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### Recommended Citation

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*Publications*. Paper 162.

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

# Engineering Design Thinking and Information Gathering Final Report

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Sponsored by  
National Center for Engineering and Technology Education under the  
National Science Foundation Grant Number ESI-0426421.

## ***Objective***

The objective of this research was to explore the relationship between information access and design solution quality of high school students presented with an engineering design problem. This objective is encompassed in the research question driving this inquiry: How does information access impact the design process? This question has emerged in the context of an exploratory DR-K12 grant project titled, *Exploring Engineering Design Knowing and Thinking as an Innovation in STEM Learning*. The research work presented here has expanded the data set developed in the DR-K12 and examined the larger data set with a focus on how information access impacts design thinking. The opportunity to explore the impact of information gathering was not afforded in the DR-K12, but emerged as an area of interest during the pilot phase.

## ***Problem Statement***

The mission of the National Center for Engineering and Technology Education is to “improve understanding of the learning and teaching of high school students and teachers as they apply engineering design processes to technological problems” (National Center for Engineering and Technology Education, 2010). A common theme in the Center’s work in teaching engineering design has been the use of design challenges (Asunda & Hill, 2008; Becker, 2006; Becker & Custer, 2005, 2006; Cullum, Hailey, Householder, Merrill, & Dorward, 2008; Merrill, Childress, Rhodes, & R., 2006; Merrill, Custer, Daugherty, Westrick, & Zeng, 2007; Shumway, Berrett, Swapp, Erikson, & Terry, 2007; Tufenkjian & Lipton, 2007). The Center’s design process (Childress & Maurizio, 2007) is congruent with other models of engineering design (Dym & Little, 2004; Eide, Jenison, Mashaw, & Northup, 1998; Eide, Jenison, Northup, & Mickelson, 2008; P. Moore, Atman, Bursic, Shuman, & Gottfried, 1995) and requires students to actively explore problem and solution space.

This research proposal aligned with the Center’s goal of providing guidance for the field of Engineering and Technology Education on the development, implementation, and evaluation of engineering design. In the Center’s model, students are expected to perform the following processes (Childress & Maurizio, 2007, p. 3):

1. Identification of a need
2. Definition of the problem/specifications
3. Search
4. Develop designs
5. Analysis
6. Decision
7. Test prototype and verify the solution
8. Communication

As students work through these iterative stages of the design process, a need for information arises. High school students are novice designers, these students have a limited background and limited experiences in design thinking. This limited experiential background makes gathering information even more critical for their success. Students might be gathering information about the problem and its context including cultural, environmental, geographic types of information. As students begin to think about their potential solutions, they may search for information about previous solutions or current solutions that are insufficient in an attempt to benchmark. Developing their design may include information about standard materials and their properties or readymade components that could be integrated in a novel way. Analysis may leverage identifying variables and their relationships to be used in predicting performance. These variables and relationships might not be heuristics familiar to students or may be too complex to memorize which pushes the student to search for information.

The demand for information beyond the immediate identified need is substantial and ubiquitous in the design process. Ennis and Gyeszly (1991) 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. (2007) 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" (p. 359). To facilitate a successful learning environment during implementation of the engineering design challenge, students need access to information. Teachers can provide information to students relevant to the challenge at hand through discussions or print resources. An alternative or supplement to the teacher's resources could be providing students with access to the internet. Today's young people are digital natives (Prensky, 2009) and have grown up with information access via multiple channels, and thus, internet access would appear to be ecologically appropriate. Prensky (2009) argued that digital access to information and analytical tools enhance our thinking power.

### ***Theoretical Foundation***

The foundation of this study was built on similar previous studies of college students. Design problems in these previous studies are ill-structured and open-ended. These kinds of problems have many potential solution paths stemming from a need or problem. The Carnegie Foundation for the Advancement of Teaching has prepared a series of studies including a focus on educating engineers (Sheppard, Macatangay, Colby, & Sullivan, 2009). This 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" (Sheppard, et al., 2009, p. 25).

King and Kitchener (1994) 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 (King, 1977; Kitchener, 1977-78; Kitchener & King, 1981) 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 indicated 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 suggested that high school students may have a tendency to search for information about other peoples' solutions (an authority on playground design) rather than internalize they are the designer of this solution. By providing access to the internet, images and descriptions of other solutions are at easy reach and may alter the decision making process.

Teacher provided information can be well focused and therefore reduce the time students spend searching. Christiaans and Dorst (1992) discovered that some students get "stuck" gathering information and this fixation prevents students from making progress on their design. On the other hand, the teacher would be limiting student creativity by providing information that is bias toward a solution or set of solutions envisioned by the teacher. Preparing all the possible information for students would be a demanding (perhaps impossible) task and, based on limited preparation time, will have to be abbreviated. If the teacher allows students to utilize the internet for web based searches, a virtually unlimited pool of information is accessible. Successful negotiation of this material requires complex information literacy skills and time management. Students could spend countless hours researching online, possibly drifting aimlessly, rather than thinking critically about the design challenge at hand.

### ***Design Thinking***

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" (National Academy of Engineering, 2004, p. 7). Specifically, "Americans are poorly equipped to recognize, let alone ponder or address, the challenges technology poses or the problems it could solve" (Pearson & Young, 2002, pp. 1-2). 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” (Pearson & Young, 2002, p. 18).

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” (Pearson & Young, 2002, p. 58). Sheppard, Macatangay, Colby, and Sullivan (2009) stated that “engineering design involves a way of thinking that is increasingly referred to as *design thinking*: a high level of creativity and mental discipline as the engineer tries to discover the heart of the problem and explore beyond the solutions at easy reach” (p. 100). This study will identify 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” (p. 108).

### ***Operationalizing the Construct of Design Thinking***

While design thinking is an elusive and difficult construct to define, measurements for this study were a pertinent subset of measurements consistent with previous literature, much of which was generated through work of the Center for Engineering Learning and Teaching (Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Kilgore, & McKenna, 2008; Morozov, Yasuhara, Kilgore, & Atman, 2008; Mosborg et al., 2005; Mosborg et al., 2006b). In this study, measurements included:

- Solution quality
- Time spent developing a solution
- Time allocated to gathering information
- Number of information requests
- Identification of categories of information requested

### ***Methodology***

A quasi-experimental design was implemented where two groups of students were identified. One group of students had internet access during the design session while the other group did not. All other variables and student demographics were held constant to the best of the research team’s abilities. Students were presented with a design problem and provided three hours to develop a solution while “thinking aloud”.

### ***Sample***

A sample size of sixty was used in this study, which yielded thirty students per group. Students volunteered from six schools spanning four states. The schools selected to participate had a

recognized engineering program associated with an outreach effort by a university engineering program. Four universities were involved in identifying the six target schools. Curricular offerings at the high school included Project Lead the Way, EPICS High and locally developed courses supported by their regional University.

Teachers at the target schools permitted advertising to their students. Students in this study were representative of experienced students having taken most or all engineering related courses at their high school. Students were recruited who were actively engaged in the study of engineering design through a criterion sampling strategy (Creswell, 1998) using the following criteria:

- The high schools will 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 will participate in design activities which engage their critical thinking and problem solving skills within the framework of the engineering design process.
- Students will be selected who represent diverse backgrounds and have chosen to enroll in this sequence of courses.

### ***Instrumentation***

***The playground problem*** has been used in multiple studies and can be traced to Dally and Zang (1993) They identified the need for project driven approaches in the freshman engineering design course to increase student performance and retention Project driven approaches situate student learning of abstract concepts through real world applications in an experiential activity. In the original activity, students designed a swing set with slides and seesaw. Atman, Chimka, Bursic and Nachtmann (1999) revised the foundational work of Dally and Zang to create a playground design problem. In this challenge, 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 (2005) 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 (2006b) compared groups of freshman and senior engineering students with practicing engineers using data previously collected on the playground design challenge. Atman, Kilgore and McKenna (2008) 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 data for comparisons with the proposed study participants.



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 (Mosborg, et al., 2006b). The endeavor to model problem solving satisfactorily has eluded scholars across domains (Hayes, 1989; Newell & Simon, 1972; Polya, 1945; Rubenzer, 1979). 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 mere 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 (1988) 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 (2004, 2005). 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 (Mawson, 2003). As students are given more freedom and choice, they become further engaged in their own education (McKeachie, 2006; Schulz, 1991). 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 (Yair, 2000). 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 (Mosborg, et al., 2006b).

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

### ***Administration of the Design Problem***

A team of graduate and undergraduate students and university faculty conducted the data collection. A total of six students were involved with data collection efforts spanning just over one year. A lead researcher administered the problem and trained the student researchers through observation and direct participation. The researcher reviewed data collected and reflected with the students following the session. Student researchers' administration of the design problem was video recorded as part of the data collection and videos were reviewed for training purposes to ensure consistency while data collection was active.

Data included video and audio recorded design sessions. Video cameras were small, pocket sized on miniature tripods to minimize the invasive intrusion. Audio recorders were used as a backup to the video cameras and were positioned on the work space near the student. Generally, students were wired with a lavalier microphone to ensure high quality audio feeds. Students generated documents and other artifacts with traditional office supplies provided. Artifacts typically included sketches, notes, formal drawings and, in one case, a prototype solution made from torn and folded sticky notes. Two-dimensional works were anticipated by the research team and scanned to digital image form. The three-dimensional work was video recorded. Data were archived in digital format on hard drives. Drives were shared with the research team for analysis purposes.

### **Data Analysis**

The playground problem coding scheme was congruent with the approach used in prior studies (Atman, et al., 1999; Bursic & Atman, 1997; Mosborg, et al., 2005; Mosborg, et al., 2006b). Solution quality, time and information requested were considered.

### ***Solution Quality***

Data gathered from the student participants was analyzed for solution quality. Solution quality was identified in previous work as being an essential measure of the design process. In the previous work, the design session concluded with the designer presenting the administrator with their final design. This final design was assessed based on how well it met the design criteria. Consistent with the previous work (Atman, et al., 1999; R. C. Moore, Goltsman, & Iacofano, 1992), this study used a four part measurement to evaluate design solution quality:

1. The first element included seven criteria based on the constraints provided in the problem brief.
2. Moore, Goltsman and Iacofano (1992) published documentation used to assess the safety of playground designs including 33 criteria were appropriate for all playgrounds.
3. According to Moore, et al. (1992), an additional 79 criteria were specific to elements which could potentially be included in a playground. These criteria applied only if the element was included in the design. Therefore a participant would receive a score based on the elements they included and the level of appropriateness per element. As

- an example, wood should be protected from rot, but only if wood was included in the design. A student's design score would be lower if they included wood but did not consider longevity of the material.
4. The fourth element of quality included a Likert scale rubric relating of five categories: diversity of activities, aesthetics, protection from injury, uniqueness, and technical feasibility. The rubric was adopted from Atman's (1999) and was specific to elements of the designer's solution and standards for playground design.

A spreadsheet was created with each of the previous four quality elements. A pair of undergraduate students assessed the quality of the solutions and facilitated inter-rater reliability analysis. The criteria and safety considerations (elements 1, 2 and 3 above) included 119 points which were awarded on a binary scale, 0 if evidence was not presented in the data or 1 if evidence was presented that the student's design included this consideration. The fourth element (rubric) included a five point rating for each of the categories. A total quality score was presented by Atman (1999) which was calculated by averaging elements 2, 3, and 4 together. Each of these elements was weighted equally and the three were averaged to yield a total quality score, presented in this document as a comparison to previous work. A more full description of these elements and their assessment was described by Mosborg, et al. (2006b).

Solution quality measurements were coded independently by two undergraduate research assistants. Each research assistant had been involved with the data collection and, as a result, was familiar with the design task. Training and calibrating the quality and request coding was done by introducing the research assistants to the coding scheme. A few participants' data sets were reviewed together and coded collaboratively as a team. The research assistants coded one data set independently and inter-rater reliability was calculated. Discrepancies were discussed and resolved. Assistants coded the next data set and compared results. This iterative process continued until reliability values were satisfactory (about four iterations). At that point, previously coded data was re-coded and all remaining data was coded. Each assistant was assigned 30 participants for a total of sixty in this study.

Eleven of sixty participants' quality and information request data were coded by both research assistants. These data were used to calculate inter-rater reliability. Reliability was calculated as follows for the dimensions of solution quality:

Constraints: Kappa value 0.709

Playground Safety Criteria: Kappa value 0.821

Rubric Rating: Cronbach's Alpha value 0.880

## ***Time***

Time is a limited resource and how designers allocate their time in areas of the design process has been a focus of previous work. Two measurements of time were made while the designers are at work:

1. Total time engaged in design was measured from start to finish and was limited to three hours.
2. Time allocated to information gathering was measured. In previous work, time spent gathering information was critical to generating quality solutions, however, becoming stuck in the information gathering mode became detrimental. This measurement was defined as time participants spent searching for information, reviewing information requested and considering information they would request (Mosborg et al., 2006a). This time did not include reading the problem statement.

Data were independently analyzed for time by two coders. Each coder was responsible for approximately 30 participants. While pairs of coders were compared on this data set, analysis spanned a duration of one year and involved three different pairs of raters. Training was conducted by introducing the coders to the coding scheme as outlined by Mosborg, et al. (2006a). Training on coding was done in an iterative fashion where each participants' data were coded independently and compared. Coders then negotiated to consensus and documented their improved understanding. This iterative calibration went through multiple cycles before Kappa values were satisfactory. One pair of raters reviewed 16 participants, overlapping for comparison purposes on 25% of the time with a Kappa value of 0.809. A third coder was hired and compared to one of the previous coders. The Kappa value for this comparison was 0.939, representing 25% of the data set and the third coder coded approximately 14 participants. A fourth coder was hired and calibrated with the third for the remaining 30 participants. Their average Kappa value on 25% of the data set was 0.950.

## ***Information Requests***

The data were coded for "gathering information" as presented by Mosborg et al., (2006b, p. 15). The gathering information element of the design process was one of nine elements considered in the previous foundational work and included students looking for information to help them solve the problem. Coding included what information was requested by the participant and at what point in time. Also consistent with prior research, the following categories of information were available for participant request (Mosborg, et al., 2006b, p. 21): budget, information about the area, material costs, neighborhood opinions, utilities, neighborhood demographics, safety, maintenance concerns, labor availability and costs, legal liability, material specification, supervision concerns, availability of materials, body dimensions, disabled accessibility, technical references, and other information.

Within these categories, specific detailed information were available upon request, and participants' requests for this information provided researchers with data regarding problem scoping and definition techniques employed. "Question asking while designing is influential to the cognition of designers. It is related to the cognitive aspects of their problem solving, creativity, decision making, and learning processes, and, consequently, to their overall performance" (Eris, 2004, p. 11). In addition to paper based information available upon request, the internet group had a Google search browser launched on a laptop computer at their worktable. Participant information gathering behaviors were coded regardless of source (digital or paper based) for each group. Adopted from previous literature, (Mosborg, et al., 2006a, pp. 11-14), information requests were coded into the following categories, with one exception added by this research team, which was "Image Searches":

1. AGE - Statements addressing the "1-10 years of age" constraint.
2. OCCUPANCY - Statements addressing the "12 children kept busy" constraint.
3. ACTIVITIES - Statements addressing the "at least 3 activities" constraint.
4. SAFETY - Statements addressing the "safe for children" constraint.
5. HANDICAPPED ACCESSIBILITY - Statements addressing safety or accessibility for persons with disabilities.
6. SUPPLIER - Statements addressing the "use material available at any hardware or lumber store" constraint.
7. SCHEDULE - Statements addressing the "ready in 2 months" constraint for constructing the playground
8. equipment.
9. CLARITY - Statements addressing the "explain your solution as clearly and completely as possible"
10. constraint. Includes statements about making instructions or diagrams for the people building the playground.
11. BUDGET - Statements about the amount of money available for the project.
12. MATERIAL COST - Statements about the cost of specific materials.
13. MATERIAL COST and BUDGET - Statements about the cost of specific materials with respect to budget or affordability.
14. LABOR - Statements about workers for the project.
15. MATERIAL TYPE - Statements about the general type of material needed (e.g., wood, 2x4's, steel, screws, nails, paint).
16. MATERIAL SPECIFICATIONS - Statements about technical material requirements.
17. TECHNICAL REFERENCE - Statements about technical construction requirements.
18. DIMENSIONS - Statements about the specific measurements (typical, ballpark, or actual) of playground
19. equipment, layout, or the lot.
20. BODY DIMENSIONS - Statements about human body size(s).
21. NEIGHBORHOOD AREA - Statements about the location of objects in the area surrounding the lot.
22. DEMOGRAPHICS - Statements about the composition of the neighborhood population.

23. OPINIONS - Statements about stakeholders' reactions to the proposed playground, or their preferences for equipment or activities.
24. NEIGHBORHOOD CONDITIONS - Statements about other conditions of the area.
25. PARK AREA INSIDE THE LOT - Statements about the lot's characteristics or layout.
26. UTILITIES - Statements about gas, water, or power lines.
27. FACILITIES - Statements about playground facilities such as bathrooms, night lighting, or water fountains.
28. MAINTENANCE - Statements about property or equipment maintenance for the playground's operation.
29. LEGAL - Statements about liability for potential injuries or accidents.
30. SUPERVISION - Statements about looking after children during playground hours.
31. IMAGE SEARCHES – (introduced by this research team) – related to students searching for pictures of playgrounds or related topics to look at.

Information requests data were assembled into a spreadsheet which included the request made by the participant and time of request. When the request was verbal to the administrator, the information requested was documented by the administrator. When the request was made via computer on the internet, the search term and resulting websites visited were recorded by a software application running in the background called *Spector Pro*. Each undergraduate coder was responsible for 30 participants. Eleven of the sixty were reviewed by both coders to permit inter-rater reliability to be computed. Coders were instructed to document purposeful information requests. They attempted to count only unique information requests which meant they had to segment multiple requests together in some instances and code as one request. For example, if a student was searching for the cost of a 2x4 and searched an online retailer, a second online retailer, a classified advertisement online and requested this information from the administrator, the individual actions were grouped and counted as one information request about the cost of a 2x4. Coders reviewed the spreadsheet of information requests and watched the video to code the data situated in context. Spreadsheets from each coder were aligned for training purposes and compared line by line. Coders tallied total requests for each of 31 categories. Total requests are reported here and were used to calculate inter-rater reliability with a Cronbach's Alpha: 0.850.

## **Results**

Data were coded for this study and assembled into a spreadsheet for quantitative analysis. SPSS version 18 software was used to generate mean and standard deviation data comparing the two groups of participants (one with internet access and one without). Independent samples T-Tests were used to compare mean scores for each of the comparisons. A Levene's Test of Equality of Variances was used to determine if T-Tests for equality of variances should be assumed or not. Four tables are presented here relative to the research question and, where appropriate, draw a comparison to Atman's (2007) work and collegiate freshman data.

### ***Solution Quality***

Solution quality included four measurements: Constraints met, safety criteria for all playgrounds, design element specific safety criteria, and rubric ratings. Of the seven constraints presented in the design brief, both groups averaged meeting just under 4 of the 7 with no statistical difference between group means. This is, on average, 1 constraint less than college freshmen. The overall safety criteria score was generated by adding the criteria for all playgrounds with the element specific criteria and dividing by the total possible criteria score (with each designer’s specific elements) to get a score out of 1. The internet access group had a slightly higher mean score, but no significant differences existed between groups. The rubrics measured five categories: diversity of activities, aesthetics, protection from injury, uniqueness, and technical feasibility. The rubric scores were averaged per participant and compared. Students without internet access had slightly, but not statistically significantly higher mean scores. The quality score included an average of design criteria scores and rubric scores, weighted equally, and presented out of 1. The no internet access group scored slightly higher, but differences were not statistically significant. Both high school groups scored lower than college freshman with approximately 0.30 as compared to 0.45. Solution quality indices are presented in Table 1 as mean scores with standard deviation in parenthesis and independent samples T-test significance values are shown.

Table 1. Solution Quality

	High School		T-test (2 tailed) Significance	College Freshman
	Internet Access Group n=30	No Internet Access Group n=30		Atman (2007) n=26
Constraint Score (out of 7)	3.967 (1.63)	3.967 (1.19)	1.000	5.0 (1.1)
Safety Criteria for all playgrounds (out of 1)	0.222 (0.09)	0.224 (0.07)	Not tested	
Design element specific safety criteria (out of 1)	0.132 (0.13)	0.0924 (0.07)	Not tested	
Overall safety criteria score (out of 1)	0.182 (0.07)	0.170 (0.05)	0.422	
Rubric (out of 5)	2.640 (0.83)	2.920 (0.93)	0.222	
Quality score (Design criteria scores and rubric, weighted equally – out of 1)	0.294	0.300	Not Tested	0.45 (0.1)

Note: Standard deviations are in parenthesis.

## ***Time***

Two measurements are presented related to time: Total design session duration and time allocated to information gathering. Students with access to the internet spent significantly more time engaged in the design process with a mean of 139 minutes as compared to students without internet access whose mean was 90 minutes. Most of the difference in design session duration was explained by the additional time allocated to gathering information. The internet access group allocated significantly more time (mean of 42 minutes) to gathering information as compared to the group without internet access (mean of 10 minutes). The mean non-internet access group was higher than the college freshmen but less than high school students with internet access. Table 2 presents mean values for the number of minutes engaged in the design session and information gathering, standard deviation shown in parenthesis, significance test probability values and a comparison to college freshman.

Table 2. Minutes Spent Designing and Allocated to Information Gathering

	High School			College Freshman
	Internet Access Group n=30	No Internet Access Group n=18	T-test (2 tailed) Significance	Atman (2007) n=26
Design Session Duration	139 (44)	90 (56)	0.002*	104 (41.0)
Information Gathering	42 (22)	10 (13)	<0.001*	13.8 (12.6)

Note: \* Denotes statistically significant difference at the 0.05 level. Standard deviations are in parenthesis. Also note that at the time of this publication, only 18 of the 30 students times were analyzed. A revision is pending will be replacing this document soon.

## ***Information Requests***

Both groups had access to paper based information by requesting it specifically from the administrator but only one group had internet access. Each request for information was documented and the groups were compared. The group with internet access requested significantly more information with a mean score of 16.7 pieces of information as compared to the groups without internet access with a mean of 3.7 pieces of information per student. Students with internet access requested more different kinds of information measured by spanning multiple categories. Thirty-two categories were identified including a category of “other”. An information request fell into the “other” category when it did not fit into the previous 31 categories or the data analyst could not figure out which category was most appropriate because the request was vague. The group without internet access was most comparable to the college freshman, but they requested less information spanning fewer categories. Table 3 displays mean



numbers of information requests and categories spanned, significance values for the independent samples T-tests and a comparison to collegiate freshman.

Table 3. Information Requests and Information Categories

	High School			College Freshman
	Internet Access Group n=30	No Internet Access Group n=30	T-test (2 tailed) Significance	Atman (2007) n=26
Information Requests	16.7 (8.7)	3.7 (5.0)	<0.001*	11.4 (10.1)
Categories	7.0 (2.6)	2.0 (2.2)	<0.001*	3.4 (2.9)

Note: Standard deviations are in parenthesis. \* Denotes statistically significant difference at the 0.05 level.

Information requests were categorized and the mean number of requests per student was identified for each category. Table 4 presents the mean and standard deviation data for both groups in this study for each category. Statistically significant differences are considered at an alpha of 0.05. Material costs were requested more than any other category of information for both groups and significantly more among the internet access group compared to the no internet access group.

Table 4. Mean Requested Pieces of Information per Student by Category:

	Internet Access Group n=30	No Internet Access Group n=30	T-test (2 tailed) Significance
Material Cost	6.57 (5.1)	1.67 (3.0)	<0.001*
Other	1.33 (1.4)	0.33 (0.8)	0.001*
Activities	1.30 (1.4)	0.00 (0.0)	<0.001*
Dimensions	1.27 (1.1)	0.07 (0.4)	<0.001*
Disabled Accessibility	1.00 (0.5)	0.60 (0.6)	0.006*
Material Type	0.87 (1.8)	0.07 (0.3)	0.023*
Image Searches	0.80 (1.2)	0.00 (0.0)	0.001*
Material Specifications	0.63 (0.8)	0.10 (0.4)	0.002*
Budget	0.57 (0.6)	0.23 (0.4)	0.013*
Safety	0.53 (1.0)	0.13 (0.4)	0.046*
Technical Reference	0.37 (0.7)	0.03 (0.2)	0.019*
Neighborhood Area	0.27 (0.6)	0.10 (0.4)	0.233

Demographics	0.17 (0.7)	0.07 (0.4)	0.464
Body Dimensions	0.17 (0.4)	0.07 (0.3)	0.235
Clarity	0.13 (0.4)	0.00 (0.0)	0.103
Labor	0.13 (0.4)	0.00 (0.0)	0.103
Opinions	0.13 (0.4)	0.10 (0.4)	0.732
Neighborhood Conditions	0.13 (0.4)	0.00 (0.0)	0.043*
Maintenance	0.10 (0.4)	0.00 (0.0)	0.184
Utilities	0.07 (0.3)	0.03 (0.2)	0.561
Supplier	0.07 (0.3)	0.03 (0.2)	0.561
Facilities	0.03 (0.2)	0.00 (0.0)	0.326
Legal	0.03 (0.2)	0.00 (0.0)	0.326
Age	0.00 (0.0)	0.00 (0.0)	1.000
Occupancy	0.00 (0.0)	0.00 (0.0)	1.000
Schedule	0.00 (0.0)	0.00 (0.0)	1.000
Material Cost and Budget	0.00 (0.0)	0.00 (0.0)	1.000
Park Area Inside the Lot	0.00 (0.0)	0.07 (0.3)	0.161
Supervision	0.00 (0.0)	0.00 (0.0)	1.000

Note: Standard deviations are in parenthesis. \* Denotes statistically significant difference at the 0.05 level.

### ***Discussion and Implications***

Students provided with internet access used this resource. As measured by time, they spent significantly more time searching and they made significantly more information requests. The additional effort measured by time and requests did not impact solution quality. Solution quality was measured by number of constraints addressed, expert playground design criteria addressed and a series of rubric scores and there was no statistical or practical difference between the groups.

Engineering design challenges provide a context for students to engage with the material, but are time consuming. These data suggest providing internet access is not an efficient tool in the design process. Students requested substantially more information regarding costs of materials than any other category. This pattern was consistent among both groups, but the number of requests were dramatically greater for the internet access group. While costs are an important consideration in the design process, they are not the only consideration and investigating cost did not have measurable impacts on the solution quality.

Access to information via the internet is ubiquitous in the workplace and a rich resource. On the surface these data suggest internet access was a waste of time relative to its negligible impact solution quality. Students had little difficulty navigating the internet as a source of information, but it had no impact on their solution quality. Elements such as the end user of the solution,

community where the solution is situated, transportation of materials to the site, communication with the builder about the solution, and maintenance were seldom considered.

The implication of this work may be that students do not know what information is most helpful in developing a good quality solution. They have access to an unlimited information resource, but don't take advantage of much more than material cost. One student of the sixty considered the constraints and asked for information: "What does this community consider safe?" While other students read the requirement for safety, it was only one student who treated this requirement as more than just a superficial check off. He recognized that safety was a continuum and playgrounds could be more or less safe, not just "safe" or "not safe". Students frequently drew on previous experience, which is consistent with the work of King and Kitchener (1994). Student memories of personal experiences may have influenced their thinking and may have been the substantial source of information in their work but was unmeasured by this study.

Engineering design should consider a systems level approach to solutions. Few students requested information about the social, political, environmental, geographic, or historic conditions related to the playground location. This lack of requests was perhaps a measure of a more significant concern about problem definition. Student understanding of the problem was not measured, but these data highlight a potential concern that students did not fully comprehend the problem at hand. Low quality solutions could be a result of a poor exploration of the problem. Problem definition was not measured as part of this study, but was considered in the pilot study for the DRK-12 project titled, *Exploring Engineering Design Knowing and Thinking as an Innovation in STEM Learning* (Mentzer, Becker, & Park, 2011). According to their study, high school students spent 3.14 minutes, just over 1/3 of the time spend by experts.

Students were asked to develop a solution that could be built without requiring the designer answer any questions. The extent to which a builder would be ready to order materials and begin construction was not quantitatively measured, but in a general qualitative consideration, few student designs could be built. Most were messy, disorganized, and incomplete. One student commented that she did not need to gather information about material strengths because the builder would follow her design during the construction phase. The builder would then test out the design by climbing on the playground equipment, if it broke, the builder would rebuild the equipment using stronger materials. If the equipment did not break, it would be ready for public use. This student, representative of more than one-half the participants, never asked for a budget. Questioned afterwards about how she met the constraint about "not costing too much" she confidently stated that all the materials for her design were available at the local hardware store, and "everybody knows nothing at the hardware store costs too much". Her reflection suggested that she was thinking about costs and budget even though she had not requested this information directly.

## ***Future Research***

Consistent with previous literature, this study investigated the information requests of student designers. Immediately evident in the data analysis phase was an unplanned opportunity which the research team was not prepared to exploit. Students made requests for information, but in both groups (internet and no internet), students discovered and used more and different information than they had initially been looking for. The concept of measuring information *discoveries* may be a value for future research as it impacts student thinking. As an example, one student initially searched for pictures of playgrounds (categorized as images searchers). In reviewing the pictures, she accidentally discovered a need for maintenance. The maintenance document online was used to guide her material selections (she avoided wood because it might splinter). The maintenance information had related links to safety which lead her to consider fall heights based on equipment design. The allowable equipment height was related to surface materials and this pushed her to specify soft surface materials in target areas around equipment. The research team believed these were serendipitous discoveries that would not have been considered if they had not appeared on the computer screen as related links to the original search. This project did not permit a detailed investigation of information discoveries, but the research team noted a series of related discoveries based on a single information request as a consistent theme. It seems feasible to investigate information discoveries as a web of interconnected elements, similar to concept mapping in future work.

Further research should investigate problem definition more deeply. Students' understandings of the problem were questionable and could be the reason solution quality was low and additional information requests minimally impacted solution quality. While previous work investigated the amount of time a student spent on the problem definition, perhaps future work could investigate the extent to which students understand the problem. Time is a proxy for effort spent considering the problem, but it may be un-calibrated in younger learners as they are not familiar with the full breadth of considerations appropriate to the engineering design process. Conducting formal interviews after the design process might provide an opportunity to provide insight on student understanding of the problem.

Classroom observation data combined with an investigation of curriculum used in the classroom may provide insight as to the treatment of problem scoping in the design process. Students in this study may have limited experience in investigating the problem, these data were not collected. A formal curriculum review could lend insight to the procedures and methods expected of students as they engage in the design process relative to information gathering. Student may not be coached on how to identify relevant information while developing their solution.

## ***Summary***

Sixty students were presented with a design challenge. Thirty of these students had access to the internet and the other 30 did not. Both groups were asked to think aloud while attempting to develop a solution individually within a three hour time limit. Students represented six states

geographically distributed across the U.S. Solution quality was measured consistent with previous literature. Students with access to the internet spent substantially more time developing a solution, but their solution was of similar quality to the group who did not have access to the internet. The group with internet access made more information requests in more varied categories and spent more time doing so. Further research should investigate a potential concern which emerged during the data analysis regarding student understanding of the problem. If students failed to fully understand what they were asked to do, they may have just drifted aimlessly through relevant information without knowing how to use it efficiently.

### ***Acknowledgements***

This material is based on work supported by the National Science Foundation under Grant Number ESI-0426421. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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