Considering Context: A Study of First-Year Engineering Students

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ABSTRACT

High-quality engineering design requires an understanding of how the resulting engineered artifact interacts with society, the natural environment, and other aspects of context. This study examines how first-year engineering undergraduates approached two engineering design tasks. We focused on how much students considered contextual factors during problem-scoping, a critical part of the design process. As part of a larger, longitudinal study, we collected data from 160 students at four U.S. institutions. Students varied in their consideration of each design task's context, and women's responses were more likely to be context-oriented than men's. Overall, context-orientation was positively correlated between the two design tasks, despite differences in data collection and analysis. Having found that beginning engineering students, particularly women, are sensitive to important contextual factors, we suggest that efforts to broaden participation in engineering should consider legitimizing and fostering context-oriented approaches to engineering earlier in the curriculum.

Keywords: context, design, women.

I. INTRODUCTION

As engineers contribute to solving the increasingly complex problems facing our society, there is a growing need for the engineers graduating from undergraduate programs to understand deeply the context within which they are solving problems. There is a particular need for engineers who recognize the complexities of global and societal issues and respond to those complex issues with the solutions they develop.

The importance of incorporating contextual issues into the undergraduate curriculum is widely acknowledged in the engineering education community [1–7]. The ABET *Criteria for Accrediting Engineering Programs* incorporate context in two of the eleven learning outcomes expected to be achieved by engineering graduates. Among ABET's technical and professional learning outcomes are both "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" and "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [8].

More recently, a gathering of engineers and social scientists [9] and a National Academy of Engineering (NAE) report [10] reinforced the importance of these issues. The NAE report "The Engineer of 2020" stated strongly, "Successful engineers in 2020 will, as they always have, recognize the broader contexts that are intertwined in technology and its application in society" [10, p. 56]. This issue assumes greater importance as the economy, environment, and social structures of the world become more linked, and change happens at an ever-increasing rate.

Consideration of the broader aspects of engineering incorporates many concepts. Engineers must design solutions that address the needs of diverse peoples in diverse cultures in ways that are "user-centered." They must design solutions that do not harm the natural environment in which we all live. Furthermore, they must be thinking simultaneously at the local and global level about the impact of their proposed design solutions. This aspect of engineering is referred to in many ways: as broad thinking or broad problem-scoping; thinking of global and societal implications of engineering; incorporating the context of engineering; and valuing the importance of the links between science, technology, and society. We refer to the consideration of global and societal implications of engineering design as *breadth of problem-scoping*, and the *context* of engineering.

Broad thinking and problem-scoping activity can be observed when an individual engages with a specific engineering design task. In this study, we focus on the problem-scoping activity of engineering students in the early stages of their education, as opposed to that of advanced students or professional expert designers, and describe the findings from students who completed two separate engineering design tasks. One is an open-ended exercise in which students were given 10 minutes to write their answer down on paper in any

format they liked. The other is a closed-ended question on a larger online survey in which students were given a list of kinds of information and asked to select the kinds of information that they would most likely need to complete a given engineering design task. In our analysis, we sought to determine how broadly first-year students scoped these design tasks; that is, to what extent they considered the global and societal implications of engineering design. We also examined gender differences in problem-scoping.

II. Literature Review

Preparing future engineers who understand the global and societal implications of the products and systems they design and implement is clearly a priority for the engineering community of the twenty-first century. The community has been involved in many conversations about this important need and has responded in innovative and effective ways. There is an active Science, Technology, and Society community with 27 national programs that address these issues [11], as well as a professional association: the International Association of Science, Technology, and Society [12]. Examples of the engineering education community's response include innovative courses and workshops [13–17], curricula and programs [18-26], and tools to help guide assessment [27–28]. Many of these engineering programs and courses teach students about the importance of global and societal issues through design experiences. This is a natural place for those learning experiences to occur for two reasons. First, design is one of the core elements of engineering that we teach our students. Second, when engineering has an impact on global and societal issues, it is often through the consequences (intended and unintended) of artifacts and systems designed by engineers [29]. This signals a need for continuous empirical inquiry into the design experiences of engineering students, to ensure that design strategies and processes used to teach and learn engineering are aligned with the learning outcomes anticipated by the larger engineering community and society.

The characteristics of the design process used can influence the quality of the final solution, and some design strategies have been found to be more effective than others. Strategies such as "thorough goal analysis," which characterize the early stages of the design process, have been associated with better solutions [30]. Studies of both novice and expert designers have highlighted the importance of effective conceptualization of the design problem. For instance, a study of novice software analysts by Sutcliffe and Maiden [31] indicated that design performance appeared to be linked to the ability to reason through the problem and to define and conceptualize the problem domain and scope. Similarly, Cross and Clayburn [32] found that a systematic approach to the problem from the outset and careful framing of the problem space were common features in the design processes of two expert designers. In an expertise study focusing on electronics engineers, Ball et al. also found that "designers were implementing a highly systematic solution-development strategy which deviated only a small degree from a normatively optimal top-down and breadth-first method" [33, p. 247]. Overall, research on how designers define and frame problems [33–36], reflect on their designs [37–39], gather information [40–43], and assign importance to aspects of the design process [44] illustrates that the initial thinking about the nature of the problem can significantly impact the quality of the resulting solution.

Overall, there is much research on design processes [45–46]. A few studies have characterized engineering students' design processes with regard to the breadth of problem-scoping and consideration of the design context. Research has uncovered differences in the breadth of problem-scoping exhibited by "novice" student engineers and "expert" designers, who are typically advanced professionals with significant work experience. For example, Christiaans and Dorst [41] found that novices solicited less information and exhibited less extensive problem scoping, compared with expert designers. In addition to novice–expert comparisons, progress has also been made on analyzing student problem-scoping activity across academic levels and engineering disciplines [47–49]. For instance, Bogusch et al. found that more seniors than freshmen were able to consider broad aspects of a design problem [47]. Comparing freshman and senior designers, Atman et al. found that seniors gathered more information than did freshmen [49]. In a follow-up study, Atman et al. confirmed most of these findings, supporting the expectation that seniors outperform freshmen in design [50]. This study also highlighted the importance of using a variety of engineering performance tasks in research, as the nature of the engineering design task influences the dynamics of the design process and the measures used to assess and compare design activity among the study participants, such as time allocated to each stage of the design process. Overall, such work resulted in detailed descriptions of freshman and senior student design processes and insights into the differences between them. Insights from these studies can shed light on how student designers might incorporate broad factors into their design solutions. The research also suggests that it is useful to explore the patterns of student design thinking and doing, using a combination of performance tasks.

An additional impetus for studying the ways in which undergraduate engineering students approach design problems is related to the continuing effort to attract a more diverse and representative enrollment in engineering [51]. In spite of years of research and intervention, women earned less than one fifth of the Bachelor's degrees in engineering and engineering technologies granted in the U.S. in 2004 [52]. Sex-based disparities in enrollment and retention rates can *not* be attributed to differential ability or academic performance [53] nor are they attributable to differences in student engagement [54]. The same is true of underrepresented minority (URM) students. Although URM students are not the focus of this study, it is important to note that both women and URM students are differentially served by different institutions of higher education. Some institutions are better than others at recruiting and retaining women and URM students [55–57].

In their report on the Women's Experience in College Engineering Project, Goodman et al. corroborated prior research suggesting that women who leave engineering perceive that it is not compatible with their dominant interests [53]. Besterfield-Sacre et al. also found that freshman women had a lower perception than men of "how engineers contribute to society" [58]. Goodman et al. found that exposure to the connection between engineering and society and/or the natural environment positively affected women's initial interest in and choice to study engineering [53].

The vast literature on intellectual development suggests an additional clue to the disparity between male and female enrollments in engineering. As Felder and Brent described in their overview of significant models of intellectual development and their relation to engineering education, women and men are likely to exhibit different

patterns of knowing at various stages of their intellectual development. Masculine ways of knowing are more likely to match the culture and norms of engineering programs and classrooms [59]. Because *doing* engineering is fundamentally tied to thinking about engineering, our findings about how broadly first-year women and men scope engineering problems may reflect their varying interests, perceptions, and patterns of knowing as they embark on their engineering education journeys. From this point forward in this paper, we refer to gender rather than sex-based differences, to represent our belief that the variations in thinking about and doing engineering that we observe are grounded in social interaction and experience rather than biology. As Tai et al. reported, regardless of natural aptitude, students who had early exposure to science are significantly more likely to earn degrees in physical science and engineering [60].

The highest levels of intellectual development involve the ability to make commitments to judgments of knowledge and truth while acknowledging the uncertainty and dynamism of the contexts in which such judgments are situated [59]. In addition to enabling students' mastery of math and science concepts, of course, engineering education must promote intellectual growth in order to move students beyond simple acquisition of knowledge toward the contextual application of these concepts to real-world problems. By studying how first-year students do engineering, we may further understand their readiness for intellectual challenges, as well as their need for support.

In this study, we compare data from students solving two design tasks and consider the role of gender in the design performance of students at an early stage in their engineering education. The specific research questions we ask are the following:

1. How broadly do first-year students scope an engineering design problem?
2. Is a student's gender related to their problem-scoping behavior?
3. Do first-year students exhibit similar problem-scoping behavior regardless of the engineering problem in which they are engaged?

We expect that a detailed understanding of student design thinking and doing could yield ideas for creating effective design learning experiences for students, as well as insights for applying the results to classroom practice [61]. This study also contributes to our ongoing program of empirical research, providing a foundation for directing instructional development in college-level engineering design education.

III. Methods

The Center for the Advancement of Engineering Education (CAEE) is a collaboration of scholars focused on the development of knowledge about engineering learning and teaching that can contribute to the improvement of engineering education. The Academic Pathways Study (APS) research element of CAEE is a multi-institution, mixed-method, longitudinal study which examines engineering students' learning and development as they move into, through, and beyond their undergraduate institutions. Data were collected from students at each of four institutions: Mountain Technical Institute (MT), a public university specializing in teaching engineering and technology; Oliver University, a private, historically black, mid-Atlantic institution; University of West State (UWest), a large, public university in the Northwest U.S.; and University of Coleman, a medium-sized, private university on the West Coast (pseudonyms).

The APS uses a concurrent triangulation mixed-methods design, in which both qualitative and quantitative methods are employed to collect and analyze data. The integration of results occurs during the interpretation phase [62], enabling researchers to address a broad range of research questions directed toward discerning complex phenomena like student learning and development [63]. Data were collected from students at the four institutions using surveys, structured and unstructured interviews, and ethnographic observations. Students were also asked to perform simple engineering tasks during timed sessions at the conclusion of interviews. The study was designed to collect data from forty students at each of the four institutions ($N = 160$). This paper describes a subset of the first-year data gathered for the APS. Specifically, we describe findings from a brief engineering design task administered to 124 students during one-on-one interviews in the spring of the first year of the study, and findings from an engineering design question asked of all 160 students on the spring survey in the first year of the study. The survey was administered to all student participants, but only 143 students answered the engineering design question adequately to be included in the analysis. These data collection instruments are described in detail below.

A. Midwest Floods Problem

In Spring 2004, 124 first-year students were asked, "Over the summer the Midwest experienced massive flooding of the Mississippi River. What factors would you take into account in designing a retaining wall system for the Mississippi?" Students were given 10 minutes to write down their answers on paper. This exercise was administered at the end of either a structured or unstructured interview in which students had been asked a number of open-ended questions about their engineering knowledge and educational experiences.

The Midwest floods problem (MWF) has been used in previous studies of design behavior in engineering students [37, 47, 48, 64-67]. The problem is intended to provide a problem-scoping goal orientation, directing respondents to think about the constraints, or factors, to be considered given a proposed solution approach to a broad-based, real-world problem. The data collected give a sense of how broadly students think about engineering problems, and to what extent students situate engineering problems in context.

1) Data collection and management: Students' written responses were transcribed and stored digitally. Care was taken to faithfully reproduce handwritten responses to the extent possible. The students' line breaks, spelling errors, corrections, bulleted lists, and so forth, were indicated in the digital file. Figure 1 is an example of a transcript of a student's written response to the MWF question:

Four members of the research team each segmented all of the transcribed data into distinct "thought units." Each segment is meant to contain one discrete idea. Segmenting separately, researchers achieved 70 percent agreement. The team then met to compare segmenting choices and negotiated differences to consensus.

2) Data analysis: A coding scheme that was previously developed and validated for use with verbal protocol data [37, 47, 48, 64–67]

was adapted for use here. This scheme consists of two dimensions of breadth containing four categories each. The first dimension, "frame of reference," includes the categories *technical*, *logistical*, *natural*, and *social*, to reflect the perspective of the student's focus contained in the segment. The second dimension, "physical location," represents the physical area of focus of the segment. Broad descriptions of each of these categories are shown in Table 1.

Two research assistants coded each segment with respect to frame of reference and physical location. Cohen's kappa test was used to assess inter-coder reliability. During pilot coding, the two coders did not achieve satisfactory agreement. The researchers then adapted the codebook for use with the written data, and descriptions of codes were elaborated upon to better articulate how the research team understood the codes. After revision, the researchers, coding separately, achieved substantial agreement for both the frame of reference and the physical location codes, with kappa values of 0.748 and 0.746, respectively. The team met to discuss coding choices and negotiated differences to consensus.

> I would take into account the pH or type of water which flows through the river. This would be a decisive factor as to what kind of material the retaining wall should comprise of. I wouldn't want the wall to disintegrate or even wear away. As the issue of wearing away comes into play, i[sic] would also have to determine the current strength of the river.
>
> Another factor to take into account would be the type of soil that surrounds the river. Is it dry or water logged, does it comprise of stones, shrub, etc. Slip soil may cause the wall to lean.
>
> The material of the wall should be one that can beat its surroundings and stand tall.

Figure 1. Transcript of an example student response to the MWF problem.

Table 2 illustrates how the data in Figure 1 were segmented and then coded. The student's response to the MWF problem comprised 10 distinct segments or thought units. Each was coded using the codebook described previously. For example, the "kind of material the retaining wall should comprise of" is a technical issue with respect to the wall itself. In contrast, "the type of soil that surrounds the river" refers to the natural properties of the bank.

B. Information-Gathering Task

In addition to the paper-and-pencil MWF task, a quantitative survey that collected data on the students' experiences and engagement in their higher education was administered twice in each year of the Academic Pathways Study. During the spring administration in their first year, we asked students to answer a closed-ended question about the information they would need to design a playground. Figure 2 contains the text of the question.

The purpose of the information-gathering task was to orient respondents toward the information-gathering component of the design process. The problem itself was drawn from a related body of work by Atman and her colleagues [49–50]. In this research, verbal protocol analysis was used to provide rich descriptions of design processes used by various populations, including freshman and senior undergraduate students and practicing engineering professionals. The process of gathering information is one of the important distinctions across these populations [37, 49, 64]. The problem

Frame of Reference	Description
Technical	Technical or engineering vocabulary, design issues, decisions about having the wall.
Logistical	Cost, funding, construction process, maintainability issues, resources needed.
Natural	Volume of water, damage, effects of flood, topography, animals, plants, weather and weather predictions.
Social	People, safety concerning people, towns, living areas, fields of engineering and education.
Physical Location	**Description**
Wall	The wall itself, things that interact with the wall, alternatives for having a wall, where to put the wall.
Water	Length of the river, fish, flood without effects, pressure issues without mention of the wall.
Bank	Interface of the wall, edge of the river, width of the river.
Surroundings	Anything away from the water, living areas, things along the water, specific effects of the wall or flood to the shore.

Table 1. Code descriptions for the MWF problem. Each segment was coded with respect to "frame of reference" and "physical location."

Segment	Frame of Reference	Physical Location
I would take into account the pH or type of water which flows through the river.	Technical	Water
This would be a decisive factor as to what kind of material the retaining wall should comprise of.	Technical	Wall
I wouldn't want the wall to disintegrate or even wear away.	Logistical	Wall
As the issue of wearing away comes into play, i[sic] would also have to determine the current strength of the river.	Technical	Water
Another factor to take into account would be the type of soil that surrounds the river.	Natural	Bank
Is it dry or water logged, does it comprise of stones, shrub, etc.	Natural	Bank
Slip soil may cause the wall to lean.	Technical	Wall
The material of the wall should be one that can beat its surroundings and stand tall.	Technical	Wall

Table 2. Sample of data segmenting and coding.

You have been asked to design a playground. You have a limited amount of time and resources to gather information for your design. From the following list, please put a check mark next to the FIVE kinds of information you would MOST LIKELY NEED as you work on your design:

__ Availability of materials
__ Budget
__ Information about the area
__ Legal liability
__ Material costs
__ Neighborhood demographics
__ Safety
__ Technical references
__ Body proportions
__ Handicapped accessibility
__ Labor availability and cost
__ Maintenance concerns
__ Material specifications
__ Neighborhood opinions
__ Supervision concerns
__ Utilities

Figure 2. Text of the information-gathering task.

statement and kinds of information used in the problem statement displayed in Figure 2 are drawn directly from this work.

The research described in this paper provides an opportunity to learn what respondents from a larger population of first-year engineering students consider most important as they establish the problem space for playground design. It also provides an opportunity to triangulate with data gathered from other engineering design tasks, like the MWF problem. We are interested to know whether there are any patterns in how individuals exhibit problem-scoping behaviors for one problem and information-gathering behaviors for another problem.

C. Interpreting Problem Orientation

As discussed previously, we were especially interested in the extent to which students situated the MWF and playground information-gathering problems in context. This section details how we interpreted the data gathered for each of the problems.

For the MWF problem, we used the concepts of *design detail* and *design context* to quantify and compare students' breadth of problem-scoping. As illustrated in Figure 3, ideas focused on the wall or the water and from a technical or logistical perspective were interpreted to be oriented toward the detail of the design problem. All other ideas were considered oriented toward the context of the design problem.

For example, a stated factor such as, "materials for the wall" was assigned the codes (*wall*, *technical*), and was therefore interpreted as oriented toward design detail. This stands in contrast to "people who live in the flood plain," which was assigned the codes (*surroundings*, *social*), and identified as oriented toward the design context.

To develop an analogous interpretation of the data gathered for the playground design task, three researchers coded the kinds of information separately, and then negotiated to consensus our interpretation of items over which we differed. Table 3 contains our interpretation of the kinds of information from the playground design task, categorized as detail- or context-oriented. *Supervision concerns* was considered neither detail- nor context-oriented.

For both the MWF problem and the playground design task, we consider our separation of context and detail to be an approximation, and we recognize that one designer's context-oriented condition may be another designer's detail-oriented constraint. Indeed, it is a goal of engineering education that factors or kinds of information considered important for a particular design problem be understood in terms of the interaction between the details of the problem and the context in which it is situated. Our findings in the following section are pragmatic, acknowledging that to some extent it may be difficult to separate detail and context into mutually exclusive categories.

IV. Findings

This section describes the results of analyzing the two data sets: the written responses to the MWF performance task and the responses to the playground design information-gathering question. In the MWF task, participants were asked to write down the factors they would consider in designing a retaining wall to contain river flooding. This was a free-response question, and the written responses were prepared for quantitative analysis in a process of transcription, segmenting, and coding, as described previously. The comparatively simpler playground design information-gathering question asked participants to select the information most likely needed for designing a playground from a fixed list. Since the question was forced-choice, these responses did not require any preparation for analysis.

The number of collected responses suitable for analysis differs between the questions, but each response set includes roughly equal representation of the four participating institutions. In both response sets, about 35 percent of the participants were women.

We begin with results of independent analyses of the MWF and playground question responses, followed by results of a paired analysis examining how each participant responded to both questions. In addition to characterizing the response sets as a whole, we discuss gender comparisons made throughout the analyses.

A. Midwest Floods

We collected MWF responses for 124 participants. Recall from the methods section that the number of segments in a participant's response basically represents the number of factors they said they would consider in designing a retaining wall to contain river flooding. Figure 4 shows that most participants' responses consisted of six to 16 segments, with a few responses consisting of as many 29 segments. The mean segment count was 11.48 (SD = 4.58).

Next, each segment was coded in two dimensions, physical location and frame of reference. In each dimension, there were four codes, as described above and shown in the axis labels in Figure 5. This figure represents all 124 participants' responses in aggregate and shows the distribution of the 1,418 segments across the possible

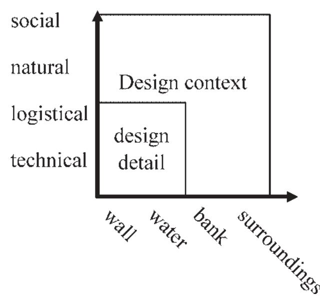


Figure 3. Illustration of interpretation of MWF problem codes. Segments coded wall or water and logistical or technical are considered oriented toward the detail of the design, while all others are considered oriented toward the context of the design problem.

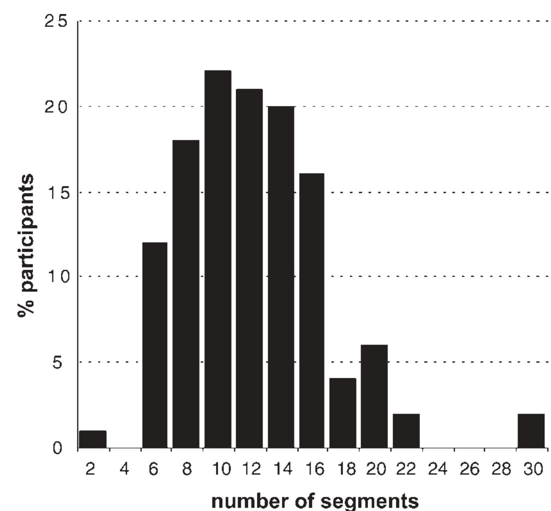


Figure 4. Histogram showing distribution of the number of segments in participants' responses to the Midwest floods retaining wall design question. Segment count corresponds to number of factors represented in the response. (Mean = 11.48, SD = 4.58, N = 124).

Detail-oriented	Context-oriented	Neither
Availability of materials	Body proportions	Supervision concerns
Budget	Handicapped accessibility	
Labor availability and cost	Information about the area	
Maintenance concerns	Legal liability	
Material costs	Neighborhood demographics	
Material specifications	Neighborhood opinions	
Technical references	Safety	
	Utilities	

Table 3. Kinds of information from playground design task, categorized as detail- or context-oriented or neither.

code pairs. Certain kinds of factors were much more frequently cited in the responses, the (*wall*, *logistical*) code pair being the most frequent. This code pair, together with (*wall*, *technical*) and (*water*, *natural*), accounted for over half of the segments. The code pair (*wall*, *logistical*) comprised factors such as the site (location) for the wall, how and when the wall would be constructed, and budget considerations. The next most frequent code pair, (*wall*, *technical*), comprised factors such as the dimensions of the wall and the materials from which it would be constructed. The code pair (*water*, *natural*) matched segments discussing the natural phenomena of rainfall, flooding, water level, etc.

As described previously, the code pairs in the dotted, outline in Figure 5 are context-oriented, and the remaining four code pairs (lower left corner) are detail-oriented. At least in aggregate, the study participants seemed to give substantial consideration to both detail- and context-oriented factors. As mentioned above, technical and logistical factors related to the wall design dominated the detail-oriented factors. Among the context-oriented factors, participants more frequently considered the natural environment than social factors. (Segments coded *natural* in the frame of reference dimension numbered 431, compared to 258 coded *social*.)

Certain code pairs were associated with very few segments, or with no segments at all (*wall*, *natural*) and (*surroundings*, *technical*). Although this might be a reflection of the participants' design expertise, we expect that this is an artifact of the combined effect of the intrinsic nature of the specific engineering design task being examined and our coding method. A segment describing interactions between the wall and the natural environment, for instance, would typically be coded as (*water*, *natural*), (*bank*, *natural*), or (*surroundings*, *natural*), depending on the aspect of the natural environment discussed. In general, there was no *a priori* expectation of uniform coverage of the coding space.

We began our analysis of gender differences with a straightforward comparison of the mean number of segments constituting women's and men's responses. Women's responses contained more segments by a statistically significant margin ($p < 0.02$, Mann-Whitney). As shown in Table 4, on average, women's responses consisted of about 13 segments, and men's responses consisted of 10 to 11 segments. When we examined how these segment counts break down by context- vs. detail-orientation, we found no gender difference in the number of detail-oriented segments, as illustrated by the lighter part of the bars in Figure 6. Independent of gender, responses included an average of just below six detail-oriented segments. However, women's responses included more context-oriented segments, and this difference was statistically significant ($p < 0.01$, Mann-Whitney). On average, women appeared to be paying more attention than men to context-oriented factors, but not at the expense of regard for detail-oriented factors. In other words, gender difference in context-orientation accounts for most of the difference in segment count shown in Table 4. Furthermore, gender differences in distribution of segments between context- and detail-orientation hold regardless of race/ethnicity.

B. Information-Gathering Task

The playground information-gathering survey question asked participants to select the five kinds of information most likely needed for designing a playground, given a list of 16 choices as shown in Figure 2. Our analysis includes data from only the 143 participants who responded with exactly five selections. As with MWF results in the previous section, we begin with an aggregate view of the

		Number of Segments	
	N	Mean	SD
Women	43	13.02	5.62
Men	81	10.65	3.70

Table 4. Mean number of segments in Midwest floods response by gender. Gender difference is statistically significant ($p < 0.02$).

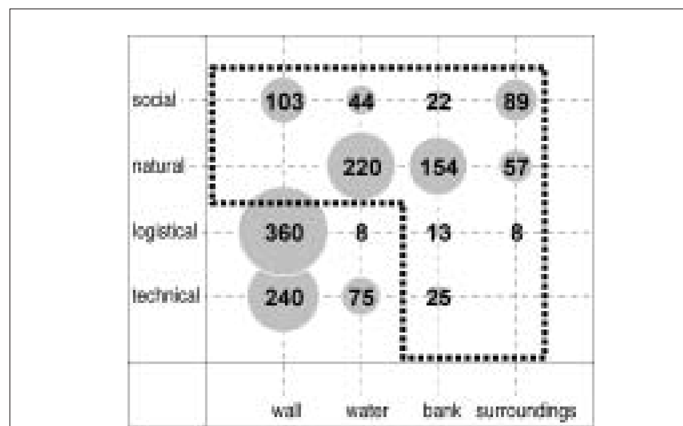


Figure 5. Distribution of segments across coding space for all participants' responses combined (1,418 segments from 124 participants). Physical location codes are on the horizontal axis, and frame of reference codes are on the vertical axis. Area of circle is proportional to number of segments for each location–frame code pair. Code pairs within the dotted outline are context-oriented.

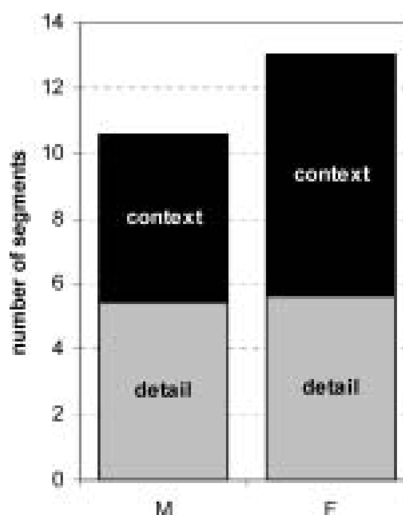


Figure 6. Mean number of segments in Midwest floods response by gender, broken down by segment type ($N = 43$ women + 81 men). Difference in number of context-oriented segments is statistically significant ($p < 0.01$).

participants' responses. For each of the 16 kinds of information, we computed the percentage of participants who included it as one of their five selections. Figure 7 shows the kinds of information sorted in decreasing order by participant selection. *Budget* and *Safety* were the most commonly selected kinds of information, with over 75 percent of participants including one or both of them among their five most needed. In contrast, less than 10 percent of participants selected *Utilities* and *Supervision concerns*, possibly because the meaning of those items was less clear.

Given the gender differences in context-orientation in the MWF responses, we performed an analogous analysis of the playground responses, using the categorization of the kinds of information presented in Table 3. As reported in Table 5, we found that the women tended to select more context-oriented kinds of information than the men, with the difference being statistically significant at the $p < 0.005$ level (Mann-Whitney). Recall that eight kinds of information were categorized as context-oriented, including *Information about the area*, *Legal liability*, and *Neighborhood demographics*.

Applying the Fisher exact test on participant counts for each kind of information to identify the specific gender differences, we found statistically significant differences for six of the 16 kinds of information, as shown in Figure 8 ($p < 0.05$). A larger percentage of the men included three detail-oriented items in their selections: *Budget*, *Material costs*, and *Labor availability and cost*. On the other hand, a larger percentage of the women selected three context-oriented items: *Neighborhood demographics*, *Handicapped accessibility*, and *Utilities*.

C. Paired Analysis of Context-Orientation in the Midwest floods and Playground Responses

The MWF and playground information-gathering questions are very different in format and provide different kinds of data. The former is an open-ended question that participants were given up to 10 minutes to answer in written form. The latter is a forced-choice question that was designed to take much less time and was administered separately from the performance task as part of a larger web-based survey. However, responses to both questions yield quantitative measures of the extent to which students consider the context of a specific engineering design problem. In the case of MWF, coded response segments were divided into context- and detail-oriented segments. For playground information-gathering, each kind of information was classified as context- or detail-oriented (or neither), as shown in Table 3.

With two separate quantitative measures of context-orientation, we asked the natural question of whether the measures were related. Were students whose MWF responses were context-oriented also context-oriented in their playground information-gathering selections? Such a relationship would give us more confidence of the two questions' validity in measuring a common notion of context-orientation. We examined the relationship between the number of context-oriented segments from MWF and the number of context-oriented kinds of information from playground information- gathering, using Spearman rank correlation. The relationship between the two counts is indeed positive and significant, if not particularly strong ($p < 0.02$, $r_s = 0.218$). Correlation was determined from the 115 participants for whom we had responses to both the MWF and playground information-gathering questions.

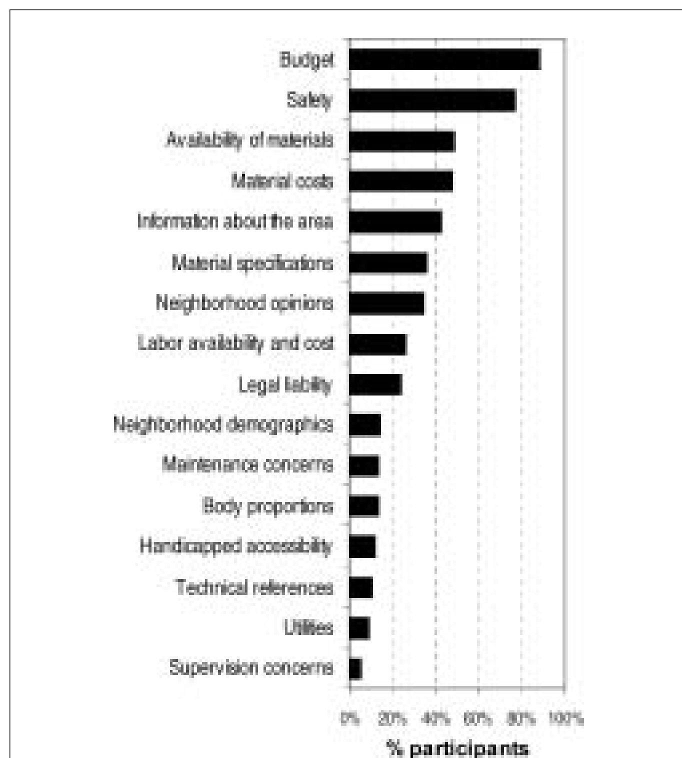


Figure 7. Information needed for playground design. Each participant selected five kinds of information that they would most likely need. For each kind of information, the bars represent the percentage of participants who included it as one of their five selections. (N = 143).

	Number of context-oriented items		
	N	Mean	SD
Women	51	2.69	1.07
Men	92	2.02	1.01

Table 5. Mean number of context-oriented kinds of information selected by gender. Gender difference is statistically significant ($p < 0.005$).

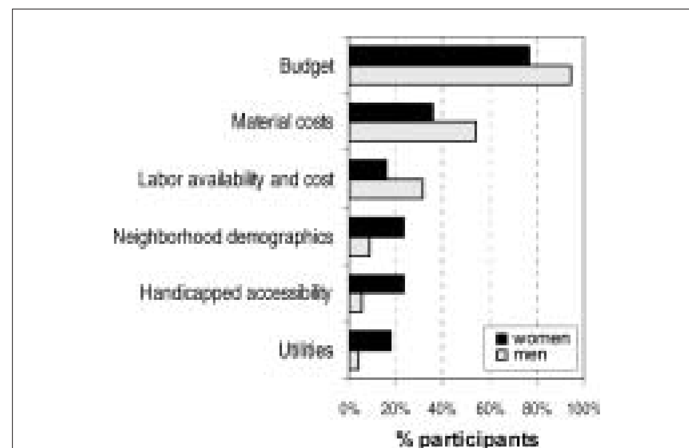


Figure 8. Kinds of information with statistically significant gender difference ($p < 0.05$; $N = 143 = 51$ women + 92 men).

To illustrate the relationship more concretely, we present responses and analysis for a number of example participants. Case 1 is a woman at Mountain Tech whose responses were heavily context-oriented. For contrast, Case 2 is a man at UWest whose responses were heavily detail-oriented. Finally, Case 3 is a man at Oliver University whose emphasis on context and detail was balanced. For each case (starting with Figure 9), we show the participant's responses to the MWF and playground information gathering questions, followed by a chart showing how the MWF response was coded. (We remind the reader that a correlation coefficient of $r_s = 0.218$ suggests weak correlation. Accordingly, there were participants whose context-orientation was not positively correlated across the two questions.)

In Case 1, the participant's MWF response (Figure 9) reflects considerations of natural environment (the area's flora and fauna, water quality), social context (local population), and physical context (pre-existing structures). In Figure 10, we see many segments coded as natural and social in the frame of reference dimension and as bank in the physical location dimension. Their playground response includes analogous considerations (e.g., *Information about the area*, *Neighborhood opinions*), with all five selections being context-oriented and suggesting a broad approach to the design problem.

Case 2 represents a contrasting approach, with both MWF and playground responses almost entirely focused on the details of the designed artifact. As shown in Figure 11 and Figure 12, budget, materials, and labor were this student's primary concerns for both design problems. The contrast in context-orientation with Case 1 is emphasized by the lack of segments represented in the outlined context section of the coding space chart in Figure 12.

As a final case, we consider a student whose relative emphasis on detail and context was balanced in their approach to both the MWF and playground design tasks. The factors they considered in designing a retaining wall (Figure 14) include specifics of the wall's design (specifications, materials, cost). However, the response also

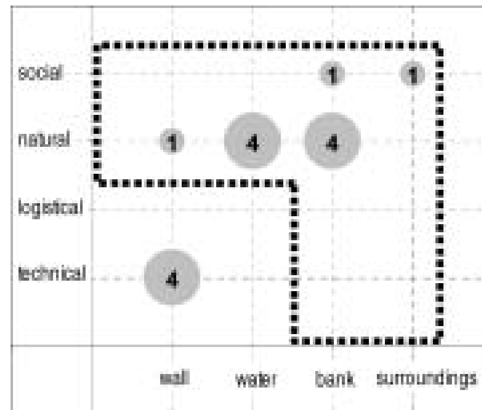


Figure 10. Distribution of Case 1's Midwest floods response segments across coding space. Eleven segments within dotted outline are context-oriented.

Midwest Floods Response

1) Placement of the retaining wall
2) Materials used in the wall: strength, cost, durability, availability.
3) Available Man-power for building the wall is also important. I suppose this could go under materials as well

Playground Response

Legal liability
Budget
Labor availability and cost
Material costs
Material specifications

Figure 11. Transcribed Midwest floods response and playground response for Case 2 (detail-focused), a man at UWest. Gray shading indicates context-oriented segment (in Midwest floods response) or kind of information (in playground response).

Midwest Floods Response

- flood plain
  - how often floods occur (ex: 100-yr. flood)
- biological life of the River
- Structures near the river
- how strong the wall needs to be and what is should be made of
- how wide and high the wall needs to be
- human civilization near the river
- vegetation on banks of river and in surrounding areas (and wildlife)
- water flow (direction, velocity, slope, etc.)
- how much pressure the wall needs to be able to withstand
- chemical composition of the river pH, alkalai content, oxygen content, temperature, etc)
- how building a wall will affect river quality

Playground Response

Handicapped accessibility
Information about the area
Legal liability
Neighborhood opinions
Safety

Figure 9. Transcribed Midwest floods response and playground response for Case 1 (context-focused), a woman at Mountain Tech. Gray shading indicates context-oriented segment (in Midwest floods response) or kind of information (in playground response).

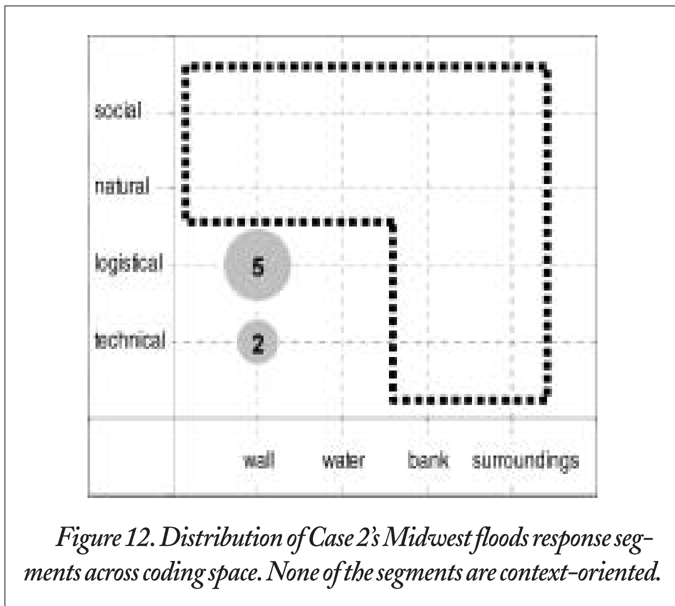
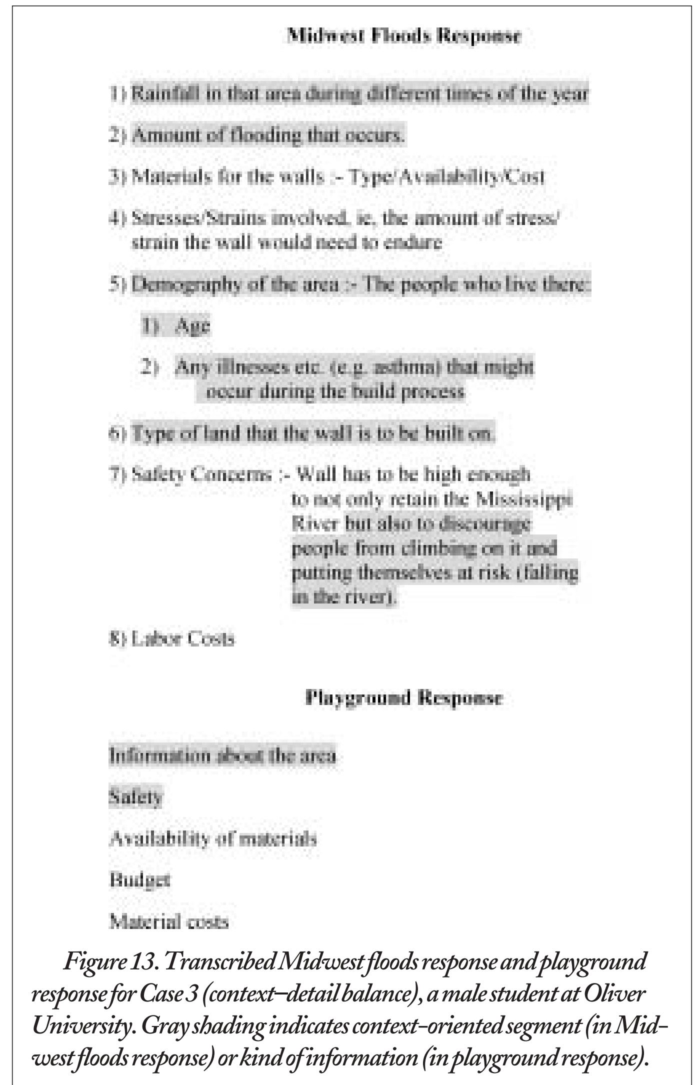


Figure 12. Distribution of Case 2's Midwest floods response segments across coding space. None of the segments are context-oriented.

exhibits awareness of how the project might affect people in the region, both due to the wall's design (risk of accidents at the wall) and its construction process (effect on local air quality). Broad coverage of the coding space in Figure 14 reflects this participant's orientation. Their playground response exhibits similar considerations, with two of the five selected kinds of information being context-oriented (Figure 13). Similar to the pattern in Case 2, the MWF and playground responses in Case 3 share a common set of concerns: information about the surrounding area, safety, materials, and costs.



Midwest Floods Response

1) Rainfall in that area during different times of the year

2) Amount of flooding that occurs.

3) Materials for the walls :- Type/Availability/Cost

4) Stresses/Strains involved, ie, the amount of stress/ strain the wall would need to endure

5) Demography of the area :- The people who live there:

1) Age

2) Any illnesses etc. (e.g. asthma) that might occur during the build process

6) Type of land that the wall is to be built on.

7) Safety Concerns :- Wall has to be high enough to not only retain the Mississippi River but also to discourage people from climbing on it and putting themselves at risk (falling in the river).

8) Labor Costs

Playground Response

Information about the area

Safety

Availability of materials

Budget

Material costs

Figure 13. Transcribed Midwest floods response and playground response for Case 3 (context–detail balance), a male student at Oliver University. Gray shading indicates context-oriented segment (in Midwest floods response) or kind of information (in playground response).

D. Summary of Findings

In both the MWF and playground information-gathering responses, we observed a variety of problem-scoping approaches. Although the factors students most frequently cited were detail-focused (logistical and technical details related to the retaining wall), most students were relatively balanced in their emphasis on detail and context. Breadth in the playground responses was similarly varied, but as in the MWF responses, context-orientation was more common among women, who were more likely to select items such as *Neighborhood demographics* and *Handicapped accessibility* and less likely to select items such as *Budget*. Since students were forced to select exactly five kinds of information in their playground responses, more focus on context almost always meant less focus on detail. In the MWF responses, however, which were free-response and not constrained in this way, women matched men in the number of detail-related factors but exceeded men in the number of context-related factors, on average. Finally, a joint analysis of context-orientation revealed a weak but statistically significant, positive correlation between responses to the two problems.

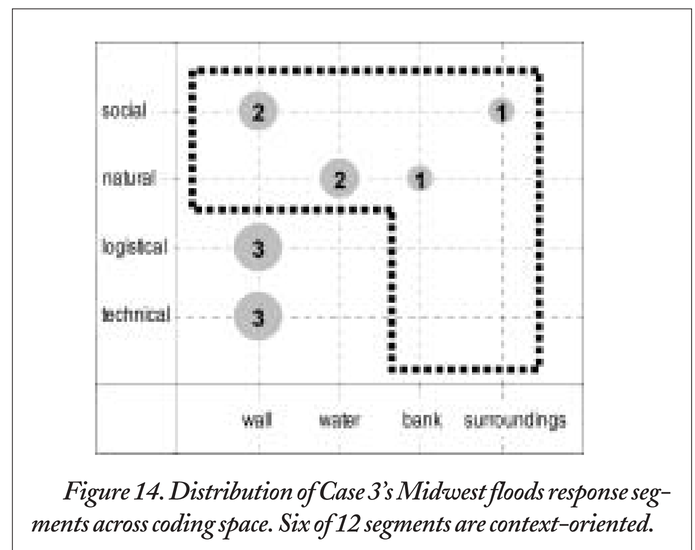


Figure 14. Distribution of Case 3's Midwest floods response segments across coding space. Six of 12 segments are context-oriented.

V. Discussion and Implications

There are many factors to consider when analyzing how broadly engineering students scope a particular engineering design problem, including the qualities of the design problem itself and how analysts interpret students' responses to the problem; students' familiarity with different aspects of the problem; and finally, students' inclination to situate any problem in context. A specific engineering design task like the MWF problem may lend itself to a particular distribution of ideas oriented toward detail or context. In the aggregate, segments were distributed evenly between detail (48.2 percent) and context orientation (51.8 percent). As described previously, this distribution is at least in part a function of the nature of the problem itself and how the research team coded and interpreted the data.

Furthermore, students may view the problem in relation to their interests and/or abilities to solve it, and therefore may be inclined to focus their approach on aspects of the problem that highlight their strengths. First-year students' reasonably strong performance in terms of including natural and social factors in their responses to the MWF problem actually may be related to their novice status as engineers. Many first-year students may feel unqualified to discuss technical and logistical details related to the design of a retaining wall, but we think most students were comfortable making general statements about water quality, river flooding, and rainfall (everyone can find at least something to say about the weather!).

This leaves us with the factor most important to our claims: the extent to which students are motivated and have the skills and abilities to situate any engineering design problem in context. Our study not only described one contextually situated design task, but described results from two such tasks. The finding that students who emphasized context in the MWF problem also were likely to emphasize context in the information gathering task suggests that there is an aspect of the student's ability and inclination to situate design problems in context more generally that is not an artifact of a particular design problem itself nor the student's knowledge of or interest in the specific task domain.

Our findings that women emphasized design context more than men suggest that first-year students' experiences, interests, and ways of knowing are also sources of this variation in how broadly students scope design problems. As discussed previously, women and men tend to exhibit differences in patterns of intellectual development, and women may perceive that there is a mismatch between what engineering has to offer them and what and how they know about their world. This is especially unfortunate if first-year women's greater emphasis on context is associated with their different ways of knowing, because those who are discouraged from engineering leave for precisely the reasons we want them to stay.

Considering the fact that the engineering education community wants students to approach engineering design contextually, it is important to acknowledge that there is a discrepancy between our intentions and what we actually accomplish. The gender differences in the present study suggest that first-year women are more ready than men to do engineering in context, yet the literature shows they are less likely to be recruited and retained.

While excellent examples of courses and curricula to address issues of context exist across the country, the majority of engineering students in the country do not have access to them. Most engineering students still take a traditional sequence of math, science, humanities, and engineering classes, but often it is not until their senior capstone course that they are involved in engineering design. In these capstone courses, the students must learn a myriad of critical elements of engineering practice, such as risk analysis, probabilistic thinking, creativity, ethics, project management, engineering analysis, and many other aspects of high-quality and responsible engineering design. Given the competing demands for course time, study of context can be limited.

While difficult to achieve, there is still a practical need to have our graduating students achieve the ABET outcomes described previously and enter the work world better prepared to participate in the global society. There is also a need to support the engineering faculty who typically teach design courses, some of whom do not have the experience or expertise to develop classroom materials to teach these topics. Both the students and the faculty need access to research-informed classroom materials and assessment instruments to ensure that engineering students include global and societal issues in their engineering design processes. These specific tasks and others like them may themselves be incorporated as educational tools to promote learning about context, and as assessment tools to establish how broadly students are scoping engineering design problems.

This study suggests many directions for future research. Longitudinal data exist for these students, and we expect that how they think about and do engineering will change over time. An examination of this engineering performance task data through a cognitive developmental lens may provide a more sophisticated illustration of the relationship between engineering thinking and doing, as well as additional input into instructional design and program planning that provides appropriate learning challenges and support that are sensitive to students' readiness.

Furthermore, the literature tells us that certain engineering disciplines attract more women than others. An analysis of this dataset by engineering major will provide insight into whether there is a connection between context-oriented engineering thinking and doing and choice of major.

In conducting gender studies, we must not ignore the fact that there are intersecting sources of identity development and social group membership, including race/ethnicity and socioeconomic class. We chose to focus on gender differences in this paper, and intend to conduct similar analyses in the future to see if these differences hold across race/ethnicity categories. Future work should include a more thorough investigation of these important components of students' identity and experience.

The engineering education community continues to struggle to attract and retain women in engineering, despite years of research and interventions designed to improve our abilities in this area. This study provides important information toward greater equity between men and women. The way women "do" engineering contains at least one set of qualities we aim to develop in our students. Opportunities to engineer in context early in engineering education programs would communicate our respect for such attitudes and abilities, thus drawing and keeping more women among our ranks.

Acknowledgements

This material is based on work supported by the National Science Foundation under Grant No. ESI-0227558 which funds the Center for the Advancement of Engineering Education (CAEE). CAEE is a collaboration of five partner universities: Colorado School of Mines, Howard University, Stanford University, University of Minnesota, and the University of Washington. The analysis described here is also supported by the National Science Foundation under Grant No. EEC-0639895. We would also like to acknowledge Robin Adams and Jenni Rees for their contributions to this project and Jennifer Turns, Eddie Rhone, and Laura Bogusch for their efforts on related work.

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