pre-reflective thinking cluster while college students are in the quasi-reflective cluster of development. Results of design thinking studies conducted on the college level might yield different results based on the advanced cognitive development of college students. The quasi- reflective cluster of development is characterized by people recognizing that some problems are ill-structured and that uncertainty requires judgment. This quasi- reflective cluster differs from the pre-reflective thinking cluster wherein individuals perceive knowledge to be certain and its sources are that of authority or direct experience. These developmental differences in cognitive approach to ill-structured problems suggest that high school student performance may differ from college student and expertise performance. This framework for cognitive development also suggests that high school students may have a tendency to search for information about other peoples' solutions (an authority on playground design) rather than accept that they are the responsible designer of this solution.

Design thinking is fundamental to understanding the technologically dependent nature of our society. A need for a technologically literate populace, therefore, includes an understanding of the engineering design process. It is this design process which connects technology and engineering, two elements of STEM education. "Design is the central component of the practice of engineering and a key element in technology education" [7]. This study identified quality high school engineering learning and teaching environments in a criterion based sampling strategy, the setting envisioned by Pearson and Young (2002), where "technology teachers with a good understanding of science and the interactions between technology, science, and society will be well prepared to work with other teachers to integrate technology with other subjects" [7].

The playground problem has been used in multiple studies and can be traced to Dally and Zang [19], who identified the need for project driven approaches in the freshman engineering design course to increase student performance and retention and to situate student learning of abstract concepts through real-world applications in an experiential activity. In this activity, students designed a swing set with slides and seesaw. Atman, Chimka, Bursic and Nachtmann [9] revised the foundational work of Dally and Zang to create a playground design problem. In this challenge, university engineering students were presented with a brief playground design task and access to background information upon request. Participants were provided with a maximum of three-hours to develop a solution to the problem while thinking aloud. Mosborg, Adams, Kim, Atman, Turns, and Cardella [11] applied the playground design challenge using the "think aloud" research protocol to 19 practicing engineers who were identified as experts in the field. Mosborg, Cardella, Saleem, Atman, Adams, and Turns [12] compared groups of freshman and senior engineering students with practicing engineers using data previously collected on the playground design challenge. Atman, Kilgore, and McKenna [10] analyzed data from previous studies using a lens focused on the language of design and its relationship to design thinking as a mediator and how this internalization of design thinking relates to language acquisition. This work provided a well developed design task and results for comparisons between the high school student data collected for our study and experts.

The playground design task is an effective task to demonstrate design thinking by students as it is an open-ended, realistic, accessible, and complex problem [12]. The endeavor to model problem solving satisfactorily has eluded scholars across domains [20-23]. Engineering design problems in practice tend to be structurally open-ended and highly complex. An open-ended problem may have numerous solution paths and be bound by some rigid and some negotiable constraints, not always presented with the problem. Engineering design is more than the manipulation of numbers and the solving of scientific equations. The processes employed in engineering design encompass a broad variety of topics and field of study. Through the lens of an ethnographer, Bucciarelli [24] described engineering as a social process. The National Academy of Engineering suggested that engineering education was deficient if it did not include the global perspective in engineering design such as social, political, and environmental issues [8, 25]. The global perspective of engineering is synonymous with the term "systems engineering." Systems engineering involves design from the whole systems level rather than from an isolated modular perspective.

Not only do open-ended problems more accurately reflect industry practices, they also provide students more flexibility and choice [26]. As students are given more freedom and choice, they become further engaged in their own education [27-28]. Authentic problems provide a broad impact, rich in real-world contexts. As such, open-ended problems give the student an authentic experience and greater motivation [29]. Furthermore, playgrounds are familiar to students as they are common to most neighborhoods. This design activity does not require domain-specific knowledge such as electrical, biological, or mechanical engineering and, therefore, is accessible to many student participants with a variety of backgrounds and experiences [12].

The participants of the playground problem are initially given a one page design brief. The constraints are vague with the participant, acting as an engineer, assigned to design a playground on a donated city block. The constraints include limited budget, child safety, and compliance with laws or zoning. The participant is also able to query the research administrator for additional specific information such as, for example, the lot layout, cost of materials, or neighborhood demographics. There is a three-hour time limit for completion of the design proposal. The participants present a written proposal describing their design. This activity engages the participants in problem framing and developing an initial solution. Limitations of this design task include the lack of opportunity for participants to investigate the need for a solution; it is directly presented to them. Students do not have an opportunity to construct physical models or prototypes. Participants are aware that implementation of the design project will not occur, and their designs will not have the potential to become realized.

Data Collection Methods

Consistent with triangulation mixed methods research strategies, quantitative and qualitative data were collected and analyzed, concurrently, providing multiple lenses from which to understand engineering design thinking among high school students. Areas of congruence between quantitative and qualitative data will enable strong conclusions regarding design thinking, while points of divergence may highlight gaps in student learning between "design knowledge and its practical application" [10]. Sheppard also addressed the gap between knowledge and application, "in addition to 'knowing that' – having a firm grasp of the theories and principles-students need to ‘know how’ – how, when, where, and why to use theories and principles in analyzing engineering problems or situations” [14].

Before the design task was administered, the research team would enter the room and set up equipment for the data collection. First, the research team would arrange a table to create a workspace for the students. The table was usually square in shape and had enough space to make the student comfortable while working through their design task. On the table a calculator, ruler, a small note pad, graph paper, white 8.5” x 11” paper, pencil, highlighter, sticky note, and the design task were placed before the student entered the room. Video recorders were used to capture the student’s work and were placed to create a view of the students working as well as to capture the table the students were working on. The research administrator discussed the agenda for data collection and provided food for the research participant before the task was administered. During this time, the researcher made a judgment about the student’s voice projection. Quieter students were asked to wear a lapel microphone. Audio/video recording was done to capture the participants as they verbally worked through the problem, as well as, to show what participants were reading, drawing, and so on. The documents used in administering the problem were colored to help the observer differentiate between information (blue), problem definition (yellow) and student work (white).

Three hours were allotted for students to complete the design task, although the average student completed the problem prior to the administrator stopping the session. During the participant’s design session, a member of the research team acted as the administrator of the problem. The administrator provided the students with a physical copy of the design task and read it aloud with them [for more details on the design task refer to Atman [9-10]]. The design task included a description of the general constraints and the method students could use to access information. The administrator provided various documents containing information upon specific request as well as access to an internet search engine. Use of the internet was a variance from previous work and discussed further in the results section of this paper. While students were working, administrator kept track of the information requested by the students. Using a simple chart, the administrator made a note of what information was requested by the participant, as well as the specific time the information was requested.

During the design task, the administrator was responsible for ensuring students were continually thinking aloud. It was imperative for the participant to verbalize their thoughts while simultaneously working through the problem. This was done by the administrator prompting the students, such as, “keep talking”, “what are you thinking”, “what are you doing”, “what are you drawing”. The administrator also created a list of questions that were focused on the participant’s solution development to be used for a follow up interview that was conducted after all data for each site was collected.

The administrator would continue the problem until the participant indicated they were finished (or the three hour session had expired). Once the participant felt that they had completed a design that satisfied the problem, the administrator would thank them for participating in the study and remind them that there will be a follow up interview in a few weeks. Follow up interviews were usually conducted 2-4 weeks after the initial design task was completed. These served as a way for the research team to gain more information about what student were doing while developing their solution. Common questions asked of participants were, how did you define the problem, how did you compare ideas, why and how did you choose your final idea or plan, along with question directly related to the students work. When the follow up interviews were completed, students were compensated for their time with a 40 dollar check.

Data Analysis

The playground problem coding scheme was congruent with the approach used in prior studies [9, 11-12]. The data were coded into these nine categories presented by Mosborg et al., [12]: **Problem Definition (PD)**: Defining what the problem really is. **Gather Information (GATH)**: Searching for and collecting information needed to solve the problem. **Generating Ideas (GEN)**: Thinking up potential solutions (or parts of potential solution) to the problem. **Modeling (MOD)**: Detailing how to build the solution (or parts of the solution) to the problem. **Feasibility Analysis (FEA):** Assessing and passing judgment on a possible or planned solution to the problem. **Evaluation (EVAL)**: Comparing and contrasting two (or more) solutions to the problem on a particular dimension (or set of dimensions) such as strength or cost. **Decision (DEC)**: Selecting one idea or solution to the problem (or parts of the problem) from among those considered. **Communication (COM)**: The participants' communicating elements of the design in writing, or with oral reports, to parties such as contractors and the community. **Other**: None of the above codes apply. See table 1.

Table 1

Coding Scheme and Description

Code	Description of Code
Problem Definition (PD)	Define what the problem really is, identify constraints, identify criteria, reread the problem statement or information sheets, question the problem statement
Gather Information (GATH)	Search for and collect information
Generating Ideas (GEN)	Develop possible ideas for a solution, brainstorm, list different alternatives
Modeling (MOD)	Describe how to build an idea, measurements, dimensions, calculations
Feasibility Analysis (FEAS)	Determine workability, does it meet constraints, criteria, etc.
Evaluation (EVAL)	Compare alternatives, judge options, is one better, cheaper, more accurate
Decision (DEC)	Select one idea or solution among alternatives
Communication (COM)	Communicate the design to others, write down a solution, or instructions

Adopted from Atman [9]

Two graduate students were trained in the coding methodology using documents shared by the University of Washington. While the coding scheme was consistent with previous literature, the technique was slightly different. Previous work used transcriptions, segmenting coding as three separate activities in the analysis process [9]. Inter-rater reliability was calculated on the coding to ensure reliability of the multiple coding analysts. The pilot phase of this project bypassed transcription using NVIVO software which presented coding analysts with synchronized video and audio feed. Segmenting and coding was done simultaneously while watching the multimedia. Codes were associated with the timeline on the video/audio tracks and inter-rater reliability was computed with Cohen's Kappa statistics. Each rater was responsible for one-half of the data set. Each rater also coded 25% of the other rater's set to estimate inter-rater reliability. Inter-rater reliability data is presented for each code in table 2. The average inter-rater reliability of 0.607 was comparable to previous work [30]. Some Kappa values, however, were very low such as Generating Ideas, Modeling, and Feasibility and caused the research team concern. Techniques to address these deficiencies are discussed in the results and implications sections.

Table 2

Cohen's Kappa For Each Design Activity

Design Activity	Cohen's Kappa
Problem Definition activity	0.7144
Gathering Information activity	0.8094
Generating Ideas Activity	0.3911
Modeling activity	0.4909
Feasibility Analysis activity	0.4811
Evaluation activity	0.8659
Decision activity	0.5275
Communication activity	0.5732

Sample

Four schools were identified and recruited for this study representing four states, and range from urban to rural (refer to table 3 and table 4 for school and community demographic information). Utah State University, Purdue University and two other well recognized universities with strong engineering outreach programs collaborated to identify the four schools. A criterion sampling strategy [31] was used which included:

- The high schools have an established program of study which employs a focus on engineering in a sequence of courses developed in association with an engineering outreach effort as part of a university program.
- In these courses, students participated in design activities which engage their critical thinking and problem solving skills within the framework of the engineering design process.

Table 3

School Demographics

School	Enroll-ment	Female	Male	African American	American Indian	Asian	Caucasian	Hispanic
1	1136	45%	55%	2%	1%	3%	65%	30%
2	216	54%	46%	1%	1%	1%	76%	20%
3	1833	47%	53%	4%	1%	1%	86%	7%
4	874	55%	45%	96%	0%	1%	1%	2%

Source: http://nces.ed.gov/ccd/schoolsearch/index.asp

Table 4

Community Demographics by School

School	Community Population	Median Household Income	African American	American Indian	Asian	Caucasian	Hispanic
1	91,000	$45,000	1.2%	0.5%	4.0%	88.3%	8.2%
2	78,000	$34,000	2.3%	1.2%	1.4%	79%	23.6%
3	61,000	$36,000	3.2%	0.4%	1.2%	88.9%	9.1%
4	>500,000	$59,000	54.0%	0.4%	3.2%	40.6%	8.8%

Source: http://quickfacts.census.gov/qfd/index.html

Meetings were held with the engineering and technology education teachers to help create an understanding of what the overarching goals of the study were and their role providing researchers with access to the school facilities and students. Once the teacher was familiar with the study, a member of the research team made classroom visits to begin the recruitment process. The researcher explained the purpose of the study and the student's role within the study.
The target student for the pilot study was one who had completed several engineering based courses at the high school level. Senior students were targeted for the pilot study because they were most likely to demonstrate design thinking after having studied multiple courses, thus allowing researchers to pilot the methodology. The average student in the pilot study reported taking 4.7 engineering related courses. Student demographic data and courses taken, as reported by students, are shown in tables 5 and 6.

Table 5

Participant Demographics

	Number of Participants	
Self reported identity	Male	Female
White	9	3
Black or African American	3	0
Asian	0	1

Table 6

Courses Taken by Participants

Courses	Number of Participants
Intro to Engineering Design	12
Intro to Engineering in a Global Society	4
Principals of Engineering	12
Civil Engineering/Architecture	8
Aeronautical/Aerospace Engineering	7
Digital Electronics	7
Computer Integrated Manufacturing	4
Bio-Medical/Bio-Technology	2
Robotics	2
Drafting	1
Design Capstone	16

Students were provided a recruitment packet including a letter to parents which provided a description of the study, a parental consent form, participant information form, a student assent form, and a demographic data sheet. Four students from each participating school were selected and times were set up for data collection. Data collection was scheduled not to interfere with students academic responsibilities. In most situations, students were able to complete the design task after school hours or on weekends. Due to the logistics of data collection, efforts spanned multiple days which presented the chance participants would talk with each other about the challenge. At the conclusion of each participant's session, they were asked not to discuss the session with peers until all the data had been collected from that school.

Results

The results of this pilot will inform the development of the main study (n=60). The pilot established a relationship with four schools and tested our ability to gain entry and use the school facilities. The pilot challenged the team's ability to manage multiple files for each student including video, audio, and scanned copy of the student generated documents. Video files were imported into NVIVO software for analysis and coded by two graduate assistants. The purpose of this pilot was to identify challenging areas of this research and provide an opportunity to improve the methods prior to administering the main study. Experts and novice comparisons were made to identify differences which may provide an early indication of the main study results, but may also indicate challenges in methodology. The challenges identified by the research team included maintaining satisfactory inter-rater reliability and participant information access.

The Cohen's Kappa values averaged 0.61 for this study which was comparable to previous literature. Kappa values for each category in the coding scheme had a wide range. The lowest was *Generating Ideas* at 0.39. This code was applied when students were developing possible ideas for a solution, brainstorming, or listing different alternatives. High school students in this study rarely followed a "textbook" approach to brainstorming. This classic step is characterized by creating a list of possibilities without passing judgment. All judgment should be suspended during brainstorming so that wild ideas may spark another related, but practical idea. Students in the pilot rarely conducted this form of brainstorming. Rather, they searched for information about playgrounds or recalled their previous experiences and frequently stuck with the first thoughts that came to mind. Students spent a good deal of time in communicating their design through sketching, written description, and materials lists which indicated they had ideas, but differentiating between *Generating Ideas* and *Information Gathering* or *Communication* were difficult.

Evaluation and *Information Gathering* had very high levels of inter-rater agreement (0.87 and 0.81 respectively). In the *Evaluation* element, we looked for students to compare alternatives and prepare to make judgments. Pilot data indicated that students did very little *Evaluation*. When they did compare alternatives, they did so in a very clear overt way. Interestingly, all comparisons (though there were very few) were done verbally. None of the students created a decision matrix or anything that even resembled a matrix to compare alternatives. As senior students, all having taken a capstone course, it seemed reasonable to spend more time making decisions and have a systematic method for comparing alternatives.

Students spent a substantial amount of time in the *Information Gathering* phase and it had a high Kappa value. This high Kappa value was due, in part, to the volume of time students spent gathering information in long uninterrupted segments of time. *Information Gathering* code applied when students were looking for information about their design problem or solution. Students were able to query the research administrator with specific questions to probe for information which is consistent with previous literature. Internet search engines were provided, departing from previous methodologies to maintain consistency with youth culture. Today's young people are digital natives [32] and have grown up with information access via multiple channels, and thus internet access would appear to be logical. Prensky argued that digital access to information and analytical tools enhance our thinking power [32]. In our pilot study, researchers provided students with internet access to maintain a sense of ecological validity. The demand for information beyond the immediate identified need is substantial and ubiquitous in the design process. Ennis and Gyeszly [33] found that gathering information was an essential element of the expert designers' approach to problem solving and that generation of ideas was influenced by the information. Experts have practice accessing information and are familiar with the structure and content of databases, previous project examples and other experts with whom to collaborate. Novice students do not have these engineering domain specific information literacy skills. In a recent study comparing college student and expert engineering design behaviors, Atman et al. [30] stated that "Results support the argument that problem scoping and information gathering are major differences between advanced engineers and students, and important competencies for engineering students to develop" [30]. These differences, according to Christiaans and Dorst, [34] include a finding that some students get "stuck" gathering information and this fixation prevents students from making progress on their design.

Atman [30] transcribed the audio and segmented thoughts by as "distinct pause-bound utterances". In our pilot study, we asked the coders to simultaneously segment and code the data sets. Pilot study inter-rater reliability was calculated after coding and segmenting were both completed, not sequentially after segmenting and then again after coding. We noticed that high school students integrated multiple elements of the design process without pause. This continuous flow of thinking made differentiating between segments ambiguous and difficult. In reflection, this technique presented coding analysts with difficulty in agreeing on segment size which compounded challenges associated with identifying the segment code. The level of resolution was a contentious issue and a source of Kappa value degradation.

Pilot comparison between novice high school students and experts suggest substantial differences to be confirmed by the main study. Table 7 provides the average time and standard deviation represented by minutes spent and percentage of total time. Expert data are presented from Atman [30] for comparison. Atman identified eight elements of the design process grouped into three stages. We choose to display "other" which represents time in the design process not coded in the other eight elements.

Table 7

Mean and Standard Deviation Summary Statistics for High School Students and Experts

Design Process Measures	**High School Students (n=16)**		**Experts (n=19)**	
	Minutes (SD)	Percent of time (SD)	Minutes (SD)	Percent of time (SD)
Total Time	136.63 (40.4)		131.9 (20.3)	
Problem Scoping stage	50.29	37.11	31.3 (16.2)	24.4 (12.5)
Problem Definition	3.14 (2.3)	2.37 (1.6)	8.3 (2.8)	6.3 (2.0)
Gathering Information	47.15 (23.7)	34.74 (15.6)	23.0 (16.3)	18.0 (12.5)
Developing Alternative Solutions stage	33.01	25.7	93.3 (25.3)	70.2 (12.1)
Generating Ideas	5.33 (4.4)	3.94 (3.0)	6.6 (5.8)	5.0 (4.5)
Modeling	25.66 (20.0)	20.00 (15.6)	73.2 (24.6)	55.1 (13.6)
Feasibility Analysis	1.80 (1.7)	1.60 (2.1)	11.6 (6.5)	8.8 (4.4)
Evaluation	0.22 (0.3)	0.16 (0.2)	1.9 (2.3)	1.4 (1.7)
Project Realization stage	36.00	24.97	7.3 (5.4)	5.5 (3.7)
Decision	0.52 (0.4)	0.50 (0.5)	2.4 (1.8)	1.8 (1.2)
Communication	35.48 (19.9)	24.47 (9.7)	4.9 (5. 0)	3.7 (3.5)
Other	17.33	12.22	0.0	0.0

Pilot data suggested that high school students spent more time in the problem scoping and project realization phase, while experts spend considerably time in developing alternative solutions. Figure 1 graphically represents the average time in each phase. Figure 2 provides graphical representation breaking each stage into an element of the design process. This detail suggested that pilot students spent nearly twice the amount of time gathering information as did experts. Experts were substantially more involved with modeling, feasibility, and evaluation than were high school students. High school students spent much time communicating their results, though researchers noticed their documentation was generally of very poor quality. Quality was not objectively measured in this study, but without exception, a contractor would not be able to build the playground from the design documentation as presented. In most cases, the documents were very disorganized, messy, and incomplete.

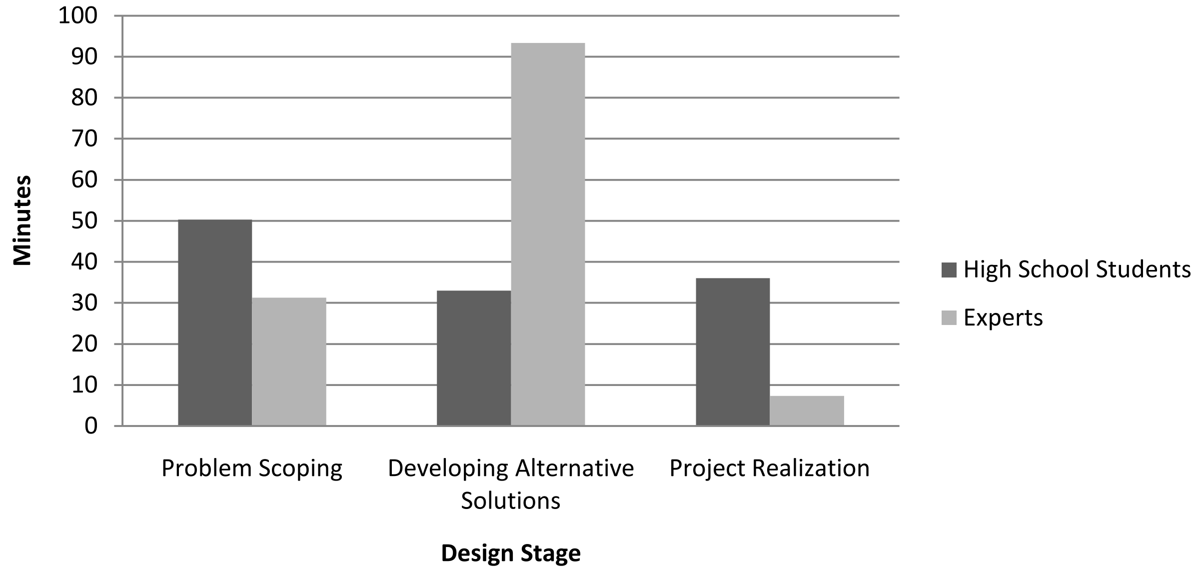

Figure 1. Mean time expressed in minutes each group spent in playground design stages.

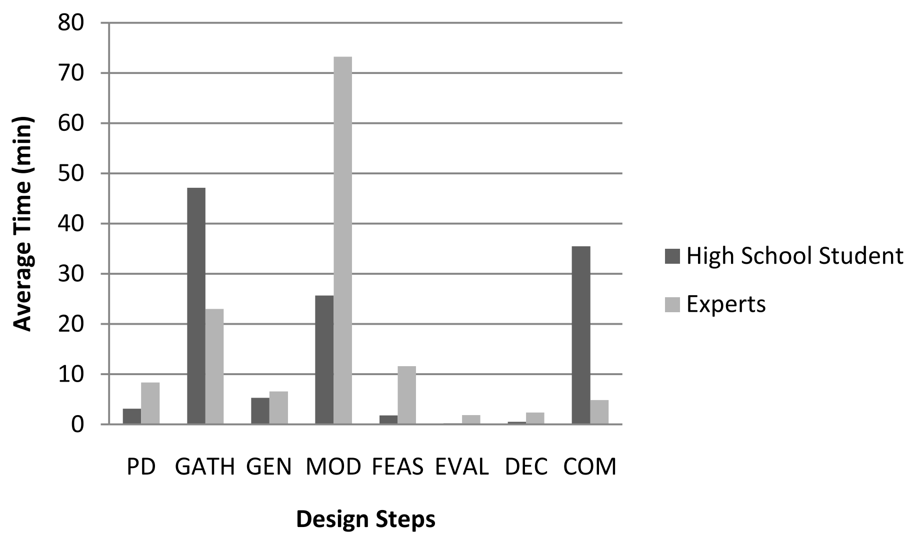

Figure 2. Average time spent in each design step for high school students and experts.

Implications

This pilot has several implications for the main study and high school student design thinking. Data collection techniques and data analysis techniques will be reviewed by an advisory board for input. The advisory board has provided preliminary feedback that internet access may have a significant impact on information gathering behaviors. The balance between providing a resource that is a mainstay of youth culture and maintaining sense of consistency with previous work (wherein the internet was not used) is challenging. The validity of our work hinges on the comparison to previous efforts which the advisory board recommended trumps the ecological validity of providing internet access to the digital native generation.

The coding procedures will be revisited to address the low inter-rater reliability scores. Consideration will be given to segmenting separately from coding the segments. Inter-rater reliability statics representative of code agreement and also code timing. For instance, frequently, one coder would indicate the code began (or ended) a few seconds before the other coder. Especially in short code segments, this is problematic because while both coders agreed on what they saw, Kappa values were low because of inconsistent starting and stopping of the code. NVIVO software would permit coders to segment by applying a set of codes to the timeline. These “blank” codes would allow for comparison of the segmenting process and serve as placeholders for the actual codes to follow. This multi-step process, to be considered for the main study, is more congruent with previous work and may increase the reliability of the main study.

Information gathering may have been dominant in the student’s performance because the internet harbors a wealth of information and students may have gotten distracted. As discussed previously, students are in the pre-reflective stages of cognitive development which suggests they may look for an authority who knows the “correct” answer rather than conducting the modeling, feasibility, evaluation, and decision making that are integral to the engineering design process. Thus, by limiting information access, efforts in the other areas may become more evident and increase reliability because behaviors are more clearly focused on the design process.

Teachers may take note of the pilot results and consider a few aspects of this research: information gathering, modeling, decision making, and communication. Students in this pilot spent a substantial amount of time accessing the internet and very little time brainstorming. While students may memorize the purpose and procedure of brainstorming, few students in this pilot had internalized the method. Students used the internet extensively and perhaps as a substitute for a classic brainstorming method. Further research should investigate the impacts of information access on solution quality for younger learners. The balance between becoming fixated on finding information related to the problem and using that information to make decisions is delicate and may be difficult for novice learners.

Teachers may consider the general lack of modeling and decision making from these pilot results as an area to strengthen in their classrooms. How can modeling be taught? Curriculum and teaching methods should be reviewed for their treatment of analysis [see Katehi, Pearson, and Feder 2009 for a discussion of existing curriculum]. Teachers need to emphasize the role of analysis such that students can apply these techniques in the context of the problem at hand.

Analogical reasoning is often used in engineering design and should be included in engineering design curriculum and instruction [35]. Decision making should be based on data derived from analysis and information gathered. Textbook examples guiding decision making include use of the decision matrix, but not one student demonstrated this technique. While students may be able to use a matrix when asked, they are not choosing to do so when provided with an opportunity. Quality decision making is essential to the engineering design process and pilot data suggested that students are making very few thoughtful decisions. Research team member reflection on the pilot student performance suggested that high school students are rarely considering alternatives.

Next Steps

Results of the pilot will be formally reviewed by the advisory board and main study data collection and analysis will be conducted. Results from the main study (n=60) will be compared to previous work to respond to the first research question: How does high school student engineering design thinking compare to that of experts in terms of engineering design performance and knowledge? In the main study, data will be collected from students starting and finishing the sequence of engineering courses at each high school to help the team address the second research question: Does student participation in a multi-year sequence of courses focused on engineering correlate with changes in performance or design knowledge?

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References

1. National Center for Technological Literacy. *Our Nation's Challenge*. 2010 [cited 2010 January 12]; Available from: http://www.mos.org/nctl/our_nations_challenge.php.
2. Katehi, L., G. Pearson, and M. Feder, eds. *Engineering in K-12 Education*. 2009, The National Academies Press: Washington, D.C.
3. Garmire, E. and G. Pearson, eds. *Tech Tally: Approaches to Assessing Technological Literacy*. 2006, National Academies Press: Washington, D.C.
4. Gorham, D., *Engineering and Standards for Technological Literacy*. The Technology Teacher, 2002. **61**(7): p. 29-34.
5. International Technology Education Association, *Technology for All Americans: A Rationale and Structure for the Study of Technology*. 1996, Reston, VA: Author.
6. International Technology Education Association, *Standards for Technological Literacy: Content for the Study of Technology*. 2000, Reston, VA: Author.

7. Pearson, G. and A.T. Young, eds. *Technically Speaking: Why All Americans Need to Know More About Technology*. 2002, National Academy of Engineering.
8. National Academy of Engineering, *The Engineer of 2020*. 2004, Washington, DC: The National Academies Press.
9. Atman, C., J.R. Chimka, K.M. Bursic, and H.L. Nachtmann, *A Comparison of Freshman and Senior Engineering Design Processes.* Design Studies, 1999. **20**: p. 131-152.
10. Atman, C., D. Kilgore, and A. McKenna, *Characterizing Design Learning: A Mixed-Methods Study of Engineering Designers' Use of Language.* Journal of Engineering Education, 2008. **97**(3).
11. Mosborg, S., R.S. Adams, R. Kim, C. Atman, J. Turns, and M. Cardella. *Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals*. In *2005 American Society for Engineering Education Annual Conference & Exposition*. 2005. Portland, Or.
12. Mosborg, S., M. Cardella, J. Saleem, C. Atman, R.S. Adams, and J. Turns, *Engineering Design Expertise Study, CELT Technical Report CELT-06-01*. 2006, University of Washington: Seattle.
13. Morozov, A., K. Yasuhara, D. Kilgore, and C. Atman, *Developing as Designers: Gender and Institutional Analysis of Survey Responses to Most Important Design Activities and Playground Information Gather Questions, CAEE-TR-07-06*. 2008, University of Washington: Seattle.
14. Sheppard, S.D., K. Macatangay, A. Colby, and W.M. Sullivan, *Educating Engineers: Designing for the Future of the Field*. 2009, San Francisco: Jossey-Bass.
15. King, P.M. and K.S. Kitchener, *Developing Reflective Judgment*. 1994, San Francisco: Jossey-Bass Inc.
16. King, P.M., *The Development of Reflective Judgment and Formal Operational Thinking in Adolescents and Young Adults.* Dissertation Abstracts International, 1977. **38**(7233A).
17. Kitchener, K.S. and P.M. King, *Reflective Judgment: Concepts of Justification and Their Relationship to Age and Education.* Journal of Applied Development Psychology, 1981. **2**(2): p. 89-116.
18. Kitchener, K.S., *Intellectual Development in Late Adolescents and Young Adults: Reflective Judgment and Verbal Reasoning.* Dissertation Abstracts International, 1977-78. **39**(956B).
19. Dally, J.W. and G.M. Zhang, *A Freshman Engineering Design Course.* Journal of Engineering Education, 1993. **82**(2): p. 83-91.
20. Rubenzer, R., *The role of right hemisphere in learning & creativity implications for enhancing problem solving ability.* Gifted Child Quarterly, 1979. **23**(March 1979): p. 78-100.
21. Polya, G., *How to Solve It: A New Aspect of Mathematical Method*. 1945, Princeton: Princeton University Press.
22. Hayes, J.R., *The Complete Problem Solver*. 2nd ed. 1989, Hillsdale: Lawrence Erlbaum Associates.
23. Newell, A. and H. Simon, *Human Problem Solving*. 1972, Englewood Hills: Prentice-Hall.
24. Bucciarelli, L.L., *An ethnographic perspective on engineering design.* Design Studies, 1988. **9**(3): p. 159-168.
25. National Academy of Engineering, *Educating the Engineer of 2020:Adapting Engineering Education to the New Century*. 2005, Washington, D.C.: The National Academies Press.
26. Mawson, B., *Beyond `The Design Process': An alternative pedagogy for technology education.* International Journal of Technology and Design Education, 2003. **13**(2): p. 117-128.
27. McKeachie, W.J., *McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers*. 12th ed. 2006, Boston: Houghton Mifflin.
28. Schulz, N.N. *Methods to stimulate electrical engineering concepts to non-EE students*. In *IEEE Proceedings of Southeastcon 1991*. 1991.
29. Yair, G., *Reforming motivation: How the structure of instruction affects students' learning experiences.* British Educational Research Journal, 2000. **26**(2): p. 191-210.
30. Atman, C., R.S. Adams, M. Cardella, J. Turns, S. Mosborg, and J. Saleem, *Engineering Design Processes: A comparison of Students and Expert Practitioners.* Journal of Engineering Education, 2007. **96**(4).
31. Creswell, J.W., *Qualitative Inquiry and Research Design*. 1998, Thousand Oaks: Sage Publications.
32. Prensky, M., *H. Sapiens Digital: From Digital Immigrants and Digital Natives to Digital Wisdom.* Innovate: Journal of Online Education, 2009. **5**(3).
33. Ennis, C.W. and S.W. Gyeszly, *Protocol Analysis of the Engineering Systems Design Process.* Research in Engineering Design, 1991. **3**(1): p. 15-22.
34. Christiaans, H.H.C.M. and K.H. Dorst, *Cognitive Models in Industrial Design Engineering: A Protocol Study*. Design Theory and Methodology, 1992. **42**: p. 131–140.
35. Christensen, B.T. and C. Schunn, *The relationship of analogical distance to analogical function and preinventive structure: the case of engineering design.* Memory & Cognition, 2007. **35**(1): p. 29-38.