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Keywords

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This study measured the information gathering behaviors of high school students who had taken engineering design courses as they solved a design problem. The authors investigated what types of information students accessed, its quality, when it was accessed during the students' process, and if it impacted their thinking during the activity. Students overwhelmingly relied on internet searching to acquire information, rather than printed materials available to them. The sites they found were generally popular rather than technical, and persuasive (i.e., trying to sell something) rather than informative. The high school students understood the need for information, as they sought a large volume of information, which they did, generally, incorporate in their solution development process, but their skill in locating high-quality information was relatively poor.

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Introduction

The Standards for Technological Literacy require that to be technologically literate, students should develop an understanding of design. The International Technology and Engineering Educator's Association published the Standards in 2000, which has become the guiding document for the field of K-12 technology and engineering education, specifying standards and developmentally appropriate benchmarks. According to the Standards document, design includes identifying and defining a problem, researching the problem, generating ideas for a solution, selecting an idea, modeling, testing, and reevaluation in an iterative fashion (International Technology Education Association, 2000, p. 6). In most of these phases of design, information literacy is a critical tool. Information literacy is also critical in developing transferable knowledge and skills in the 21st century according to the National Research Council (Committee on Defining Deeper Learning and 21st Century Skills, 2013). Ennis and Gyeszly (1991) concluded that gathering information is an essential element of the expert designers' approach to problem solving and that generation of ideas is influenced by access to and use of 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

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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). Mentzer (2013) showed that in a sample of 60 high school students working on a design problem, access to the internet (in addition to paper-based information resources) extended total design time and increased significantly the amount of information accessed. However, the additional information accessed did not improve solution quality. The authors hypothesize that high school student designers spending additional effort accessing information might not be positively impacting their solution quality because the information may not be of high quality.

Information Literacy in K-12

For high-school students, literature on information literacy suggests the *Big 6* by Eisenberg and Berkowitz (1990) provide a standard framework for assessing information literacy skills of students. The *Big 6* consist of Task Definition, Information-Seeking Strategies, Location and Access, Use of Information, Synthesis, and Evaluation. Task Definition involves determining what the information problem is and identifying what information is needed to address that problem. This can also be described as determining a well-defined research question. Information-Seeking Strategies refer to the identification of the types of resources that might be appropriate to consult (reference works, web sites, books, articles, blogs) for the particular information need, including the strengths and weaknesses of those information sources. Location and Access refers to actually connecting to the information sources identified in the Information-Seeking Strategies phase, including using appropriate search terms to locate relevant information quickly. Use of Information involves reading the material and extracting the relevant pieces of information to apply to the information problem, including using appropriate note-taking techniques and documentation of sources. Synthesis requires students to organize and integrate information from different sources and assemble the information into some final statement/presentation that communicates what was learned about the problem. Evaluation in this context is a reflective step, asking students to determine how effective the final product was in answering the information problem and how efficient the process was in getting to the solution.

The Information Search Process developed by Carol Kuhlthau (2004) provides a conceptual, research-based, framework for information-seeking behaviors. Kuhlthau described the research process as containing the following steps: Initiation, Selection, Exploration, Formulation, Collection, Presentation, and Assessment. Each stage is characterized by Thoughts, Feelings, and Actions, as the students move from a vague idea of the nature of the problem to a more focused idea, from feelings of uncertainty, frustration and doubt, to confidence and clarity (or dissatisfaction), and from the search for relevant information to the search for pertinent information (i.e., finding any information related to the problem, to finding information that will fill holes in knowledge). Holliday and Li (2004) found that the ease of access to internet sources, allowing students to get "some" results without having a well-formulated search strategy, enables them to skip steps in the Information Search Process. This, however, leads to lower quality resulting products, as students have not engaged deeply with the problem and rather plug in whatever results they get that superficially match the assignment parameters.

The Association of College and Research Libraries Information Literacy Competency Standards for undergraduate students, similarly focus on students' ability to determine an information need, locate relevant information, evaluate its quality, and to apply it appropriately and ethically (Association of College and Research Libraries, 2000). The Association of College of Research Libraries standards provide more emphasis on evaluation of source quality and relevance of information to the problem, but otherwise, mastering the *Big 6* in K-12 transfers to expectations for information literacy in higher education.

Although many of the facets of the *Big 6* were beyond the scope of this project, the authors were able to investigate the quality of sources found by students, the variety of sources used, and the purpose of consulting those sources. To that end, the authors were able to identify limitations of the students' ability to search and find appropriate and relevant information to their design projects.

Information Literacy and Design

As students work through stages of the design process, information access is essential to creating a successful solution to an engineering design problem (Bursic & Atman, 1997). Students need to find information beyond their current experiences as they identify and define a problem. In this study, students were presented with a playground design problem. Although many students have experienced playgrounds before, information about the community, climate, materials available, and many other aspects of the problem need to be researched in order to come up with an appropriate final solution. Students may search for information regarding the significance of their problem such as statistics related to playground injuries, demographics on playground users, and parents' concerns regarding safety. As students generate ideas for their potential solutions, understanding current existing solutions may help foster improvements and innovations on existing work. Gathering information on materials and processes required to make solutions possible provides more authentic opportunities to evaluate solutions.

Research has been conducted on the collegiate level to understand student information gathering efforts in engineering contexts (Adams, Turns, & Atman, 2003; Atman et al., 2007; Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Kilgore, & McKenna, 2008; Cross, Christiaans, & Dorts, 2007). In a study by Mosborg et al. (2005), 19 engineers with an average of 19 years of field experience were given a list of 23 words and phrases related to design activities and asked to pick which they thought were the six most important. More than half of the participants stated that seeking information was one of the top six activities. A related study was conducted by the University of Washington in which 178 college level engineering students were provided the same list and were asked to complete the survey. Approximately one-third of the students stated that seeking information was one of the most important aspects of design (Morozov, Yasuhara, Kilgore, & Atman, 2008).

Information Gathering in High School Design

Research conducted on the high school level situated technology and engineering students as designers in a three-hour design task (Becker, Mentzer, & Park, 2012; Mentzer, Becker, & Park, 2011). The pilot study (2011) included 16 participants who were seniors and had taken a series of engineering design courses. Students were provided access to paper-based information accessible through the activity administrator and a computer connected to the internet. Results showed that students engaged in information access for an average of 47 minutes during the average of 137 minute design sessions for a total of 35% of their time. In the main study (2012), students were provided with access to paper-based information (but not the internet). The 59 students spent an average of 92 minutes engaged in developed a solution to a design problem and approximately 10 minutes (10%) accessing information. Student preference for the internet-based information may be attributable to comfort or convenience, as the computer was sitting on the table and students may be more comfortable searching than asking an administrator. However, this barrier was minimized by the research team spending approximately 30 minutes prior to the design problem introducing students to the research study, providing food and administering a short survey. In addition, the research team practiced requesting a piece of information with the students to initiate the problem session by ending the design task introduction with the statement, "if you'd like a diagram of the lot, you may ask for it now." If a student did not ask for the lot diagram following this prompt, they were prompted again with more emphasis on the phrase "you can ask for it now" so that participants understood the procedure. As additional encouragement for participants to ask for information, the stack of paper was placed within student view on the desk between the participant and the administrator. This preference for internet searching over administrator-provided information is in line with recent findings that professional engineers have started using internet searches as a "first-resort" method of finding information in addition to their traditional use of colleagues and personal collections (Allard, Levine, & Tenopir, 2009; Hirsh & Dinkelacker, 2004).

Pieper and Mentzer (2013) investigated information gathering habits of a subset of the Mentzer and Becker 2011 pilot DRK12 study to investigate student use of paper-based versus internet-based information access. Their work showed that in a small sample ($n=12$) students spent about 10% of their design time accessing information from paper-based sources and about 29% of their time using the computer to access information. Information from the administrator was generated consistent with previous research and included nearly 100 pieces of relevant information ranging from costs to material properties and from children's playground preferences to climate and neighborhood demographics. While this relevant information was available, the Pieper and Mentzer study showed that students requested an average of 8 different paper-based pieces of information from the administrator and 12 pieces of information via the internet. Pieper and Mentzer suggested that students spent triple the amount of time accessing information online, but the yield was not even double the number of different pieces. Their work showed that nearly half of the information accessed was material cost related.

Mentzer (2013) analyzed solution quality between students with ($n=30$) and without ($n=30$) access to the internet and found no significant or practical difference. Students in both groups met an average of 4 out of 7 of the constraints contained in the design brief as compared to first year undergraduate engineering students, who averaged meeting five of the constraints. Students with internet access spent considerably longer in the design process with an average time of 139 minutes as compared to 90 minutes. Specifically, the internet access group spent 42 minutes accessing information, whereas the group with access limited to paper-based resources only spent 10 minutes accessing information. Design quality was measured by the design's satisfaction of the Consumer Product Safety Commission criteria for safe playgrounds. On average, students with internet access met 0.182 of the criteria for safe playgrounds or about 1 in 5. This result is very similar to the group without internet access, in which the students met 0.170% of the criteria (roughly 1 in 6). Information gathering categories covered by both groups were similar in that they both investigated material costs, budget, materials specifications, technical information, and other categories. Differences primarily were in the volume of information gathered. Materials cost was most popular with nearly seven pieces requested per student with internet access and two pieces per student without internet access.

Although time spent accessing information on the internet indicates students are making efforts to search and use information related to their problem and solution, it appears to provide no advantage in the final solution. The primary purpose of this paper, then, is to determine the types and quality of information gathered by students, to help determine why access to internet resources did not increase quality of solution, despite longer time on task. Although determining quality of an information source is a complicated process and contingent on the specific needs of the searcher, common characteristics of sources can be characterized. According to the Association of College and Research Libraries (2000) Standard Three, Performance Indicator Two, students can determine information quality by evaluating "reliability, validity, accuracy, authority, timeliness, and point of view or bias." Metzger (2007) reviewed studies of how students determine credibility of web sites, and found they evaluated credibility of web sites somewhere between "rarely" and "occasionally," with currency, comprehensiveness and objectivity the most evaluated facets. Checking authority or verifying information was done least often. In short, evaluations of facets that are easiest to accomplish (for example, whether the information is current enough) were most likely to be carried out, whereas activities that would take longer were neglected. Scholz-Crane (1998) used a content analysis method to determine that students used mainly scope and accuracy to determine web site quality, ignoring authority and potential bias. Many of these facets are more subjective or difficult to assess, or are highly contextualized within the scope of the information problem itself, and thus are not able to be assessed easily by the investigators. However, Wertz, Fosmire, Purzer, and Cardella (2013) provided a scalable method for characterizing information quality in a written document by breaking down information quality into facets of Source Type, Intended Audience, Purpose, and Relevance. These facets are fairly objective, but can provide insight into the characteristics of reliability, validity, accuracy, and authority. The facet of Purpose directly maps to the Association of College and Research Libraries (ACRL) category of "point of view or bias."

Research Question

The research question driving this study was "To what extent do high school students access and use high-quality information while engaged in design problems?" This question is operationalized into seven specific questions which are consistent with previous literature (Wertz et al., 2013):

1. What sources do students access?
2. What content are students searching for?
3. Who is the intended audience of the information?
4. What was the author's intent?
5. What was the purpose of the student investigation?
6. Did students consider the information they accessed?
7. When was information accessed in the design process?

Methods

Data Collection

This study was descriptive in nature as it investigated student information gathering behaviors in a naturalistic environment and describes the work of the students. Quantitative and qualitative data were reviewed and coded in a categorization scheme to provide quantitative data describing the information and information sources students accessed while they worked on developing a solution. Data used for this study were gathered as part of a larger National Science Foundation funded DRK12 studytitled, "Exploring Engineering Design Knowing and Thinking at an Innovation in STEM Learning," and a smaller study funded by the National Center for Engineering and Technology Education titled, "Engineering Design Thinking and Information Gathering." In this work, (Becker et al. 2012; Mentzer et al. 2011) and Mentzer (2013) identified a total of six high schools nationally which offered a series of courses on engineering design. Exemplary students who were finishing the sequence of engineering design courses were recruited for this study. Each student was provided with a three-hour design task consistent with previous literature (Atman et al., 1999, 2007, 2008).

High school students were presented with a design problem, internet access, and an administrator who managed additional information. In a lab environment, students worked individually for up to three hours, using a "think aloud" protocol (Ericsson & Simon, 1993) to develop a solution to the design problem. Verbal protocol is a tool used by researchers (Christiaans & Dorst, 1992; Ennis & Gyeszly, 1991; Guindon, 1990; James, Goldman, & Vandermolen, 1994; Rowland, 1992; Sutcliffe & Maiden, 1992) in a variety of fields including engineering and technology to document student design processes and is a method which can provide an "in-depth understanding of the processes students use to solve engineering design problems" (Bursic & Atman, 1997, p. 121). Ericsson and Simon (1993) suggested a three-step approach to conducting verbal protocol: recording, transcription/segmenting, and coding into categories. "This is a research method in which subjects think aloud as they solve problems or perform a task. The subjects' thought processes are captured on audio and/or videotape" (Bursic & Atman, 1997, p. 121). According to Ericsson and Simon, "The concurrent [verbal] report reveals the sequence of information that is heeded by the subject without altering the cognitive processes, while other kinds of verbal reports may change these processes" (1993, p. 30). Consistent with previous literature, sessions were video and audio recorded and paper-based artifacts were gathered. In addition, internet use was recorded.

The design task that was presented to students was similar to previous work (Atman et al., 1999, 2007, 2008) and included these instructions:

> You live in a mid-size city. A local resident has recently donated a corner lot for a playground. Since

you are an engineer who lives in the neighborhood, you have been asked by the city to design a playground. Any equipment you design must:

- be safe for the children;
- remain outside all year long;
- not cost too much;
- comply with the Americans with Disabilities Act.

The neighborhood does not have the time or money to buy ready-made pieces of equipment. Your design should use materials that are available at any hardware or lumber store. The playground must be ready for use in 2 months.

Students were asked to think out loud and provided with an example of what it means to verbalize thoughts as they occur. At the conclusion of the problem statement, students were prompted that additional information is available about the problem including a lot diagram and they could ask for it now. This practice request was unique in that students were not prompted again to request information, but positioned at the start of the problem to demonstrate the process of asking for information and that information was, in fact, available as stated. It was assumed that once students understood that they could ask for information, that they would feel comfortable asking for what they thought they needed while they worked. When students asked the administrator for information, they were either provided the information requested, told the administrator did not have it, or asked to be more specific. The administrator's response to an information request was first to acknowledge that they understood and then look in the packet of information. They would look through the information available, even if they knew that the requested information was not available so that students would not feel like they were off target. Administrators were friendly and welcoming of students to be more specific prior to providing information. Students would sometimes ask for very general information such as, "What information do you have about wood chips?" The administrator would respond, "Please be more specific." The student would often respond that they wanted the cost of wood chips or they wanted to know how deep wood chips needed to be to be safe or how far around a slide wood chips should be placed to protect children or the longevity of using wood chips as compared to rubber mulch. Refer to Figure 1 for a sample of administer provided information.

Data collection included a verbal protocol with video and audio recording of student design work and documentation of information access. Students worked individually after class in their school buildings to design a playground. Students in the "Exploring Engineering Design Knowing and Thinking at an Innovation in STEM Learning" DKR12 Pilot (Mentzer et al., 2011) and the "Engineering Design Thinking and Information Gathering" study (Mentzer, 2013) were provided with information access by request in paper form and a computer with an internet connection. The DRK12 study analyzed student time allocation in stages of the design process and drew comparisons between freshmen and senior high school students and expert results from previous work related to the Atman and colleagues studies, but did not investigate information literacy related to design thinking.

A subset of the two studies' data was used as a sample for this study. Nineteen participants were identified who had data archived relevant to this study which included:

1. video and audio recordings of the design session;
2. screen captures of internet use (images captured showing each click and scroll);
3. internet search term and web sites visited logged with the time of each occurrence;
4. documented information requests from the administrator.

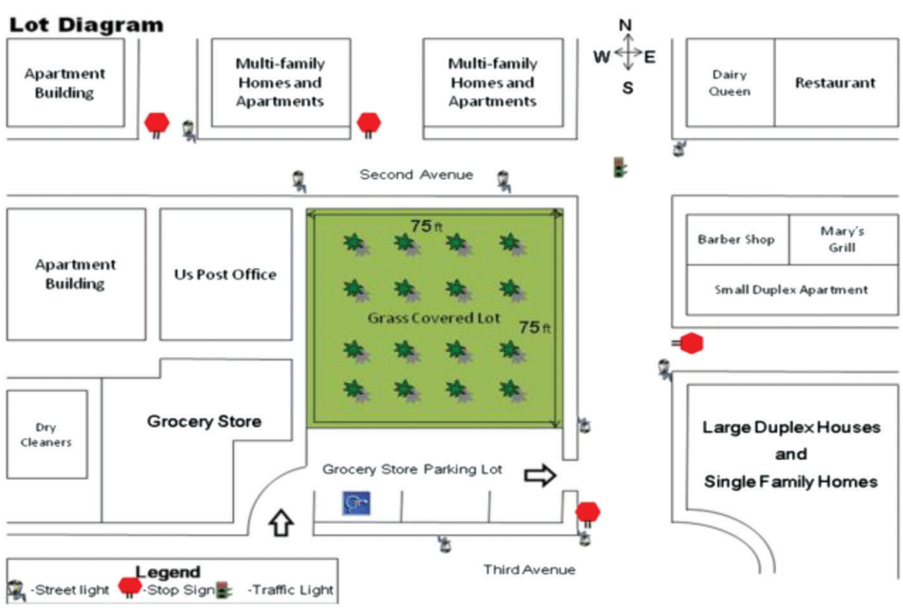

Figure 1. Sample piece of information provided by administrator.

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Coding Scheme

A coding scheme was developed a priori and aligned with the specific research questions for this study. Ericsson and Simon (1993) suggested that segmented data can be coded by words spoken (verbal signals) or by meaning (p. 62). Student access behaviors were used to create a spreadsheet log of activity and videos were reviewed to extract additional information recalled by the students. Verbal protocol added references to memory and previous experience and was analyzed for meaning. The video and verbal protocol provided a context from which to analyze each information piece accessed such that meaning could be situated in context of student design thinking rather than in isolation. Each piece of information was coded using the following scheme. Raters categorized the information pieces, if evidence existed. If evidence was not substantial and reasonable, the categories for a specific code(s) were left blank.

Information Source was predominantly defined by Wertz et al. (2013), which includes the following categories: Handbooks/Guides/Manuals, Standards, Textbooks, Encyclopedias, Technical Reports, Patents, Statistical Compilations, Newspapers, Popular Magazines, Trade Magazines, News Magazines, Journal Articles, Commercial Web Sites, News Organization Web Sites, Government Agency Web Sites (i.e., .gov), Non-Profit Organizations (.org), Scholarly Organizations (.edu), Personal Web Sites, Images and Videos, Peers, Experts, Stakeholders, Surveys, and Observations. In addition, the categories for Prior Knowledge, Prior Experience, and Direct Requests to the Administrator were added to the Wertz et al. (2013) categories, since those were unique to this study.

Information Content was based on the Center for Engineering Learning and Teaching (Mosborg et al., 2006), which defines the following categories: Cost, Dimensions, Material Type, Safety, Accessibility, Material Specifications, Technical Reference, Budget, Stakeholder Opinions, Activities, Clarifications on Design Task, Labor, Body Dimensions, Neighborhood Demographics, Neighborhood Characteristics, Lot Characteristics, Maintenance, Material Supplier/Vendor, User Age Constraint, Facilities, Neighborhood Places of Interest, Occupancy, Utilities, Legal, Supervision, and Schedule. The categories established by the Center for Engineering Learning and Teaching were used to begin the coding process. In the data analysis, additional terms were added for *examples* and *construction*. Examples were instances when students were looking for or finding existing solutions or solution elements, typically including image searches of different kinds of playground equipment. Construction refers to students investigating how something was made. Once the information requests had been sorted into the categories, the authors collapsed the results into seven related categories: Cost/Budget (Cost, Budget, Supplier, Labor), Construction Methods (Construction, Dimensions, Technical Reference), Materials (Material Type, Material Spec, Examples), Demographics/Use (Age, Occupancy, Activities, Body Dimensions, Neighborhood Demographics, Opinions), Accessibility/Safety (Safety, Accessibility, Legal, Supervision), Infrastructure/Geography (Lot Characteristics, Neighborhood Characteristics, Neighborhood Places of Interest, Utilities, Facilities, Maintenance), and Clarifications on the Design Task. Categories from Mosborg that do not appear in the seven categories are ones that students did not use.

Intended Audience for the information was defined as scholarly, technical, or popular. Scholarly information is that written for a professional audience that has some form of professional review. Journals, formal monographs, and formal reports are all examples of scholarly information. Technical information is often written for a more specialized audience, but the defining facet of this category is the focus on facts and figures. Thus, product spec sheets, standards, and handbooks are all technical sources of information. Popular information, then, is that written for a general user, with no technical background. Popular magazines, blogs, newspaper articles, and company web sites, are typically written for a popular audience.

Author's Intent was defined as informative, persuasive, or entertaining. This category was sometimes difficult to ascertain, but it was an attempt to categorize to what extent students were finding objective information rather than potentially biased sources attempting to "sell" a product, service, or advocating for a particular point of view. Entertaining sources are those such as gossip web sites or humorous sites which have almost no information content, but might provide some commentary or opinion. As an example, if a student located a home improvement store's web site, that site is trying to sell their products, so it was categorized as a persuasive source. However, if the student drilled down to a technical specification or warranty/product manual, that contained information categorized as informative. Consequently, the research team didn't just consider the base URL of a source, but investigated each web site individually, to see what information content was on that site.

Purpose of Student Investigation was categorized being primarily to facilitate: Problem Definition/Scoping, Building General Knowledge, Specific Data, Narrowing Options, Evaluation of Information, Verification of Information, Synthesis, or Presentation. These categories correspond loosely to the Information Search Process stages (Kuhlthau, 2004). The purpose of the request was contextual, based on analyzing the student's verbalization during the information request. Thus, if a student said "I need to find out what kinds of things kids play with on a playground," that was coded as Building General Knowledge. If the student wanted to know the dimensions of a tire for a tire swing, that was coded as Specific Data. This facet provided information as to the motivation for student information requests, to further pinpoint their perceived information needs.

Impact on Design Thinking was considered for each piece of information students accessed. This construct was binary and coded as yes or no (or not enough information to determine). Information coded as impacting student thinking was accessed and acknowledged by the student and processed verbally or in writing and used to inform thinking or decision making. Students might research the cost of a few sizes of lumber and discuss the cost as a determining factor in selecting one piece over another. Students might respond emotionally to the information (indicating it is impacting their thinking) such as, "Oh, wow, wood needs to be inspected annually for cracks and refinished." Information not used to impact thinking was accessed and ignored or not acknowledged. A student might be searching for safety information related to fall height from a platform and might happen to look at fall heights related to surface materials and continue the original search rather than actively considering the surface materials.

Information Access Time was defined as the time a student first started to look for a specific piece of information from a specific source. If a student began a search for information and resumed the search later, the time the search began was coded as the information access time. Each piece of information accessed was characterized by the percentage of time into the student's design process it occurred. The total time for each student was divided into 20 blocks representing each 5% interval of time on the entire task. Information pieces accessed were counted for each time block, allowing pieces of information accessed to be normalized across each student for a representation of when information was requested during their problem-solving process.

Data Analysis

In the data analysis, a spreadsheet was prepared for each participant, to permit segmenting and coding searches. The spreadsheet included columns representing the coding scheme categories and rows representing information accessed (including administrator requests, web search terms and resultant web sites visited). Rows in the spreadsheet were segmented into individual pieces of information found. Pieces of information were defined as evidence of separate topics or separate sources. Categorizing information pieces based on source is a key difference between this study and the previous Pieper and Mentzer (2013) and Mentzer (2013) studies. The second key difference between this and the two previous studies was that this study considered information accessed or requested and the previous studies only considered information requests or searches.

In the previous studies, students actively searched for information and their accidental discoveries of additional information along the way were not considered in the analysis. In this study, information accessed (intentionally or accidently) was coded. In the two previous studies, information quality was not measured and therefore searching for information from one or multiple locations was considered a single search. For this study, as an example, if a student searched a web site for both cost and material characteristics of a product, the search was considered two separate pieces of information. Similarly, if a student searched for durability of wood from two different sources, each was considered a "piece" of information for a total of two pieces so that the source quality could be judged.

Two senior undergraduate technology and engineering teacher education students (pre-service teachers) were employed to code the information gathering data. Establishing inter-rater reliability included three phases in this project. The first phase involved calibration. The second phase consisted of measuring inter-rater reliability and developing consensus on what constituted a "piece" of information. The third phase included measuring inter-rater reliability for the analysis of each piece of information.

During the calibration phase, the student researchers were introduced to the project and provided with a coding document. Collaboratively, the research team, consisting of two faculty, an information literacy and a technology education domain expert, and the two undergraduate research assistants, coded portions of a spreadsheet to provide an initial explanation of the interpretation of coding. Next, the research assistants independently coded a participant's data and compared their results. The faculty members provided oversight during the comparison to guide calibration and facilitate developing specificity of the coding document. The coding document was updated with increasingly specific definitions and examples from the data set to further define and operationalize the meaning and interpretation of codes.

After a few iterative cycles of independent coding and comparison, the research assistants' level of agreement stabilized, and the second phase of measuring inter-rater reliability began with identifying information "pieces." A spreadsheet was compiled for each participant, which included all internet search terms and resulting web pages as well as documentation of administrator information accessed. The number of pieces of information accessed by 25% of the participants (five participants, from an overall $n=19$) were coded by both research assistants and compared to measure inter-rater reliability. A percentage was generated to measure simple agreement by dividing the number of pieces identified by one rater by the number of pieces identified by the other rater (Schloss & Smith, 1999). The average of the five percentages was 81% measured on a total of 128 individual pieces of information. After independently identifying pieces of information and comparing, research assistants negotiated the discrepancies to consensus. The remaining files (14) were divided between the two raters and coded to identify individual pieces of information.

The third phase of inter-rater reliability in this study focused on coding the pieces: understanding the source, content, target audience, quality, and purpose of each piece of information and its impact on the design process. Research assistants coded each piece of information independently and compared 25% of the files. The five comparisons were made by identifying agreement in each category coded. The total number of pieces of information agreed on was divided by the total number of pieces of information for a percentage of agreement (Schloss & Smith, 1999) for each area (source, content, audience, author intent, student purpose, and impact). Six hundred and sixty pieces of information were gathered by the 19 participants. To measure inter-rater reliability for this phase of the analysis, five of these participants' spreadsheets were coded by both raters, which consisted of 132 pieces (20%) of information. Overall average agreement was 83% and considered acceptable, determined by averaging agreement in each category for the five participants compared. Agreement on source was 86%, content was 86%, audience was 90%, author intent was 79%, student purpose was 78%, and impact on thinking was 80%.

Participant Demographics

Nineteen participants were selected for this study. Thirteen participants were high school seniors, four were juniors, and two were sophomores. Students had completed an average of 4.2 technology and engineering courses. Five students were female and fourteen were male. Students were recruited from six schools representing both rural and urban settings.

Results

Sources of Information. Students were given an opportunity of asking the administrator for **pre-packaged pieces of information**, or **searching on the internet**. The **median number** of pieces of information requested was **31** (min: 0; max: 101, mean: 35). Over 70% of information pieces came from searching the internet. Ninety percent **of web sites** used by the students came from **".com" sites,** such as Lowe's or Home Depot. Table 1 displays the most accessed sources of information.

Table 1
Mean number of pieces of information per student by source of information.

	Mean (SD)
Commercial web sites (.com)	19.5 (21.5)
Administrator	9.9 (12.6)
Images or videos	1.5 (2.0)
Non-profit organizations (.org)	1.3 (1.9)
Prior experience	0.7 (1.4)
Government web sites (.gov)	0.6 (1.1)
Prior knowledge	0.6 (1.8)
Technical reports	0.3 (0.9)
Personal web sites	0.2 (0.9)
Scholarly organizations (.edu)	0.2 (0.5)
Handbooks	0.1 (0.2)
Observations	0.1 (0.2)

Information Content. Students asked for 27 different categories of information, narrowed down to seven broad themes in Figure 2. Mostly, students were **focused on the "solution" phase**, i.e., costs of materials, dimensions of materials or the layout, examples of other playground equipment and layout and construction details, **rather than "problem" focused**, i.e., demographics and use of the playground, safety or accessibility requirements, or the geography and surrounding infrastructure of the location. The mean number of pieces of information categorized by content is shown in Table 2 along with the breakdown by source (content from the administrator or content from other sources).

In almost all categories, the majority of pieces of information came from the internet, with the exception of clarifications of the design task (budget, labor, demographics) or the local geography (although only around 33% and 10% of students respectively requested these kinds of information). This makes sense, since information in those categories was created by the investigators, and doesn't exist anywhere else. For other problem-focused categories, such as safety and accessibility standards, students did consult the administrator about as often as they did the internet, which does indicate that some students are seeing an "expert" as a viable source of that type of information. Almost all of the solution focused information was sought from the internet, including the top four categories overall (cost, dimensions, examples, and material types).

Intended Audience and Author's Intent. All administrator-provided information was constructed to be technical and

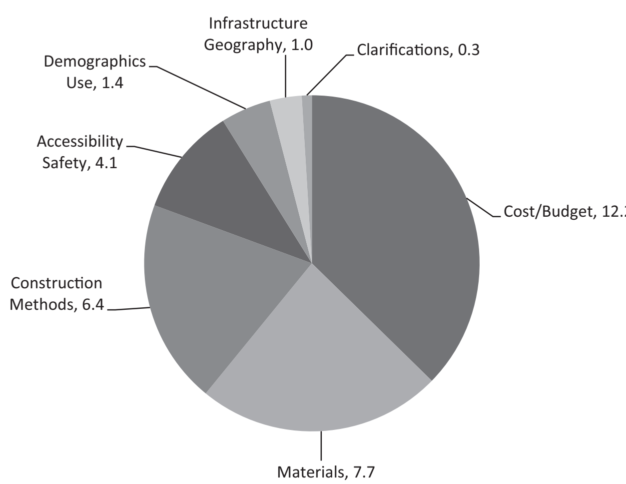

Figure 2. Mean number of pieces of information content by seven broad themes.

Table 2
Number of pieces of information requested per student by content.

	Overall	Source	
	Mean (SD)	Admin Mean (SD)	Other Mean (SD)
Cost	11.1 (11.2)	2.9 (5.0)	8.2 (10.3)
Dimensions	4.8 (4.8)	0.6 (0.8)	4.2 (4.7)
Examples of existing solutions	4.4 (4.6)	0.0 (0.0)	4.4 (4.6)
Material type	2.2 (3.3)	0.3 (1.1)	1.8 (3.2)
Safety	1.7 (2.1)	0.6 (1.0)	1.2 (2.1)
Accessibility	1.6 (1.1)	0.8 (0.6)	0.8 (1.2)
Material specifications	1.2 (1.9)	0.3 (0.9)	0.9 (1.7)
Construction	0.9 (2.3)	0.1 (0.3)	0.8 (2.2)
Technical reference	0.7 (2.2)	0.0 (0.0)	0.7 (2.2)
Budget	0.6 (0.9)	0.6 (0.9)	0.0 (0.0)
Stakeholder opinions	0.5 (0.8)	0.3 (0.6)	0.2 (0.5)
Activities	0.4 (0.7)	0.2 (0.5)	0.2 (0.4)
Clarifications on design task	0.3 (0.6)	0.3 (0.7)	0.0 (0.0)
Labor	0.3 (0.6)	0.2 (0.5)	0.1 (0.5)
Body dimensions	0.3 (0.6)	0.1 (0.2)	0.2 (0.6)
Neighborhood demographics	0.3 (0.7)	0.3 (0.7)	0.0 (0.0)
Neighborhood characteristics	0.3 (0.4)	0.2 (0.4)	0.1 (0.2)
Lot characteristics	0.3 (0.6)	0.1 (0.2)	0.2 (0.5)
Maintenance	0.2 (0.5)	0.1 (0.5)	0.1 (0.2)
Material suppliers/vendors	0.2 (0.4)	0.1 (0.3)	0.1 (0.2)
User age constraints	0.1 (0.5)	0.0 (0.0)	0.1 (0.5)
Facilities	0.1 (0.3)	0.1 (0.3)	0.0 (0.0)
Neighborhood places of interest	0.1 (0.3)	0.1 (0.3)	0.0 (0.0)
Occupancy	0.1 (0.3)	0.1 (0.2)	0.1 (0.2)
Utilities	0.1 (0.3)	0.1 (0.3)	0.0 (0.0)
Legal	0.1 (0.2)	0.0 (0.0)	0.1 (0.2)
Supervision	0.1 (0.2)	0.0 (0.0)	0.1 (0.2)

informative, and was coded as such in the analysis. The students seemed to understand the information to be authoritative, coming from the activity moderators, and did not question its veracity. As students couldn't control the quality of the information gathered from the administrator, compared to their internet searching, the internet and administrator results were separated in the audience analysis. The administrator-supplied information was tracked, since it is an indication of the students' preference for internet searching over pre-vetted information provided by an "expert." Students found predominantly popular sources, with the majority being persuasive (i.e., trying to sell a service or product), rather than informative in nature. Almost no scholarly sources were consulted. Popular materials often included Wikipedia and retailer web sites. Persuasive sources were almost exclusively retailer web sites but occasionally included other web sites with a bias such as an organization promoting playground safety or environmental protection. Of the internet resources consulted, 83% were popular, 15% technical, and 2% scholarly (refer to Table 3). Most (74%) sources were persuasive, 22% were informative, and 4% were meant to entertain rather than inform (refer to Table 4).

Purpose of the Student Investigation. Students generally sought information to gather general knowledge (how something works) or to find specific information (costs or properties of materials), activities related to the first stages of the Information Search Process (refer to Table 5). These facets made up over 88% of the information requests. Very little effort was made to help scope the problem, that is, understand the needs of the clients and stakeholders and seeking to understand the constraints. With the lack of effort scoping the problem, it is understandable that relatively few constraints were actually met when the quality of the solutions was evaluated. Students spent almost no time searching for information to verify what they gathered and did not search for any supplementary information to help evaluate information they had gathered (for example, information about the

Table 3
Mean number of pieces of information by intended audience and source.

	Administrator Mean (SD)	Other sources Mean (SD)
Popular	N/A	19.4 (20.7)
Technical	7.6 (9.0)	3.5 (4.8)
Scholarly	N/A	0.4 (0.7)

Table 4
Mean number of pieces of information by author's intent and source.

	Administrator mean (SD)	Other sources Mean (SD)
Persuasive	N/A	16.4 (21.3)
Informative	7.6 (9.0)	4.9 (4.7)
Entertaining	N/A	1 (1.7)

Table 5
Mean number of pieces of information by purpose of student's request.

	Mean (SD)
Specific data	17.0 (15.3)
General knowledge	12.1 (8.7)
Narrowing options	2.4 (4.5)
Problem scoping	0.8 (1.2)
Verification	0.6 (1.1)
Synthesis	0.1 (0.2)
Evaluation	0.0 (0.0)
Presentation	0.0 (0.0)

authors of a web site, or reviews of a product or web site). Thus, from a process standpoint, it appears students did not actively engage in assessing the quality of the information they gathered. Students also did not look for information to include in their final presentation/solution, which was not expected given the nature of the activity (i.e., generating a solution in one sitting, rather than producing a formal presentation of results).

Impact of Information on Design Thinking. Students accessed an average of 35 pieces of information and provided reasonable evidence that they considered 28 of these pieces. Four pieces of information per student (on average) were ignored and the remaining 3 pieces were difficult for coders to determine if the students considered the information in their thinking. The ratio of information considered by students to information accessed was 81%, which indicates students considered most of the information they accessed and their thinking and decision making was linked to the information accessed.

Information Access time in the Design Process. Requests for information continued throughout the design process, tailing off at about 70% of time to completion (refer to Figure 3). One peak in requests occurred at 25% and another at around 60% of time to completion. As might be expected, the bulk of information requests occurred at the beginning of the design process, as the students oriented themselves to the problem, but what is perhaps less expected is that the students continued to gather information as they developed their final designs.

Conclusions

Students do actively search for information to help inform their design decision-making processes. Students are willing to allocate time during a limited design session to searches for information. Student information searches are strongly oriented toward finding cost of materials but do include a variety of other information as well, including materials specifications, construction techniques/processes, and examples of playground equipment. Most information is related to the solution or potential solutions being considered rather than refining their understanding of the problem itself. Very little information was accessed related to users of the solution or the environment within which the solution is situated. This lack of focus on the human side of design may impact participation of a broader audience of students. The National Academy of Engineering suggested that promoting the impact engineering has on society may expand participation of a more diverse student body (National Academy of Engineering, 2008).

Students accessed very few scholarly sources and relied on commercial and persuasive web sites rather than informative or technical. Although alarming, this may be strongly correlated with their searches for costs of materials. Often costs are found on web sites selling the materials. The larger issue to be addressed is that information related to design should include far more considerations than simply the cost of a material. If students can be encouraged to look at other considerations than cost, perhaps their reliance on commercial web sites would not be so overwhelming.

These data suggest that students are not searching for broad categories of relevant information, and they are not using high-quality sources. This monolithic focus on information needed for design decisions may provide insight into the previous findings of Mentzer (2013) related to solution quality and information gathering, which suggested that information

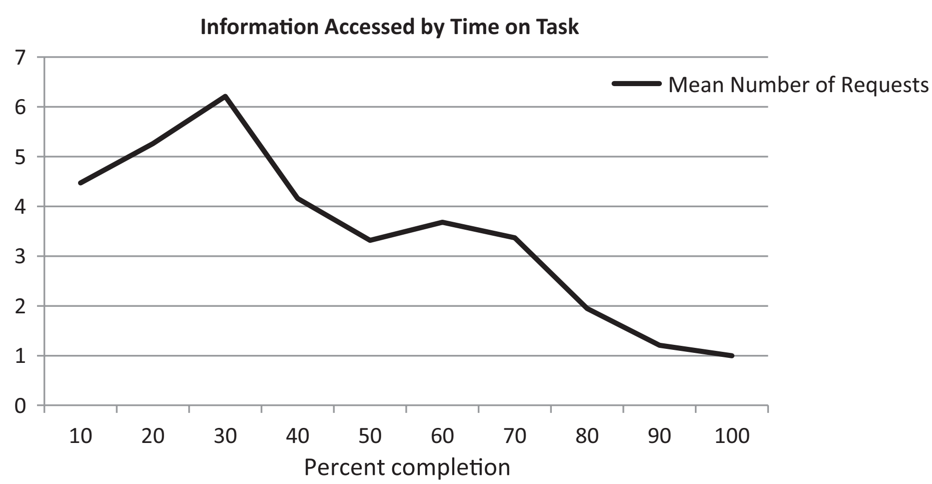

Figure 3. Pieces of information accessed by percent complete in the design process.

gathering was not correlated with solution quality conflicting with previous research the suggested the contrary (Atman et al., 2007). Thus, it may not be the amount of information or time spent with the information, but rather the breadth, relevance or quality of the information that is a determining factor influencing solution quality.

Recommendations for Future Research

We see gaps in student information literacy performance. Further research can probe different methods of improving student skill sets and attitudes toward information gathering, to see if they can be improved. Future research can determine baseline information literacy skill levels of high school students to investigate whether deficiencies are largely transfer related, or if students have never been exposed to information literacy concepts. Follow-up interviews could also be conducted to determine why students choose predominantly to search the internet instead of using prepackaged, more authoritative, information provided by the administrator. This could help clarify whether students prefer internet searching because they are more familiar with the medium, if the administrator information wasn't sufficient for their needs, if they were intimidated by the administrator, or if they wanted to let the search engine "do the thinking for them," i.e., if they couldn't articulate a research question specific enough for a human intermediary, but were willing to use a generic search and hope the results were relevant to their question.

Recommendations for Teacher Action

Instruction on the availability of higher quality information, especially information found in places other than the open web, needs to take place. In addition, instruction and curriculum materials should promote student ability to search resources more efficiently. If students are unaware of tools or sources of information, they cannot use them effectively, so including an awareness of these resources will enable them to better satisfy their needs.

Including an expectation for the acquisition of external information, and high-quality information, in assignments will also reinforce its importance in the design task. The assignment rubrics for design projects should include categories for number and quality of information sources used (Wertz et al., 2013). Furthermore, guidelines for assessing the quality of an information source, especially for web sites, and an expectation that students will use those guidelines, will help students develop habits for critically evaluating the information they do find, so they only incorporate relevant and authoritative information in their designs.

Finally, introducing students to the variety of types of project information that exist (cost, budget, geography, human factors, politics, environmental conditions, etc.) will help them understand the problem better so they can develop a more targeted and satisfactory solution. As a human undertaking, engineering design requires that a problem be solved for a particular set of user, clients, and stakeholders. Thus, neglecting this aspect of the design process limits the inspirational potential of engineering design (National Academy of Engineering, 2008). For example, providing a grid of the different facets of information and asking students to fill out a chart of what they know, what they assume, and what they need to find out will help them understand the bigger picture of what they "can" know about the problem (Fosmire & Radcliffe, 2013).

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Appendix: Coding Scheme for Student Information Requests

Raters determined the SOURCE, CONTENT, QUALITY (AUDIENCE), QUALITY (PURPOSE), and PURPOSE of the request.

Source:

Sub-Classification	Definition	Description/Examples
Monographs	Handbooks, guides, and manuals	Provides quick facts, formulas, equations, and/or procedures
	Standards	Provides standards and/or codes
	Textbooks	Provides in-depth details of specific topic or related group of topics
	Encyclopedias	Provides overview of wide range of topics
	Technical reports	Official reports published by government or public agencies
	Patents	Existing and/or pending U.S. or foreign patents
	Statistical compilations	Published data sets
Periodicals	Newspapers	For example, *New York Times, Wall Street Journal, Journal Gazette*
	Popular magazines	For example, *Good Housekeeping, People, Parents*
	Trade magazines	For example, *Engineering News Record, Contracting Business*
	News magazines	For example, *Newsweek, Time*
	Journal articles	For example, *Journal of Solar Energy Engineering, Journal of Energy Resources Technology*
Web resources	Commercial	Websites published by commercial enterprises (for example, www.ge.com, www.lightingexpert.com)
	News organizations	Web sites published by news organizations (for example, www.cnn.com, www.bbc.com)
	Government agencies	Web sites or reports published by federal, state, local or foreign government entities (for example, www.energystar.gov)
	Non-profit organizations	Web sites published by non-profit organizations (for example, www.greenpeace.org)
	Scholarly organizations	Web sites published by educational entities (for example, www.purdue.edu)
	Personal	Web sites authored by amateurs and non-experts (for example, blogs, personal webpages, etc.)
	Digital media	Digital images or videos
Internal Sources	Peers	Correspondence with peers
	Experts	Correspondence with experts
	Stakeholders	Formal interviews with stakeholders
	Surveys	Formal or informal surveys developed by teams
	Observations	Measured observations recorded by teams
	Images	Photos and/or videos taken by teams

APPENDIX
(Continued)

Content:	
User age constraint	Statements addressing "1–10 years of age"
Occupancy	Addressing "12 children kept busy"
Activities	Addressing "'at least three activities"
Safety	Addressing "safe for children"
Accessibility	Safety or accessibility for people with disabilities.
Material suppliers/vendors	2Use material available at any hardware of lumber store2
Schedule	Addressing "available in 2 months"
Clarifications on design task	"Explain your solution as clearly and completely as possible"
Construction	Making instructions or diagrams for people building the playground
Budget	Amount of money available for the project
Cost	Costs of specific materials
Labor	Statements about workers for the project
Material type	General type of material needed (for example, wood, screws, steel)
Material spec	Statements about technical material requirements
Technical reference	Statements about technical construction requirements
Dimensions	Specific measurements of the playground
Layout	Configuration of the park itself
Body dimensions	Size of human body or parts thereof
Neighborhood places of interest	Location of objects/places/services near the playground
Neighborhood demographics	Information about the composition of the neighborhood population
Stakeholder opinions	Stakeholder' reactions to proposed playground
Neighborhood characteristics	Other conditions of the area, community related. Includes: patterns of weather, crime, gang activity, level of civic engagement, economic activity.
Lot characteristics	Lot's characteristics or layout
Utilities	Gas, water, or power lines
Facilities	Facilities, such as bathrooms, lighting, water fountains
Maintenance	Property or equipment maintenance for operation
Legal	Liability for potential accidents or injuries
Supervision	Oversight of children during playground hours
Examples of existing solutions	Students searching for existing solutions, such as pictures of playgrounds to get ideas for playground equipment. Most Google image searches will fall within this category.

Quality (Audience):	
Scholarly	Journal articles, conference reports, textbooks, technical reports, etc. Requires technical background to understand/interpret
Technical	Includes spec sheets; may contain advanced or specialized vocabulary, but accessible to a non-specialist
Popular	Non-scientific/Non-technical

Quality (purpose):	
Informative	Information is provided with minimal bias. Typically, provides both sides of a controversial issue. Main purpose is to allow reader to make informed decisions
Persuasive	Information advocates a particular idea (i.e., asserts a particular position). Includes commercial sites selling products and non-profit sites advocating for a particular viewpoint.
Entertaining	Information is meant for entertainment purposes, rather than educational use

Purpose (of request):	
Problem Definition/Scoping	Trying to understand constraints or content of the problem the participant is trying to solve
Building general knowledge	Collecting information to build a general understanding of the context or concepts of the problem. For example, Why do children play? How do you build playground equipment? What rules or laws do you have to follow?
Specific data	Looking for a particular fact or figure to answer a concrete question. For example, how expensive, how much, how long, how strong
Narrowing options	Looking for information to narrow choices/design options.
Evaluation of information	Looking for supplementary information to evaluate an assertion. For example, looking for authorship of a web resource
Verification of information	Attempting to corroborate information the student already knows (prior knowledge) or has found in a prior search
Synthesis	Attempting to bring together two or more concepts into a single design solution
Presentation	Information gathered to assist in presentation of final design. For example, an image or table that visualizes the data gathered

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