AC 2012-5232: EXPLORING IF AND HOW KNOWLEDGE OF A HUMANITARIAN DISASTER AFFECTS STUDENT DESIGN THINKING

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Exploring If and How Knowledge of a Humanitarian Disaster Affects Student Design Thinking

Abstract

Successful engineers increasingly need skills and knowledge beyond the technical know-how that engineering education has traditionally provided. To respond to the calls of ABET and NAE, engineering educators seek ways to emphasize and develop broad thinking. The work presented in this paper provides insight into how engineering education might broaden its coverage to better address such modern challenges as globalization, climate change, and issues of social justice. In this paper, we present new findings from a recent analysis of semi-structured interviews that were conducted during the spring of 2006 as part of the Center for the Advancement of Engineering Education's (CAEE) Academic Pathways Study (APS). These interviews of third-year engineering students at a large, public research university in the western U.S. took place immediately following a short design-scoping task (the analysis of which is reported elsewhere [1, 2]) that asked students what factors they would take into account in designing a retaining wall system to contain flooding of the Mississippi River. The follow-up interviews then asked the students to reflect on their design task responses and included questions about their knowledge of Hurricane Katrina, which had occurred the previous summer, and the influence such knowledge might have had on their responses.

The research question driving this analysis can be articulated as follows: In what qualitatively different ways does knowledge of a humanitarian disaster influence student thinking on a conceptually related design task? Given the qualitative nature of the data and the exploratory nature of our research question, our analysis follows a descriptive approach that incorporates elements of phenomenography and primarily aims to capture the breadth and diversity of responses. Thematic analysis of twenty-five transcripts from one institution shows that, while many students indicated their knowledge of Hurricane Katrina did not influence their design task responses, others reported ways that it affected their thinking to varying degrees. The latter group of students described four major areas of concern: people, the natural environment, the designed artifact (i.e., the retaining wall), and aspects of the design process. Interestingly, all but one of the twelve students who indicated how Katrina knowledge influenced their responses said that it caused them to consider people issues, such as the societal impacts of engineering design and the importance of protecting human life. Thus, we observe that, for those students who saw the design task as related to the events of Hurricane Katrina, knowledge of these events elicited design thinking beyond the narrow confines of purely technical considerations. One practical implication emerging from this work is that framing or associating design problem-solving with certain kinds of real-world events might improve engineering students' capacity for broad thinking and concern for others—the kinds of competencies needed for addressing issues of sustainability, ethics, and social justice. Future work includes analysis of interview transcripts from three other institutions where these design tasks and post-task interviews were also conducted.

1. Introduction and Related Literature

Current national priorities in engineering education in the U.S., such as those advanced by ABET (formerly known as the Accreditation Board for Engineering and Technology) and the National Academy of Engineering's *Engineer of 2020* reports [3, 4], emphasize the importance of training engineers to situate their work more broadly. For example, ABET requires accredited engineering programs to have documented specific student outcomes, including the following*:

(c) 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
(f) an understanding of professional and ethical responsibility
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

Due to factors such as globalization, climate change, and even issues of social justice, engineers must learn to include and address considerations beyond the traditional engineering purview of the technical and economic. Ethics and the social/societal impacts of engineering, for example, rarely find much space (let alone integration) in a curriculum packed with technical topics [5].

There are many possible ways to expand coverage of these important broader considerations, and thus to provide opportunities for broader ways of thinking in engineering education. Common approaches to teaching engineering design incorporate some of these ways through project-based learning, which finds instantiation in senior capstone design projects [6, 7], first-year cornerstone design projects [7], and service learning [7, 8]. Closely related, the Aalborg problem-based learning (PBL) model also focuses on contextualizing learning and problem-solving [9]. Litzinger et al.'s [10] discussion of expertise and engineering education emphasizes the importance of the "context-rich, multifaceted problems" commonly embedded in all of these approaches.

Empirical research on engineering design validates ABET's and NAE's calls for developing engineering students' broad thinking ability. Atman et al. [11] found that senior engineering students who gathered a wide range of information about a design problem tended to produce better solutions. However, further studies suggest that engineering students are *not* developing abilities in context consideration: two longitudinal, multi-institution studies of engineering majors show little change in the consideration of design problem context over the course of four years of undergraduate study [12, 1].

Another way to facilitate broad thinking might be to increase student awareness of the design process. In his review of work on design expertise, Cross [13] reported that the use of design strategies (instead of crude, "guess and check" approaches) distinguishes expert designers from novices in engineering and in product design. As detailed later in this paper, both breadth of thought and awareness of aspects of the design process are reported to be triggered by knowledge of Hurricane Katrina.

2. Data and Analysis

The research question driving this work can be articulated as follows: ***In what qualitatively different ways does knowledge of a humanitarian disaster influence student thinking on a conceptually related design task?*** To address this question, we are conducting a qualitative study

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* ABET Criteria for Accrediting Engineering Programs, 2012 – 2013, General Criteria 3 Student Outcomes http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Process/Accreditation_Documents/Current/eac-criteria-2012-2013.pdf

on a subset of longitudinal cohort data from the Center for the Advancement of Engineering Education's (CAEE) Academic Pathways Study (APS). As described in the CAEE final report [14] and further detailed in the CAEE Technical Report CAEE-TR-09-03 [15], a broad and diverse selection of forty undergraduate students at each of four U.S. institutions was surveyed, interviewed, and observed throughout the course of their four years of undergraduate education. In the first and third years of this study, these students performed a ten-minute design-scoping task that read, *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?* In the third year (spring of 2006), upon completion of the design task, the students were then asked to reflect on their design task responses using the interview protocol summarized in Table 1.

Table 1: Protocol Questions from the Year 3 Post-Task Interviews

Question #	Question Text
1	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?
2	What questions came to your mind as you were brainstorming your list?
3	Take a look at both the response you just wrote today and your response from two years ago. What similarities and differences do you notice between the two responses?
4	You've told me a little about how your responses are similar or different. How about how you came up with them? Consider how you thought about the activity and how you came up with the factors you wrote down, both today and two years ago. What similarities and differences do you notice?
5	Have you had any past experiences that helped you do the written activity? (If so, please describe.)
6	Have you had any educational experiences that helped you do this activity? (If so, please describe.)
7	How familiar are you with Hurricane Katrina and the flooding in New Orleans? Could you tell me what you know about these events?
8	**Did what you know about these events affect how you approached the Mississippi flooding activity today? (If so, please describe.)**

Most students who had completed the design task in Year 1 were given an opportunity to compare their Year 1 and Year 3 responses as part of this post-task interview. In this paper, analysis is focused on student responses to Q8 (highlighted in the table), which asks about the influence that Hurricane Katrina might have had on their design task responses. Specifically, the interview question associated with the data analyzed in this paper asked, *Did what you know about [Hurricane Katrina] affect how you approached the Mississippi flooding activity today? If so, please describe.* Hurricane Katrina struck land in August of 2005; therefore its aftermath in New Orleans and surrounding areas of the Gulf Coast had been in the news for the eight to nine months prior to these interviews. In our sample of 32 interviews conducted at a large, public research university in the western United States, 25 transcripts contained responses pertinent to Q8. The difference is a result of having not asked all interviewees the Katrina questions (Q7&8) at this institution due to the use of a branched protocol, the details of which have been omitted for clarity. Interestingly, two students spontaneously mentioned Katrina during the interviews, though only one of these was later prompted by the interview protocol questions (Q7&8) to discuss it. As explained below in Section 2.2, any responses pertinent to Q8 are utilized in this study regardless of where in the transcript they might have occurred.

Table 2 summarizes the demographics of the 25 students whose responses provide the data for this analysis. In recruiting study participants, diversity was a major objective (see [15]), so student groups that are traditionally underrepresented in engineering, such as women and racial/ethnic minorities, were intentionally over-sampled. The limited degree of racial/ethnic diversity in our sample is reflective of the demographics of the analyzed institution's enrollment. However, 40% of the study participants were female—significantly higher than the approximately 20% in the sampled population. Other demographic highlights include the inclusion of a significant number of Asian / Asian Americans and non-native speakers of English, as well as representation from nine different engineering majors.

2.1. Analysis Methods

Given the qualitative nature of the data and the exploratory nature of our research question, analysis followed a descriptive approach that employs elements of phenomenography in order to capture the breadth and diversity of responses. Case & Light [16] provide an introduction to phenomenography in their recent paper outlining a selection of qualitative methodologies that are "promising but as yet not well represented in engineering education research." Recent examples of phenomenography in use in engineering education can be found in Mann et al. [17], who used it to study student conceptions of sustainable design; Calvo & Ellis [18], who used it to study student conceptions of tutor and automated feedback in professional writing; and Zoltowski et al. [19], who used it to examine student conceptions of human-centered design.

Phenomenography can be described as an interpretive research methodology that makes use of thematic analysis to study the qualitatively different ways in which a group of people report their experiences of a specific phenomenon. Its focus is on the variations in ways people experience or think about something. This is in contrast to the better-known phenomeno*logy*, which attempts to identify the common or essential experience of a phenomenon. As described by pioneering contributors to the methodology, phenomenography seeks "the totality of ways in which people experience, or are capable of experiencing, the object of interest and interpret it in terms of distinctly different categories that capture the essence of the variation…" [20]. The purpose of a phenomenographic study is thus to gain a clearer understanding of the participants' collective breadth of experience by creating inductively derived codes or themes and grouping them into higher-level "categories of description" that describe the "outcome space" (a term for the totality of ways people experience something). As described by Marton and Booth [20], the resulting categories of description should (a) show "something distinct about a particular way of experiencing a phenomenon"; (b) have a logical and frequently hierarchical relationship with one another; and (c) as a group, be parsimonious, with as few categories as possible to capture the critical variation in the data. Other important elements of phenomenography include taking participant self-reports as the object of analysis (rather than holding the phenomenon itself as the object of study) and utilizing interview transcripts in their entirety (rather than decontextualized selections of the transcripts). Phenomenographic studies are usually conducted using structured or semi-structured interviews of participants sampled to maximize variation, in the interest of capturing breadth of perspectives (and thus a more complete picture of the outcome space).

Table 2: Summary of Interviewee Demographics

Demographic	Value	# of Participants
Gender	Female	10
	Male	15
Race/Ethnicity	Asian American / Asian	9
	Mixed*	3
	White / Caucasian	13
Native Language	English	17
	Other than English	8
Birthplace	United States	18
	International	7
Major	Aeronautical Engineering	3
	Bioengineering	1
	Chemical Engineering	4
	Civil & Environmental Engineering	1
	Computer Science & Engineering	5
	Electrical Engineering	2
	Industrial Engineering	2
	Mechanical Engineering	6
	Technical Communication	1

* In this data set, those reporting mixed race/ethnicity indicated both White / Caucasian and one of the following: American Indian / Alaska Native, Mexican American / Chicano, or Native Hawaiian / Pacific Islander

2.2. Application of Analysis Methods

Consistent with accepted practices in qualitative research for ensuring methodological soundness, we provide here a summary of our specific analysis approach, to aid the reader in understanding the research context and process of the work. The purpose here is to allow the reader to gain a sense of the "trustworthiness and authenticity"[21] of the work by providing evidence of its credibility, dependability, and confirmability (qualitative analogues to the quantitative notions of internal validity reliability, and objectivity, respectively [22]). Papers presenting qualitative research commonly include details about the study context and process, enabling the reader to make judgments about the work's transferability (the analog to quantitative notions of external validity and generalizability).

In this paper, the following elements of phenomenography were used to guide our analysis:

- taking participant self-reports of experiences as the object of study
- utilizing the entire transcript as the corpus for analysis rather than just the response to protocol question of interest, which would have not only lost some important context, but would have missed all unprompted mentions of Katrina influence
- utilizing a diverse sample of engineering students as study participants (see Section 2)
- providing a descriptive coverage of the entire space of responses rather than just focusing on the most common responses
- striving for parsimony and logic in the resultant system of categories of description

Another element of phenomenographic analysis is the examination of relationships among the categories of description. The findings reported here primarily describe the outcome space (i.e., the range of variation exhibited in the responses). The category relationships will be analyzed and articulated later using additional data from the other three participating institutions. Ongoing preliminary analyses of this data indicate that the categories of description presented in this paper cover the outcome space. However, we recognize the possibility that further analysis could expand the outcome space with additional categories of description or even possibly change it entirely, should we find a better one (see Section 4). Findings concerning how Katrina knowledge influenced design from our initial, single-institution analysis not only address our research question (see Section 2) but also suggest a variety of new research hypotheses (e.g., see the last paragraph of Section 4).

While the focus of this analysis was on responses to Q8 (i.e., whether and how knowledge of Katrina affected design task responses), initial coding was performed by reading the entire post-task interview transcripts, tagging each protocol question asked (for subsequent navigational purposes), and inductively coding (i.e., without a priori codes) all Katrina-related responses, regardless of where in the transcript they may have occurred[*]. ATLAS.ti qualitative data analysis software was used to facilitate this process. Following the initial coding pass, an iterative process of re-reading and evaluating applicability of the passages to the codes was performed. This process included renaming and/or re-assigning codes to some of the passages and was conducted while writing up the Findings section of this paper. In parallel with this iterative process, the lead author met frequently with the second author to discuss both the low-level, grounded[†] code names, definitions, and applications, and the higher-level categories of description. Furthermore, the lead and second authors held regular conference calls with the other members of the project team to report out and get feedback on the analysis and higher-level categories of description.

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[*] This decision, made in accordance with the phenomenographic principle of utilizing the complete interview transcript, maximizes available data by allowing the inclusion of pertinent data that happens to fall outside the direct response to the prompted interview question. In the reported analyses, such responses were few and were interpreted and utilized judiciously.

[†] Grounded codes are "closer to the data" in that they are assigned with minimal interpretation of data and are given names that match or closely resemble relevant wording in the coded data where possible.

In selecting quotations for inclusion in this paper to illustrate emergent themes, the following criteria were used, presented here roughly in order of priority:

a. The quote should be clearly illustrative of the intended theme.
b. The quote should be easy for the reader to understand without excessive additional contextual explanation to situate and clarify the interviewees meaning (where possible).
c. The quotes selected should illustrate the breadth of any nuanced sub-themes within a major theme.
d. The number of quotes selected should be approximately related to the number of individuals contributing to that theme (i.e., more quotes for more common themes).
e. The quotes selected should give voice to a variety of interviewees and thus not privilege some perspectives over others.

3. Findings

The post-task interview question analyzed in this paper was Q8: "Did what you know about [Hurricane Katrina] affect how you approached the Mississippi flooding activity today?" We found in the responses indications of *if*, *why*, and *how* Katrina affected the design task responses. Thus, the responses are discussed below under the following three groupings:

1. Indications of *if* knowledge of Katrina affected their design tasks
2. Indications *why* knowledge of Katrina affected or did not affect their design tasks (where such information was provided)
3. Indications of *how* knowledge of Katrina affected their design tasks (where such information was provided)

When discussing each of these groupings, a summary of the low-level grounded codes and any higher-level categories of description are first presented, followed by example quotations that illustrate each code. Quotations are numbered for ease of reference. Note more than one grouping (i.e., *if*, *why*, or *how*) and more than one code within those grouping may apply to any given quotation, since the quotations are intentionally presented in context to allow the reader to evaluate the quality of the codes. In accordance with phenomenographic methodology, findings in the tables do not include explicit participant counts. Such quantitative reporting could facilitate essentializing interpretations that would neither be aligned with our research question nor be appropriate for the small sample size.

3.1. Findings: Did Knowledge of Katrina Affect Responses?

Table 3 indicates *if* knowledge of Hurricane Katrina affected student thinking. Responses ranged from affirmative to negative, with many students indicating at least some influence. The first code listed in the table (Definitely) is comprised of responses indicating that Katrina definitely affected performance of the design task. The second code (A Little) contains responses that indicate Katrina had a little bit of effect, with a positive and sometimes surprised connotation. The third code (Not Much) contains responses indicating that knowledge of Katrina did not have much effect, with a negative connotation. The fourth code (Not at All) is comprised of responses indicating that knowledge of Katrina did <u>not</u> affect their design task responses. This set of codes is mutually exclusive in that each interview was coded with one and only one of these four codes.

Table 3: Indications of *If* Knowledge of Katrina Affected Design Tasks

If Code†		Reported effect of Katrina knowledge	Pseudonyms of interviewees
Yes	Definitely	definitely affected performance of the design task	Mimi, Amanda, Justin, Nicholas, Jesse, John
	A Little	had a little bit of effect (i.e., with a positive connotation) on the design task	Bryn, Emily, Samantha, Johnny
	Not Much	did not have much effect (e.g., with a negative connotation) on the design task	Tarja, Lauren, Matthew, Brian, Austin
No	Not at All	did not affect performance of the design task	Jill, Kara, Elizabeth, Andy, Colin, Drew, Ethan, Brandon, Frank, Michael

† These codes are mutually exclusive (i.e., each interview is assigned one and only one code).

3.1.1. Illustrations of the "Definitely" Code

As indicated in Section 2 above, prior to being asked the protocol questions about Katrina, most of the students were presented with their design task responses from Year 1 and asked to compare them with what they had just completed (Q3&4). This may have helped some students to recognize the influence that Katrina had on their thinking. In fact, in response to Q4 (i.e., compare similarities and differences in approach to the design task between Year 1 and Year 3), two students spontaneously indicated that Katrina affected their responses. Jesse clearly stated the influence of his awareness of Katrina:

> "Um, well, I think similarities, just visualizing just an arbitrary river with the flood and kind of what a wall would look like. I think a major difference was that before last time and this time, like Katrina happened, and so there's like actual flooding and like these levies broke, and – and, you know, caused all this water to flow into a city, and so just the consequences of that, just seeing that not firsthand but through TV. You know, that definitely had an impact on what I thought." —Jesse
> (1)

When he was later asked the protocol question (Q8, i.e., did knowledge of Katrina affect design task responses), Jesse reiterated his above assertion*. Other students, now in response to Q8, provided further reflection and comparison of their Year 1 and Year 3 design tasks as influenced

* The quote for the other student, Mimi, who was never asked the protocol question but spontaneously mentioned Katrina, will be discussed later in Section 3.3.1.

by their knowledge of Katrina. Justin, for example, was at first skeptical of an influence, but then realized and articulated that influence*:

> "I'd say at most it sounded similar, but, um – yeah, so it did affect how I approached this activity, the second response, because, I mean, my first answer is who needs to be protected from the floods, and before I never – I never really talked about the people involved. In my earlier response I didn't talk about the people involved, but in the second response I did talk about people." —Justin
> (2)

Some students were particularly confident in their affirmative responses to Q8, as exemplified by this quotation:

> "Yeah, I think definitely, because I thought about like what's – what's the reason that caused the flooding..." —Amanda
> (3)

3.1.2. Illustrations of the "A Little" Code

Some responses to Q8 were less decisively affirmative than the previous code but still indicated that knowledge of Katrina had some limited influence. The following quotes are illustrative of this:

> "So, yeah, just relate it back to Hurricane Katrina, um, it does help a little, because you know it's realistic to become concerned with [such severe flooding]." —Johnny
> (4)

> "I guess I did kind of think about that." —Samantha
> (5)

3.1.3. Illustrations of the "Not Much" Code

Similarly, some responses to Q8 indicated that Katrina knowledge did not have much influence (e.g., with a negative connotation). The following is an example:

> "It crossed my mind, but it – I guess I don't know any – much about the engineering behind rebuilding New Orleans, so it didn't come up too much." —Tarja
> (6)

Some of students even appeared to be somewhat dismissive of the influence that Katrina knowledge had on their responses, such as the following:

* An alternative explanation is that he was led by the interview protocol to attribute his consideration of people to knowledge of Katrina. However, either way, something caused him to consider the protection of people where he did not do so before. Analysis of themes such as consideration of people will be described in Section 3.3.1.

"Uh, I guess I talked about how the walls or the system would need to be better around where people were living, but that's really it, just trying to protect human life more... I didn't really take that into a huge account." —Brian (7)

"Um, I think really not too much. Um, I mean, yeah, so I mean both times you look at possibilities of, you know, how much the water could rise or, I guess, any other damage that could happen to the wall. It seems like a pretty obvious consideration. I mean you don't need a hurricane to tell you that if you're building – I mean if you're building a retaining wall you want to look at, you know, possible water rise, it seems. That's kind of the purpose. I don't think – yeah, I mean..." —Austin (8)

3.1.4. Illustrations of the "Not at All" Code

Prior to being asked Q8 (i.e., did knowledge of Katrina affect design task responses), the students were primed by the interviewer with Q7 (i.e., what do you know about Hurricane Katrina and the flooding in New Orleans). In spite of being "warmed up" by talking about what they knew about Katrina, most negative responses to Q8 were short, direct statements of "no" without explication (and without further prompting by the interviewer)*. Some students, however, provided additional insights as to why Katrina knowledge had no effect, as exemplified by Michael:

"No, not at all. Probably because I just didn't think of it the same at all. I guess I could have. I mean I see the link now..." —Michael (9)

Other students expressed somewhat less confidence in their responses, though still clearly negative, with one indicating that it could have affected him at most subconsciously:

"I don't know. They seem kind of different to me, because – yeah. Maybe it did in some subconscious way, but I don't think so, not conscious[ly]." —Andy (10)

3.2. Findings: Why Katrina Did or Did Not Affect Responses

Table 4 provides a summary of all indications given as to *why* knowledge of Katrina did or did not affect responses to the written design activity. The more prevalent responses were

a. that Katrina only crossed their minds but did not affect their responses
b. they did not recognize the similarities between Katrina and the design task

* It occurred to us that the students who replied with simple "no's" might have been less primed than those who gave longer answers if they were of the subset not asked to compare their Year 1 and Year 3 design task responses (i.e., Q3&4). This, however, proved not to be the case, as five students (Tarja, Bryn, Johnny, Andy, and Colin) were not asked Q3&4, and yet only Colin gave a short one-word negative response. Interestingly, however, none of these five gave a strong affirmative response. (Bryn gave a mild affirmative response, Johnny gave a mild negative response, and Andy gave a strong negative response with explanation.) While perhaps these five responses would all have changed had these students done the Year 1 vs. Year 3 comparison, there is clearly no direct relationship between level of priming and terse negative response.

c. design considerations are the same regardless of where a flooding incident occurs
d. lack of knowledge about Katrina limited or precluded its influence on their responses

Table 4: Indications *Why* Knowledge of Katrina Affected or Did Not Affect Design Tasks

Why Code †	Reported Reason	Mapping to *If* Responses from Table 3			
		Definitely	**A Little**	**Not Much**	**Not at All**
First thing that came to mind	Katrina was the first thing that came to mind	Nicholas			
Subconsciously	Katrina may have had a subconscious effect	Justin			Andy
Noticed similarities	explicit recognition of similarity between Katrina and the given design task (i.e., Katrina also had retaining walls)		Bryn	Lauren	
Not enough knowledge	Lack of knowledge about Katrina, but the similarities were/are recognized		Johnny	Tarja	Michael
Same considerations regardless	design considerations were/are the same regardless of where such a flooding incident occurred			Austin	Drew, Brandon
Crossed my mind but	Katrina crossed their minds but did not affect responses much, if at all			Tarja, Lauren, Matthew	Jill
Specific context matters	that the specific locational context matters (i.e., thinking of St. Louis, not New Orleans)				Drew
Did not recognize similarities	lack of recognition of similarities between Katrina and the design task (at least initially)				Jill, Andy, Michael
No Reason‡	NA (no why or why not information available)	Mimi, Amanda, Jesse, John	Emily, Samantha	Brian	Kara, Elizabeth, Colin, Ethan, Frank

† Many individuals indicated multiple reasons, thus, unlike Table 3, these codes are not mutually exclusive.

‡ This code indicates student responses that provided no information *why* Katrina knowledge did or did not influence design task performance. However, many of these interviewees did indicate *how* (i.e., in what ways) Katrina influenced their responses as described in the following section.

The total number of responses is 20, which is fewer than the number of participants because not all participants indicated why Katrina knowledge affected, or did not affect, their design task responses: 13 of the 25 interviewees who talked about Katrina provided such information. Note that many individuals gave multiple reasons; thus, unlike in the previous table, these codes are not mutually exclusive. For the sake of completeness, the last code presented in Table 4 indicates those students who gave no indication why Katrina knowledge did or did not affect their responses. To make certain patterns in the data more visible, the *why* codes of Table 4 are organized by the way they map to the responses of Table 3 (i.e., *if* Katrina knowledge affected responses), with the reasons why appearing toward the top of the table and the reasons why not appearing toward the bottom, with the last row showing students who gave no reason at all. While there appears to be some tendency for certain reasons to be associated with certain responses, as evidenced by the diagonal pattern that appears in the table, no clear or meaningful pattern has emerged from the data, since specific reasons appear across multiple contrary responses (e.g., "Subconsciously," which can be both a reason why and a reason why not).

Since the answer to this question (why or why not) (a) was not explicitly asked in the interview protocol (appearing here only as a potentially interesting byproduct of the interview responses); (b) provides little insight, beyond the listing of reasons, into why students responded as they did; and (c) is less conceptually relevant to the research questions than the next question ("if so, how"); the full quotes illustrating each of these themes will not be provided here, in the interest of brevity, thus saving the reader several pages of text. The interested reader is referred to the quotations in the section above, which illustrate many of these themes. Specifically, both the "Crossed my mind but" and the "Not enough knowledge" codes are exemplified by Tarja in quote number (6) when she said, "It crossed my mind, but…I guess I don't know…much about the engineering behind rebuilding New Orleans." Similarly, the "Same considerations regardless" code is illustrated by Austin in quote number (8) when he said, "You don't need a hurricane to tell you that if you're building…a retaining wall you want to look at…possible water rise." The code "Did not recognize similarities" is typified by quote number (9) from Michael, who said, "Probably because I just didn't think of it the same at all," and quote number (10) from Andy illustrates the "Subconsciously" code with, "Maybe it did in some subconscious way, but I don't think so, not conscious[ly]."

3.3. Findings: Ways in Which Katrina Affected Responses

Table 5 indicates *how* (i.e., in what ways) knowledge of Katrina affected responses to the written design activity. The most prevalent responses were that Katrina caused students to consider issues of human safety/protection and impacts on the ecosystem. Other common responses included consideration of economics, people in general, and the importance of technical design criteria such as wall strength and dimensions. The total number of response codes was 19, which is more than the number of participants because most participants indicated more than one way in which Katrina influenced their responses; in fact, 12 of the 25 interviewees who talked about Katrina provided such indication*. The number of different ways indicated by each student varied from 1 to 8, with a median value of 2.5. These grounded codes are grouped in Table 5 by higher-level categories of description we are referring to as *areas of concern*. These are the phenomenographic categories of description that emerged, and they are labeled "People", "Natural Environment", "Designed Artifact", and "Process of Design." It is these categories† that will be used below to present what we believe to be the most interesting findings of the analysis.

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* Note that this group of students is a slightly different subset than those presented previously in Table 4, which included some students for whom Katrina knowledge did not affect their responses (and thus gave no ways in which their responses were affected). Furthermore, a few students who indicated that Katrina knowledge influenced their thinking neglected indicate how it did so in their interview responses.

† A number of ways of organizing and discussing the 19 response codes presented in Table 5 are possible, and many were explored. See the Discussion section for more on this matter.

Table 5: Indications of *How* Knowledge of Katrina Affected Design Tasks

Area of Concern	*How* Code*	Reported way in which Katrina knowledge affected design task	Pseudonyms of interviewees†
People	Economics	consideration of cost/benefit or who pays for the retaining wall	Mimi, Johnny, Jesse
	Human Protection	consideration of human safety and protection from flooding	Amanda, Justin, Brian, Nicholas
	People	consideration of people (non-specific)	Emily, Samantha, Justin
	Politics	political considerations or impacts	John
	Population Density	consideration of population density as a design constraint	Nicholas
	Social Impacts	consideration of social issues (e.g., why only some areas flooded, housing/job loss, tourism suffering)	Bryn, Jesse, John
Natural Environment	Climate/Weather	climate or weather as a design consideration	Johnny, Jesse
	Ecosystem	environmental concerns or impacts	Amanda, Johnny, Jesse, John
Designed Artifact	Wall Aesthetics	wall aesthetics as a design consideration	Samantha, Jesse
	Wall Dimensions	wall height, length, or size (non-specific) as a design consideration	Bryn, Johnny, Jesse
	Wall Lifetime	wall lifetime as a design consideration	Bryn
	Wall Materials	wall materials as a design consideration	Johnny
	Wall Quality	wall quality as a design consideration	Bryn, Brian
	Wall Strength	wall strength as a design consideration	Bryn, Lauren, Samantha
Process of Design	Made It Real	notions of making it real (legitimizing or providing a way to visualize)	Johnny, Jesse
	Root Causes	the importance of addressing root causes	Amanda
	Unintended Consequences	the need for anticipating unintended consequences	Jesse
	Urgency	project timeline and urgency	Johnny
	Worst-case	consideration of worst-case scenarios	John

* Many individuals indicated multiple ways in which Katrina knowledge influenced their thinking, so these codes are not mutually exclusive with respect to the interviewees.

† The interviewees who did not provide *how* indications and are thus not listed on this table are Tarja, Jill, Kara, Elizabeth, Andy, Colin, Matthew, Drew, Austin, Ethan, Brandon, Frank, and Michael

3.3.1. Illustrations of the "People" Category

The "People" category includes responses indicating consideration of human interactions with the design, in both directions of influence: humans being affected by the design, as well as the design being influenced by human social constructions. As indicated in Table 5, this category is comprised of codes associated with economics, human safety and protection, non-specific consideration of people, political considerations or impacts, population density as a design constraint, and consideration of social issues (e.g., why only some areas flooded, housing/job loss, and the suffering of local businesses).

For Emily, consideration of people came up repeatedly in other parts of the interview, and by the end of the interview, a rather non-specific consideration of people was the only thing she could articulate:

> "Yeah, I'm just trying to think of how to put it in words. Um, just made me think about how it would affect the people around it. I feel like I've said that like eight times…"
> —Emily
> (11)

Justin, in quote (2) above, indicates both a general consideration of people with, "in the second response I did talk about people," as well as a more specific indication of how Katrina knowledge caused him to think about "who needs to be protected from the floods." Brian, in quote (7) above, indicates a specific way in which Katrina knowledge influenced his thinking with "trying to protect human life more."

Mimi made an unprompted association of Katrina with the consideration of economics and who pays for such infrastructure repairs or improvements, as the following statement during her comparison of Year 1 and Year 3 design task responses shows:

> "I thought more about like who would pay for it this time, stuff related to like – I guess I relate it to, you know, monorail or like the Katrina, like just what happened like people were – there was a lot of money involved."
> —Mimi
> (12)

Finally, Bryn, after speaking about the racial tensions she was aware of in Katrina's aftermath, indicated that Katrina made her think about specific aspects of her retaining wall design in terms of potential social impacts:

> "Um, maybe the – the society needs a little bit, but I think – because I remember hearing when we were – when Katrina went that there was a retaining wall and that's why a lot of this one area got flooded, and then right next to it there's another area that didn't, so that made me think of how strong would it be and how long would it last and the quality of it, so."
> —Bryn
> (13)

3.3.2. Illustrations of the "Natural Environment" Category

The "Natural Environment" category includes responses directed toward the physical, natural environment interacting with the retaining wall. As indicated in Table 5, this category is comprised of codes associated with environmental concerns or impacts and climate or weather as design considerations.

John listed a number of considerations that Katrina knowledge prompted, including environmental impacts, though he talked about it in a non-specific way:

> "Oh, yeah, yeah. Um, so I wrote down political, societal, environmental impacts as a factor into designing a retaining wall. That was definitely something I was thinking about." —John
> (14)

In contrast, Jesse had a lot to say about the weather and anthropogenic environmental impacts:

> "…and to think about different weather conditions and patterns and, you know, how, you know, for years they were saying that if – you know, they got a category 4 or 5 hurricane that came in, it would push enough water in there for it to topple over, and that was also a cause of the disappearing wetlands that acted as like natural filters of this water – not filters, but natural levies or whatever. But with the expansion of New Orleans, those were all just covered with cement so that – drainage, that's what I want. So there's no natural drainage left, so when the water just came in, and they knew, I mean, that this was coming, it's well documented, there are plenty of articles and warning signs that if, you know, this much hurricane came in it's going to topple the levies. But no one saw it coming, so you have to think about that." —Jesse
> (15)

In a similarly specific way, Johnny associated weather considerations with selection of building materials used:

> "And I also look at the weather, so if you are in different part of the country that would be like sun 24/7, and that sort of affects the materials that we use." —Johnny
> (16)

3.3.3. Illustrations of the "Designed Artifact" Category

The "Designed Artifact" category includes responses directed toward the designed artifact: the retaining wall itself. As indicated in Table 5, this category is comprised of codes associated with the wall's appearance, dimensions, functional lifetime, materials of construction, quality, and strength.

Bryn, in relation to the societal needs issue she mentioned in quote (13), indicated how Katrina knowledge made her "think of how strong would [the wall] be and how long would it last and the quality of it." Similarly, Johnny, just prior to mentioning weather in quote (16), talked first about materials:

"Um, looking at size and the materials and what kind of materials they should use…"
—Johnny
(17)

Samantha, after talking about an architecture course she took on the global South, in which the instructor also showed pictures of Katrina aftermath, indicated that Katrina made her cognizant of the aesthetics of the wall:

"I guess I did kind of think about that…I guess more on the appearance, just because that's our community, so there would be a couple of things." —Samantha
(18)

Based on the context provided by the rest of the interview, we can interpret Samantha to mean that the wall appearance is important because aesthetics influence a community's sense of pride or self-respect. Therefore, Samantha's quote was coded for both "Designed Artifact," since the appearance of the wall is her focus, as well as for "People," since "our community" is the explicit motivation for aesthetics consideration.

3.3.4. Illustrations of the "Process of Design" Category

The "Process of Design" category is conceptually distinct from the previous categories of the designed artifact and its environmental and social contexts. This category includes responses indicating how design is done or approached; i.e., it is process-focused rather than object-focused. As indicated in Table 5, this category is comprised of codes indicating notions of making it (the task) real (visualization and/or legitimization of the design task), issues of the timeliness or urgency of the work, considering worst-case scenarios (a type of heuristic design approach), anticipating unintended consequences, and addressing root causes.

Jesse, in quote (1), before even being prompted by the interviewer to consider Katrina, indicated how it helped him visualize: "…just seeing [the hurricane] not firsthand but through TV…definitely had an impact on what I thought." For Johnny, it helped with motivation by lending authenticity to the design task:

"It does help a little, because you know it's realistic to become concerned with."
—Johnny
(19)

Johnny's Katrina knowledge also caused him to think about the time element of design and its implications on the design approach:

"Well, for one, the question I was considering is, is it urgent? And for the Hurricane Katrina incident it was not urgent, it was just a one-time thing, and for the future, it would be like a pretty long time, maybe a year or two, before the wall or the levy needed to be used again, so I put out for time restraint would be like a long-term project that you can spend time actually doing, not needing to build one for like that day in like two weeks."
—Johnny
(20)

Amanda, in addition to talking about environmental impacts, also talked about how Katrina knowledge made her think about addressing root causes. We see this as evidence of a higher level of thinking about the design process, since she is in essence questioning the need for performing the design in the first place:

> "Yeah, I think definitely, because I thought about like what's – what's the reason that caused the flooding…So that all goes to because we're harming the environment, and that's pretty much what matters. If we can fix that, then we can fix a lot of things, and we cannot just like building a lot of construction, but that doesn't really help, because you know that will become worse if we don't fix the goal and the issue."
> Interviewer: "You're fixing the symptoms and not the problem."
> "Yeah, exactly." —Amanda
> (21)

4. Discussion

As shown in Table 3 (Section 3.1), which summarized *if* knowledge of Hurricane Katrina affected design task responses, a majority of the students reported that their knowledge of the disaster indeed affected their design task responses in some way; many also indicated that it did not. Possible reasons *why* it did or did not affect responses were summarized in Table 4 (Section 3.2), including reports of a lack of knowledge about the event as a limiting factor; a lack of recognition of the similarities between Katrina and the design task; that Katrina crossed their minds but did not affect responses much, if at all; and that design considerations are the same regardless of project location. These findings are interesting in their own right but are not the primary focus of this paper, which seeks to understand and describe the qualitatively different ways in which Katrina knowledge affected design task responses.

As presented in Table 5 (Section 3.3), indications of *how* (i.e., in what ways) knowledge of Katrina affected responses to the written design activity were grouped into four "areas of concern" representing the phenomenographic categories of description that emerged from the analysis. A number of ways of organizing and discussing the 19 response codes presented in the table are possible and many were explored, such as grouping by technical vs. non-technical considerations, by physical or conceptual proximity to the retaining wall (see [1]), and by types of stakeholders implied. However, each of these classifications proved problematic or undesirable in some way. Specifically, we found that grouping by technical / non-technical provided too coarse a classification that lost some of the richness of the data and ran the risk of perpetuating or implicitly endorsing the value hierarchy that persists in engineering of the "hard," important technical considerations versus the "soft," less important non-technical considerations (see [23], and c.f. "mindsets in engineering" in [24]). Grouping by physical or conceptual proximity to the retaining wall proved difficult for many codes that are either ambiguous or lie at the boundaries between categories, and this approach did not facilitate discussion of the inter-relations between considerations that many students identified (something we plan to develop later during analysis of data from the other institutions). Grouping by stakeholders required more interpretation of participants' words than we were comfortable performing, and many codes indicated multiple stakeholders. Ultimately, the most natural and parsimonious organization proved to be grouping by area of concern, as presented in the table.

One interesting observation about the emerging phenomenographic outcome space is that one of the four categories is of a conceptually distinct character from the others: Process of Design is a category characterized by reflection on self (metacognition around design) and/or reflection on engineering that involves a different level of abstraction than considerations of the designed artifact and its environmental and social contexts. Using data from the other participating institutions, further analysis of the outcome space should solidify and bring clarity to the outcome space and to the interrelations between categories of description.

In the interest of identifying patterns in the data of Table 5 (Section 3.3), Table 6 below provides a summary of the areas of concern for each interview participant, grouping them by the number of areas of concern that Katrina knowledge caused them to consider. The most striking finding Table 6 reveals is this: for nearly all the students who said Katrina knowledge influenced their design task responses, that knowledge prompted consideration of people issues, such as the societal impacts of engineering design, issues of cost and who bears it, and the importance of protecting human life. We can only speculate on what it was about Hurricane Katrina that prompted such uniformity of response to this particular area of concern across seven of the nine majors represented by this sample. It could be a random artifact of the small sample size or a byproduct of departmental culture or common classes taken, as the relatively high number of computer science & engineering (CSE) majors in Table 6 might suggest. It could have been the nature of the media coverage, or the fact that such a disaster occurred in our own country rather than in some far away place, or even some combination of these or other factors. Understanding the reasons for these findings would require additional analysis as well as data, and is beyond the scope of this work. (Here the objective is qualitative description and hypothesis generation.)

Table 6 also shows that, for some students, Katrina knowledge prompted consideration of all four areas of concern; however, for many students, only one category was mentioned in the interview. We must be careful here not to over-interpret the number of categories mentioned, because there are several possible reasons why an interviewee could have omitted considerations. Ideally, we would hope that if the interviewee did not mention something it was because he or she really did not think of it; however, given the practical constraints of the setting in which the interviews were conducted and the fact that this was the last question of a lengthy protocol, it is also possible that either the interviewee or the interviewer was tired, resulting in abbreviated or incomplete discussion. As a case in point, this interpretation is likely true for Lauren, who was the only person who did not mention a "People" area of concern. The end of her transcript is ambiguous, but it might indicate that she had something more to say before the interviewer concluded the interview:

> "Not really. I mean I thought about it a little bit. It was kind of the same way I was approaching – or I approached it the same way as last year, because I guess what happened with Katrina is the walls weren't strong enough, because it kept out the initial hurricane water but just crumbled.
> Interviewer: "Okay. That's really all I have on that part."
> "Oh, I thought… "
> Interviewer: "Do you want to add any more?"
> "No."
>
> —Lauren (22)

Table 6: Summary of How Katrina Knowledge Affected Design Tasks by Interviewee

Interviewee		Area of Concern†				Number of Areas of Concern Considered
Pseudonym	**Engineering Major***	**People**	**Natural Environment**	**Designed Artifact**	**Process of Design**	
Jesse	Mechanical	✓✓	✓✓	✓✓	✓✓	4
Johnny	Industrial	✓	✓✓	✓✓	✓✓	
John	CSE	✓✓	✓		✓	3
Amanda	CSE	✓	✓		✓	
Bryn	TC	✓		✓✓✓✓		2
Samantha	Bio-	✓		✓✓		
Brian	Mechanical	✓		✓		
Mimi	CSE	✓				1
Emily	CEE	✓				
Justin	CSE	✓✓				
Nicholas	Electrical	✓✓				
Lauren	Chemical			✓		

* Abbreviations: CEE = Civil & Environmental, CSE = Computer Science & Engineering, TC = Technical Communication (TC)
† For each interviewee, a ✓ indicates a unique (to that person) *how* code from Table 5 within the indicated area of concern.

Another interesting observation that can be made of Table 6 is that all four students for whom Katrina knowledge prompted consideration of the design process (i.e., Jesse, Johnny, John, and Amanda) indicated a greater number of areas of concern than those who did not. While the data set it small and we cannot infer direction of causality here, awareness of the design process appears to correlate with broad thinking in terms of the number of different areas of concern considered. One possible hypothesis to test is that making students more conscious of the design process might naturally lead to higher levels of broad thinking (i.e., considering more areas of concern).

Before discussing the implications of these findings, we should keep in mind the fact that Hurricane Katrina occurred in late August of 2005, and the design task exercises and post-task interviews of this research project were conducted in April and May of 2006. Katrina's aftermath in New Orleans and surrounding areas of the Gulf Coast had thus been in the news for the eight to nine months immediately preceding the interviews. Six and a half years later, however, the relevance and prominence of Hurricane Katrina in the minds of people today is likely to be much lower than in the years immediately following the disaster. Hurricane Katrina represents one example of a humanitarian disaster that engineers might learn a great deal from. Sadly, there are sure to be others in the future for which we can only hope to be better prepared.

5. Implications & Conclusions

Our findings suggest that simply invoking pre-existing knowledge of a real-world event like Hurricane Katrina could help engineering students think beyond the narrow confines of purely technical considerations during design. However, the substantial number of students in this study who did not report seeing the task as related to Katrina suggests that such an approach in teaching design would be more widely effective if the invocation of the event is supplemented by helping students connect it to the design task at hand*. The data also suggest a possible correlation between awareness of the design process and the number of different areas of concern students considered. There are several possible implications that emerge from these findings.

A broader design context that incorporates consideration of people and the environment, like that provided by Katrina, can be leveraged in educational settings to improve broad thinking skills, such as those required to address issues of sustainability, ethics, and even social justice [24]. These issues require concern for living (and sometimes non-living) things and are important to cultivate in engineers who might otherwise be too technology focused. Even the American public perceives engineers as being significantly less sensitive to societal concerns and less caring about the community than scientists are, according to the findings of a 2003 study conducted for the National Academy of Engineering [25]. Given the simplicity of the prompting to consider Katrina in this study, it suggests that even small changes in the kinds of design problems and problem-framing educators employ can effect broader thinking and reflection during design.

Another striking finding is the variation among students with respect to the number of areas of concern that the Katrina framing prompted. One explanation is that the kinds of reflection prompted by the framing (e.g., problem context, designed artifact, and/or design process) are a function of both the nature of the framing and the unique perspective, prior knowledge, and/or values of the student. Assuming so, we might expect better engineering work from design teams that exhibit diversity in these student attributes, assuming teamwork facilitation and assessment that make visible and value this diversity (see the legitimization of differences component of Brown & Campione's community of learners model [26], which aims explicitly to encourage such diversity).

The design task in this work is focused on the problem scoping that happens early in the design process. It is valuable for students to recognize the importance of contextual concerns about people and the environment, but this is just a first step. A question for engineering educators and researchers alike is how to support students in following through with the broader design thinking observed in this study. Engineering education might need to incorporate more of the knowledge and methods necessary to understand and address these contextual concerns. Solutions may lie in the project- and problem-based approaches referenced in the introduction, as well as the literature and practices of user-centered and sustainable design.

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* Note that the design task exercises and post-task interviews in this study were conducted in a research lab setting, not a classroom, and that the study not intervention based; thus, participants received no prior prompting or background materials in preparation for the design task.

5.1. Future Work

One direction we plan to pursue based on this work is using it to inform assessment of broad thinking. For example, the "area of concern" categories (People, Natural Environment, Designed Artifact, and Process of Design) can be used to create rubrics for faculty to assess student work and for students to assess their own or their peers' work in terms of breadth of design considerations.

Future work will also involve the analysis of interview transcripts from the three partner institutions at which these design tasks and post-task interviews were conducted. A more complete picture of the outcome space would be helpful, as additional data will surely provide new grounded codes and perhaps generate additional higher-level areas of concern. Additional *how* codes, which did not show up in the data, are certainly possible and easy to imagine. As a case in point, during one interview, Michael—who indicated in quote (9) that Katrina did not influence his response because he did not think of it the same way though he now sees the link—was asked a follow-up question that was not given on the protocol. The question was, "You just mentioned that it's interesting that you didn't think of Hurricane Katrina, but I'm going to go ahead and ask you, now that you have given it a little bit of thought, could you – is there any way that it would affect how you approached this problem?" Michael's response confirms the potential of simply adding the context of Hurricane Katrina in order to prompt broader considerations:

> I might have been able to like – like I put a bullet for, say, like social impact, but I didn't like put anything under it, but if I had thought about Hurricane Katrina, I probably could think of certain reactions people would have to stuff or maybe other issues dealing with maybe the other solutions, things might have came up, or maybe like the cost of rebuilding, because I didn't really think about if the area had been flooded, then it would probably be really hard to like build a retaining wall of any sort of massive – any sort of massive structure because the infrastructure around it wouldn't be there. I didn't really consider that. I just was thinking about building a retaining wall like anywhere. Yeah, I think those are probably the biggest things. Again, like I probably just don't know as much about Katrina as could help me a lot with this exercise. —Michael (23)

Thus, in addition to the indications Michael gives of two of the grounded codes of Table 5 (i.e., Economics, and Societal Impacts), he also implies a new *how* code not given in the table, which we might code as "Alternate Solutions" and group with the "Process of Design" area of concern.

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7. Bibliography

[1] Kilgore, D., Atman, C. J., Yasuhara, K., Barker, T., Morozov, A., (2007). Considering Context: A Study of First-Year Engineering Students. *Journal of Engineering Education*, 96(4), 321–334.

[2] Atman, C. J., Kilgore, D., Yasuhara, K., & Morozov, A. (2008). Considering Context Over Time: Emerging Findings From a Longitudinal Study of Engineering Students. Proceedings of the Research in Engineering Education Symposium. Presented at the Research in Engineering Education Symposium (REES), Davos, Switzerland.

[3] National Academy of Engineering & National Academies Press (U.S.). (2004). *The Engineer of 2020: Visions of engineering in the new century*. Washington, DC: National Academies Press. Available Online, accessed January 11, 2011 at: http://www.nap.edu/catalog.php?record_id=10999

[4] National Academies Press (U.S.) & National Academy of Engineering. (2005). *Educating the Engineer of 2020 Adapting engineering education to the new century*. Washington, D.C.: National Academies Press. Available Online, accessed January 11, 2012 at: http://www.nap.edu/catalog.php?record_id=11338

[5] Sheppard, S., Macatangay, K., Colby, A., & Sullivan, W. (2008). *Educating Engineers: Designing for the Future of the Field*. San Francisco, CA, USA: Jossey-Bass.

[6] Dutson, A. J., Todd, R. H., Magleby, S. P., & Sorensen, C. D. (1997). A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses. *Journal of Engineering Education*, 86(1), 17–28.

[7] Dym, C., Agogino, A., Eris, O., Frey, D., & Leifer, L. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, 94(1), 103–120.

[8] Dinehart, D. W., Gross, S. (2010). A Service Learning Structural Engineering Capstone Course and the Assessment of Technical and Non-Technical Objectives. *Advances in Engineering Education*, 2(1), 1–19.

[9] Kolmos, A., Fink, F. K., and Krogh, L. (eds.). (2004). *The Aalborg PBL Model: Progress, Diversity and Challenges.* Aalborg, Denmark: The Aalborg University Press. ISBN 87-7307-700-3.

[10] Litzinger, T., Lattuca, L. R., Hadgraft, R. G., & Newstetter, W. C. (2011). Engineering Education and the Development of Expertise. *Journal of Engineering Education*, 100(1), 123–150.

[11] Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A Comparison of Freshman and Senior Engineering Design Processes. *Design Studies*, 20(2), 131–152. doi:10.1016/S0142-694X(98)00031-3

[12] Atman, C. J., Yasuhara, K., Adams, R. S., Barker, T. J., Turns, J., & Rhone, E. (2008). Breadth in Problem Scoping: a Comparison of Freshman and Senior Engineering Students. *International Journal of Engineering Education*, 24(2), 234–245.

[13] Cross, N. (2004). Expertise in Design: An Overview. *Design Studies*, 25(5), 427–441.

[14] Atman, C. J., Sheppard, S. D., Turns, J., Adams, R. S., Fleming, L. N., Stevens, R., Streveler, R. A., Smith, K. A., Miller, R. L., Leifer, L. J., Yasuhara, K., & Lund, D. (2010). *Enabling Engineering Student Success: the final report for the Center for the Advancement of Engineering Education*. San Rafael, CA, USA: Morgan & Claypool Publishers. Retrieved October, 25, 2011 from http://www.engr.washington.edu/caee/final_report.html

[15] Sheppard, S. D., Atman, C. J., Fleming, L. N., Miller, R. L., Smith, K. A., Stevens, R., Streveler, R. A., Clark, M., Loucks-Jaret, T., & Lund, D. (2009). *An Overview of the Academic Pathways Study: Research Processes and Procedures*. Technical Report #CAEE-TR-09-03 (revised May 2010). Seattle, WA, USA: University of Washington, Center for the Advancement of Engineering Education. Retrieved October, 25, 2011 from http://www.engr.washington.edu/caee/APS_Process_Procedures.html

[16] Case, J. M., & Light, G. (2011). Emerging Methodologies in Engineering Education Research. *Journal of Engineering Education*, 100(1), 186–210.

[17] Mann, L., Dall'Alba, G., & Radcliffe, D. (2007). Using Phenomenography to Investigate Different Ways of Experiencing Sustainable Design. Presented at the 114th Annual ASEE Conference and Exposition, June 24-27, 2007, Honolulu, HI, USA: American Society for Engineering Education.

[18] Calvo, R. A., & Ellis, R. A. (2010). Students' Conceptions of Tutor and Automated Feedback in Professional Writing. *Journal of Engineering Education*, 99(4), 427–438.

[19] Zoltowski, C. B., Oakes, W. C., & Cardella, M. E. (2011). Phenomenographic Study of Human-Centered Design: Educational Implications. ASEE. Presented at the 118th Annual ASEE Conference and Exposition, June, 2011, Vancouver, BC, Canada: American Society for Engineering Education.

[20] Marton, F., & Booth, S. (1997). *Learning and Awareness*. Mahwah, New Jersey, USA: Lawrence Erlbaum Associates, Inc.

[21] Creswell, J. W., & Miller, D. L. (2000). Determining Validity in Qualitative Inquiry. *Theory Into Practice*, 39(3), 124–130.

[22] Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. Newbury Park, CA, USA: SAGE Publications.

[23] Leydens, J. A., & Lucena, J. C. (2006). The Problem of Knowledge in Incorporating Humanitarian Ethics in Engineering Education: Barriers and Opportunities. Frontiers in Education Conference, 36th Annual.

[24] Riley, D. (2008). *Engineering and Social Justice*. Synthesis Lectures on Engineers, Technology and Society, C. Baillie, Ed. (Vol. 5). San Rafael, CA, USA: Morgan & Claypool.

[25] National Academy of Engineering (NAE), Committee on Public Understanding of Engineering. (2008). *Changing the Conversation: Messages for Improving Public Understanding of Engineering*. Washington DC, USA: National Academies Press. Retrieved January 19, 2012 from http://www.nap.edu/catalog.php?record_id=12187

[26] Brown, A. L., & Campione, J. C. (1994). Guided Discovery in a Community of Learners. In K. McGilly (Ed.), *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice*. (pp. 229–270). Cambridge, MA, USA: The MIT Press.