WORK IN PROGRESS: Quantitative Information Acquisition and Utilization by First-Year Engineering Students

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Abstract

Findings from previous research focused on decision making and judgement in engineering design process show that both the quantity and type of information gathered distinguish experts from novice designers. As a component of a larger investigation of the interplay between students' mathematical and design thinking processes in design tasks, we focus this study on quantitative information acquisition and utilization.

This analysis focuses on a sample of five first-year engineering students who attend an ABET accredited university in the Midwestern U.S. During the study session, students "think aloud" as they designed a playground for a fictional neighborhood. The students were encouraged to request information from the facilitator, as necessary. Using critical incident analysis, we identified each request for quantitative information and then determined whether the student used that information for design or mathematical purposes. The results of this investigation show that each student has a unique approach to acquire and utilize information. In addition to what is already known about information gathering, this study contributes additional insights into the ways that first-year engineering students acquire, evaluate and utilize quantitative information and its role in the overall quality of the final design solution.

1. Introduction

This manuscript presents a Work in Progress study that investigates quantitative information acquisition and utilization by First-Year engineering students. Engineering work and engineering coursework are characterized by both engineering sciences (where mathematics often plays a large role) and engineering design. Too frequently engineering coursework can focus on only one or the other -- rather than integrated engineering design and engineering sciences work. One intersection between engineering science and engineering design is the use of quantitative information (and the results of quantitative analyses) in making design decisions.

Our research focuses on exploring the interplay between design thinking and mathematical thinking during students' design process, and how participants gather and use information in their design thinking processes. More specifically, in this work we explore the role of quantitative information gathering behaviors. To investigate if this topic could contribute to our purposes of explaining the interplay between design thinking and mathematical thinking, we conducted the analysis we are reporting in this paper, in which we sought to characterize students' quantitative information gathering and use. In this paper we share the results from a perspective of seeking to relate back to our larger effort to understand the interplay between mathematical and design thinking. Therefore, we investigate the following research questions:
How do mathematical thinking activities impact design thinking activities?

1. What kinds of quantitative information do First-Year Engineering students gather?
2. Why do students acquire certain quantitative information?
3. How is this information used during their design processes?

Beyond the usability of the results of our study on the interplay of design and mathematical thinking, we believe that findings from this study contribute to the existing body of literature on information gathering. Specifically, the results can add to what is known about quantitative information gathering, an aspect the mathematical thinking, which designers use when addressing an open-ended design problem.

2. Literature Review

Information gathering is a crucial activity in design practice[1,2] and is generally considered as part of the problem scoping process[3,4]. In fact, to properly scope the problem, the student must request additional relevant additional information but they must also identify what information is needed and filter irrelevant information[3]. Researchers have conducted expert-novice studies and found that experts typically spend more time engaged in problem scoping and gather more information than senior engineering students[1] and seniors gathered more information than freshman students[2]. However, information gathering alone does not distinguish experts, from senior and first-year engineering students[3]. Results of previous investigations [4-6] demonstrate that both quantity and type of information gathered are indicators of experts and novices quality work.

Shanteau[3] focused on the relationship between information use and expertise and found that the amount of information used does not reflect the designer's' level of expertise. Rather, it is the evaluation and utilization of the relevant gathered information that differentiates experts from non-experts. Other scholars have built upon this work and measured relevance more empirically by categorizing each information request, with senior engineering students covered more categories than first-year students[4] and experts gather more information across categories which addressed user needs and the situation/context[3]. Generally, both seniors and first-year engineering students fail to consider more important problem components such as safety, liability and user needs/wants[5].

Dwarakanath and Wallace[6] created categories to understand the types of information used by participants in their decision making process. The categories included: problems, alternatives, criteria, evaluation statements, previous decisions, external information, and other. In their investigation of first-year engineering and senior engineering design processes, Atman, Chimka, Bursic, and Nachtmann[4] described information gathering as that which was explicitly gathered and that which was assumed.

In summary, there are several key insights into information gathering: 1) quantity and type of information gathered indicate effective problem scoping; 2) more expert-like behavior includes gathering more narrowly focused information (usually focused on the user or client); and 3) information gathering and utilization can give insight into the decision making process used by the student. Previous scholarship has looked at different facets of information gathering and have categorized the information gathered in differing ways. In this in this paper, we share the results of an investigation of information gathering and it relation to mathematical thinking. For this investigation, any quantitative information gathering occurrence is considered an occurrence of mathematical information gathering.

3. Method

3.1. Participants

This study was conducted in an institution in the Midwestern region of the United States, where students take introductory courses targeted on developing students' design, problem solving and their mathematical skills. The participants for this study are all in the first semester of their undergraduate engineering programs. Throughout this study all participants are given a pseudonym to preserve participant confidentiality.

In order to explore differences between the students' academic profiles and their mathematical and design experiences, each participant completed a pre-design session demographic survey, which was used for participant selection. If the participant reported any form of design experience in the pre-survey, we categorized the respective student as "having design experience (Yes)", otherwise the student was categorized as "having no design experience (No)." The participants' high school mathematics GPA, any calculus-based math class completed, and any current calculus-based classes determined the mathematics experience level. The students were categorized as having "high" or "low" mathematics experiences. Based on the results of the survey and the inter-group comparison of the collected surveys, and our desire to test our analytical approach on a small sample of the available data, we selected a small sample of five students who are different from each other in terms of gender, mathematical experience and design experience. These differences may become more meaningful when we have 1) a larger sample size and 2) more diverse disciplines (i.e. engineering (first-year and seniors), mathematics and design seniors). We chose to focus on a total of five students for this study for two primary reasons: (1) the current analysis is an exploratory analysis, where a goal is to determine whether it will be productive to expand to the full data set; (2) a focused analysis of five participants allows us to examine these participants' behaviors in greater depth.

3.2. Study Design

For this study, we employed a verbal protocol methodology[7] whereby participants "think aloud" as they proceeded with their design. The entire design session is video and audio recorded for data analysis. Participants to work individually for three hours as they designed a playground for a fictional community. They are given a design task statement, which includes only critical information but they students has access to the internet and a facilitator with an information binder. Participants could acquire information from the research facilitator, by asking explicitly for the information as they completed the design task. Therefore, information gathering is necessary for this design task. The participants were also given access to a laptop with internet access and we recorded their website browse history for future analysis. For the purpose of this study, we have decided that the data analysis focuses only on the mathematical information gathered from the facilitator during students' design. Finally, participants were given access to a toolbox of resources such as rulers, calculators, writing utensils, and post-it notes. They were able to use anything inside the toolbox during their design process.

Name	Gender	Ethnicity	Mathematics Experience	Design Experience
Kasira	F	White	High	Yes
Mark	M	White	High	Yes
Claudia	F	White	High	No
Sarah	F	White	Low	No
Peter	M	White	Low	Yes

Table 1. Participants information and previous experience

3.3. Data Analysis

3.3.1 Overall data analysis method

The data analysis was divided into two parts, and therefore, required two rounds of reviewing the data. In the first round, the types of information participants gathered from the facilitator were identified. The times that the behavior of gathering information occurred were also recorded to serve as starting points that were used to trace participants' future utilization of the information. The second round of the data analysis aimed to investigate and trace participants' thinking processes using a Verbal Protocol analysis approach in which we traced how participants used the information they gathered. The use of NVIVO software for qualitative analysis allowed us to visualize critical points of the analysis within the video data and have real-time statistics for the analysis.

3.3.2. First round, identifying the type of information

For this study, we analyzed the videos recorded while participants were addressing the task. For collecting the data, we needed for the first round, (type of information gathered by participants) we defined as a critical incident any instances that participants acquired information based on the behaviors of the participants or the oral communication between the facilitator and the participants when and after they acquired information. We also recorded the type of information obtained to uncover possible answers to our third research question (How students use the information they gathered). An indicator was added to the video in NVIVO at the instance of participants asking for information from the research facilitator. The type of information that participants requested was also documented along with the indicator and was determined. After marking the video with all the possible critical incidences, we did another round to verify if they were valid for our study. Some indicators resulted in removal from the data analysis for the reason that some information may only be instruction-based and do not contain any quantitative content.

3.3.3. Second round, Investigating and tracing participants' uses of information

Participants may acquire quantitative information for either mathematical or design purposes, and the utilization of the information may also be categorized by mathematical practices or design practices. In order to distinguish the differences of each behavior, a coding scheme is applied to the video data during the second round of the analysis to aid researchers in revealing and tracing participants' thinking processes. In addition to the acquisition and utilization of information, we also recorded the different types of information gathered or used by participants, as they may be beneficial for other and future research studies. The research team developed five codes, listed below, were used during the second round of analysis.

- Quantitative information gathering for mathematical needs: acquire information for mathematical needs
- Quantitative information gathering for design needs: acquire information for design needs
- Quantitative information uses in mathematical practices: use information gathered for mathematical practices.
- Quantitative information uses in design practices: use information gathered to assist or evaluate design.
- Types of information: playground diagram, budget, safety instructions, etc.

4. Findings

Participants gathered eight different types of quantitative information with 20 information gathering behaviors. Among the 20 information gathering behaviors, 13 of them were for design purposes, and 7 for mathematical ones. Information gathered by participants were used 21 times, including 10 utilizations for mathematical practices and 11 for design practices.

4.1. Research Question 1: What kinds of quantitative information do First-Year Engineering students gather?

Our data analysis reveals a total number of eight different types of quantitative information requested (Table 2). The playground diagram was acquired by four participants, making this information the most popular one. The budget and safety instruction are gathered by two participants. And other types of information, such as flooring information, equipment guide, material information etc., are requested by one participant. One of our participantsr requested no formation from the research facilitator. Figure 1 shows the different types and frequencies of information gathered by each participant.

Types of information	Description
Playground Information	Including Playground Diagram, Community Information etc.
Budget	Maximum cost of the playground construction
Flooring Information	Including Brick Tiles Information, Stone Tiles information etc.
Equipment Price	Including Price for wood, stone, plastics, etc.
Safety Instruction	Safety guide for swings, seesaws, etc.
Number of Construction Workers	Number of workers available for playground construction
Equipment Guide	guidance on the constructions for swings, seesaws, etc.
Material Information	including piping, electricity, etc.

Table 2. Types of information and description

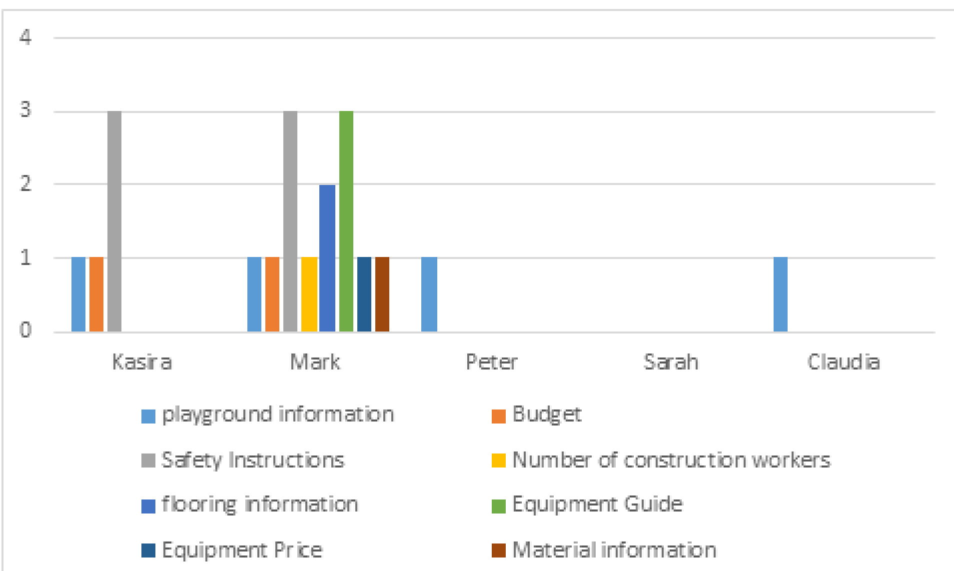

Figure 1. Figure shows different types and frequencies of information gathered by each participant.

There are three instances of participants multiple pieces of information from the same category (see Table 2 for descriptions). Since participants may gather the same type of information multiple times during their design, we record each as a separate instance but categorize the request as illustrated in Figure 1. For example, one participant requested information for construction information for swings, seesaws, and climbing equipments. These pieces of information were included in the Equipment Guide category. Safety instruction is gathered six times by two participants and Flooring Information is gathered three times by one participant (Figure 2).

4.2. Research Question 2: Why did students acquire certain quantitative information?
Among these information gathering behaviors, 13 instances were acquired for design needs, such as seeking specifications for design requirements and obtaining general guidance for equipment constructions. Seven information gathering behaviors occurs when participants sought mathematical demands, providing parameters or quantitative data for calculations.

4.3. Research Question 3: How is this information used during their design processes?

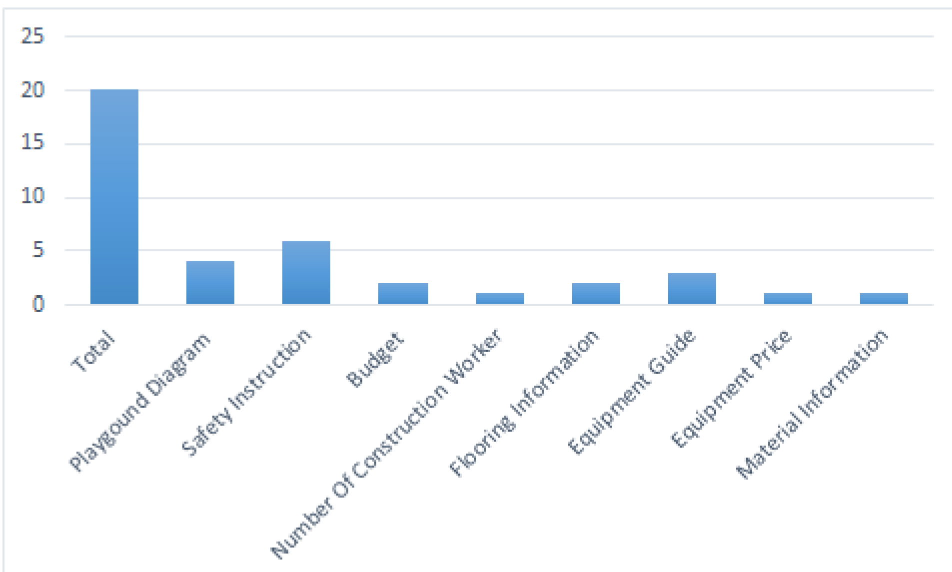

Figure 2. Number of information gathering incidents by category

Although participants requested information, they did not always use it. Data analysis indicated that there were 21 instances of information utilization across the five participants, 11 instances of use in design practices while 10 instances if use were for mathematical practices. There are also six pieces of information that were gathered but not utilized.

4.4. Participants thinking processes

By tracing each participant's' thinking processes for the information they gathered during the design, a sequence of utilizing information reveals and appears 9 times. After participant gather information, they process the information using mathematical practices and use them in design practices, such as idea generation, design requirement, and design evaluation (see Figure 3). For example, One of our participants obtained the playground diagram from the research facilitator and calculate the total area of the playground and decided that he wants to divide the playground into two areas for small kids and normal kids. Another participant, Sarah, did not request any information during the study session.

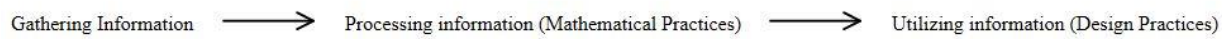

Figure 3. Information Utilization Sequence

Kasira gathered her playground diagram at the beginning of her design. She immediately extracted the dimensions of the playground shown in the playground diagram. The playground dimensions were used throughout her three-hour study, serving as a geographical constraint for her playground equipment. She asked for the budget afterwards because she was uncomfortable making her own assumption for the budget. She compared the budget requirement with the cost of her design at the end in order to verify that her design met budget requirement. Safety instructions were requested one hour into her design. She paid most of her attention on the size of the gap required between each equipment and make sure that she left enough space to ensure safe uses of each equipment.

Mark requested the largest amount of information during his design and all of them were gathered during the first hour of his design. He asked for playground diagram at the beginning as well. But unlike Kasira, he calculated the total area of the playground right after he gathered the information and decided to split the playground into two areas for different age of kids. He, then, moved his focus to the cost of the playground. He asked for the number of construction workers available for the playground because he would like to calculate the wage of workers and consider this as a part of the total playground cost. Since the research facilitator did not have the information available, he asked for the total budget. For the rest of his first hour, he focused on the playground equipment, asking for variety of information related to equipment, such as equipment guide, flooring information, and material information. He also asked for equipment prices but was unable to obtain it from the facilitator. He asked for the safety instruction as well for three different equipment, and as Kasira, he paid most of his attention on ensuring the space requirement between equipment.

Peter asked only for the playground diagram at the beginning. He extracted the dimensions the playground and decided to not put his playground equipment towards the edge of the playground. He calculated total area of the workable region for his playground design and used it to eliminate any ideas from his brainstorm activity that were not going to fit into the playground dimension.

Throughout Sarah's design, she did not request any form of information.

Claudia asked for her playground diagram at the beginning of her design as well but did not use it immediately. The first time she used this information was when she tried to fit her designed equipment into the playground. She realized that the playground was covered by grass and she started to evaluate her current equipment design on whether they can be installed on glass. She also used the playground diagram to constrain her design so that all the equipment would fit into the playground area.

4.5. Unexpected Findings (Further Exploration)

There were four instances when students requested information from the facilitator but it not included in the information binder. The participants treated the unavailable information as an unknown parameter and made an assumption and decision before providing the final solution. One participant requested information about number of workers available for playground construction for labor wage calculation. However, the research facilitator did not have this information prepared. Participant, then, treated the number of workers as an unknown parameter and made an equation for total wage calculation with this unknown. At his final stage of his design, he estimated the minimum number of workers needed for the construction of his designed playground, plugged it into his equation and calculated the total wage for the workers. Finally, he was able to complete his budget estimation taken into account the labor wages.

Studying this behavior may reveal a deeper understanding of the relationship and interplay between mathematical thinking and design thinking, and how they support each other in design tasks.

5. Discussion

While Atman et al[3] presented in their paper that experienced designers gather more information than inexperienced designer, the relationship between information gathering and information use is still unknown. In this study, we endeavored to investigate that relationship and understand its role in the interplay between mathematical and design thinking.

5.1. Finding 1 - Eight different types of information requested, Playground design most popular, no other noticeable trend.

The high variety of information gathered and low frequency that each type of information was gathered suggests that among the five participants in this study, there is no common thinking process by which they requested and used the information. Additionally, the diversity in the types of information gathered and the utilization of the information might suggest that these students do not have an established information gathering process, meaning their information requests and utilization is not planned; the participants did not appear to have a systemic way of gathering information. Information request seemed to occur “more on the fly.” Also, there was one student who never asked for information, which was also seen in a recent study in which pre-service teachers collaborated to solve a design task[8]. Authors reported that these teachers did not request information. This is similar behavior to those demonstrated by first-year engineering students in similar research studies.

Since the availability of the playground diagram is specifically stated in the design task, it is reasonable that playground diagram occupies the biggest percentage of total number of information gathered. We would assume that this pattern would remain as we analyze the information gathering practices of more participants. With respect to the other types of requested information, we have begun to noticed trends about the type and frequency of information gathered, which for this sample align with the results of similar studies. As we continue to analyze the data from other samples (i.e. more first-year engineering students, senior mathematics, engineering and design students), we anticipate investigating if a similar trend would hold. We believe that there might be an increase in the types of information gathered but the frequency of requests for each type might still be low.

5.2. Finding 2 - Participants focus on solution components.

The reason of gathering information is shown to be dominated by design needs. Given the fact that this study is designed to create ambiguity and uncertainty, the design task itself contain not enough information to specify the requirement of the design. This may suggest that a more constrained design task might yield less information gathering behaviors. For some design tasks with specific design requirements, the information gathering behaviors may decrease.

5.3 Findings 3 - 11 mathematical practices and 10 design practices for information utilization, and a potential thinking process shows up.

The findings show that the number of uses of information for mathematical practices and design practices are nearly identical, indicating that the information they gathered impacted not only their design, but also their mathematical calculation. From observing the thinking process of the five participants, we note that for first-year engineering students, the process of information utilization in design tasks might be more complex and include more layers of thought than we initially believed.

5.4 Limitation

The amount of information that the researchers prepare for participants are limited, making some of the information request (invalidated), creating discontinuity between information gathering and information uses. This causes some students to access additional information through internet searches. Some researchers critique the Verbal protocol "think aloud" because it does not accurately reflect participants complete thinking process during their design. This makes such of the data untraceable. Some information gathering and information use behaviors are also excluded in this study since participants have internet access. Participants large quantities of information online and process them without it being reported or recorded in the video.

6. Future work

Recruiting and data collection for First-Year Engineering participants has been completed. Researchers will continue analyzing more data using our current coding scheme in order to discover more general and specific results. In addition, the development of a refined coding scheme is undertaken by other members in the research team. We expect that, by having a further developed coding scheme, we will be able to reveal and trace participants' various thinking process more accurately, and therefore, enhance our data analysis procedure and results.

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