Considering Context Over Time: Emerging Findings From a Longitudinal Study of Engineering Students

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Introduction and Background

Design arguably is at the heart of all engineering practice [1, 2], and therefore it makes sense to study how students learn design for the purpose of improving engineering education. Of particular interest to policy makers today is developing a dynamic, flexible, adaptable engineering workforce [3] with "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [4]. To meet the challenge of ABET and the engineering needs of the 21st Century, engineering educators should be able to understand the extent to which an individual has developed the knowledge, attitudes, and skills resulting from this broad education. How do we know if students are acquiring the facility to consider context during engineering design and problem solving?

Some efforts to articulate and validate the means to assess what we are calling *design-in-context* focus on defining more specific student learning outcomes that elaborate on the broadly stated ABET outcome 3h (*e.g.*, [5, 6]). Other researchers have developed assessment techniques within the boundaries of their courses (*e.g.*, [7-10]). Building on past efforts to articulate and assess *design-in-context*, this study focuses on two research questions: (1) To what extent do engineering students consider issues of context while solving engineering problems?, (2) Do junior and senior engineering students scope engineering problems more broadly than first-year students?

This work-in-progress study focuses on a subset of data drawn from the Academic Pathways Study (APS), a multi-institution, mixed-method, longitudinal study that examines engineering students' learning and development as they move into, through, and beyond their undergraduate studies [11]. Data were collected from forty students at each of four institutions: a public, technical institution specializing in teaching engineering and technology; an urban, private university; a large, public university; and a medium-sized, suburban, private university. This abstract describes preliminary analyses of student responses to two engineering problem-solving questions, the first involving design of a retaining wall and the second, siting of a microchip fabrication facility. The former was administered in Years 1 and 3 of the study, and the latter, in Year 4. The next sections discuss methods, preliminary results from ongoing analyses, and next steps for each of the two questions.

Midwest Floods Design Task

Data Collection and Analysis

In their first and third years, students were given ten minutes to write their answers to the question, "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?" As described in previous research reports (*e.g.*, [12, 13]), the Midwest Floods Design Task has been used to examine the extent to which engineers consider contextual factors during problem-scoping. The task was administered to 124 and 99 students in Years 1 and 3, respectively, with an overlap of 69 students completing the task in both years. Women represented just over two-thirds of each sample.

Students' written responses were transcribed and divided into distinct ideas (segments), which were then coded on two dimensions of problem-scoping breadth, as shown in Figure 1. *Physical location* codes record the physical focus of each idea: on the wall itself, the water, the riverbank, or wider surroundings beyond. *Frame of reference* codes record the perspective represented in each idea: technical, logistical, natural, or social considerations. The coding scheme is documented in an extensive set of guidelines that was originally based on an inductive coding of responses to the Midwest Floods task from an earlier study [14]. The guidelines were iteratively refined until two independent coders were able to achieve a high level of agreement, with disagreements negotiated to consensus. Coding and negotiation of the almost 3000 segments collected in the two administrations is still in progress.

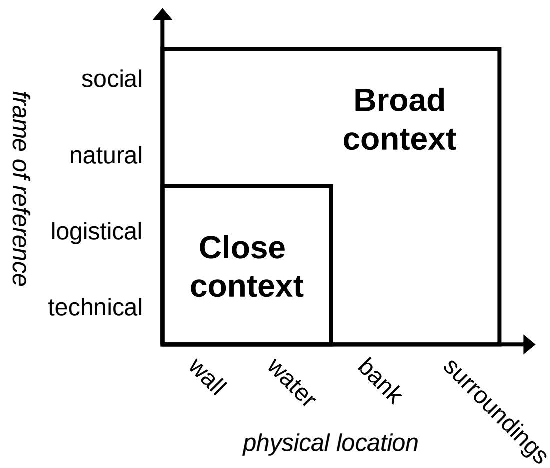

Figure 1. Midwest Floods Design Task codes and their interpretation with respect to consideration of context.

Coded segments were then interpreted to be focused on *close* design context or *broad* design context, based on their codes. As illustrated in Figure 1, ideas focused on the wall or the water and from a technical or logistical perspective were interpreted to be oriented toward the close design context. All other ideas were considered oriented toward the broad design context. For example, a segment such as "materials for the wall" was assigned the codes "wall" and "technical," and therefore interpreted as oriented toward close context. This stands in contrast to "people who live in the flood plain," which was assigned the codes "surroundings" and "social" and was identified as oriented toward broad context. This process yielded a set of quantitative measures and associated data visualizations capturing the number of factors a student would take into account. The quantitative measures enabled straightforward aggregation of multiple responses and comparative statistical analyses.

Preliminary Findings

To date, we have completed all segmenting and roughly 80 percent of the coding of the available data. Our preliminary findings are providing a thought-provoking view of the development of design-in-context ability. Based on the paired responses of the 69 participants who responded in both their first and third years, we see that students' third-year responses were more substantial after two years of engineering study. On average, Year 1 responses contained 12.3 factors, which increased to 15.3 factors in Year 3 ($p = 0.000$, two-sided Wilcoxon signed ranks).

Given our interest in the extent to which students consider problem context in engineering design, we also examined how the factors given in response to the Midwest Floods Design Task divided between the two categories of factors, close and broad design context. Additional statistical comparisons suggested that, at least for the sample analyzed to date, an increase in consideration of close context primarily accounts for the increase in total factor count reported above. For the 43 out of 69 participants' responses coded so far, the average number of factors focused on broad context increased slightly from 6.1 to 7.0, and the average number of factors focused on close context increased from 5.8 to 8.1 ($p = 0.300$ and $p = 0.000$, respectively; two-sided Wilcoxon signed ranks).

Chip Factory Siting Problem

Data Collection and Analysis

In their fourth year, the APS students were asked the following question: "You are an engineer working for a silicon chip manufacturing company. Your company's current facilities in California are close to maximum capacity and the company is out of land to expand at the current site. The company needs to build a new factory in a new location. There are three potential sites: in the U.S. in Alabama or Illinois; or in Asia in Thailand. You have been asked to evaluate the sites for locating the plant. Please list FIVE factors you think would be important in your evaluation of the sites." This open-ended question was given toward the conclusion of a web-based survey in the Spring of 2007. Seventy-five men and 47 women (N = 122) responded to the question to yield 606 statements. The statements were transcribed, and then two researchers conducted separate, inductive analyses using constant comparative analysis. The two analyses were integrated into a preliminary, two-dimensional coding scheme resembling the one applied to the Midwest Floods responses.

As illustrated in Figure 2, each statement was coded on two dimensions: factor type and factor scope. *Factor type* refers to the statement's perspective: financial, logistical, environmental, and/or strategic. A statement was coded "financial" if it referred to such considerations as budget, costs, taxes, and profits. Statements coded "logistical" concerned resource availability or transportation/communications links to a candidate site. Statements coded "environmental" concerned the impact of the factory on the natural environment. Statements coded "strategic" referred to considerations like culture, ethics, politics, public sentiment, long-term plans and history. Since a statement could encompass several elements or ideas, multiple codes could be assigned to a factor (in contrast with Midwest Floods coding, where each segment was assigned exactly one code for each of the two dimensions).

Factor scope refers to the field upon which the statement is centered. For this study, fields are defined as logically distinct geographical or organizational entity in which engineers and other stakeholders make decisions. The fields identified are: the plant itself, the corporation to which the plant belongs, the local area in which the plant will be sited, the host country in which the plant will be sited, and/or the global context. As with factor type, statements could be assigned more than one scope code, reflecting the factor's breadth. The factor scope codes were assigned independently of the factor type codes. Thus, the resulting coding of a given statement could represent any combination of factor type and factor scope codes.

Next steps for the Chip Factory response analysis include refinement and more precise definition of the codes along both dimensions. As with the Midwest Floods data, in preparation for finalized analyses, responses will be coded by two independent researchers and negotiated to consensus. For the purposes of analysis, we will interpret factors as being oriented toward close or broad context, based on their codings. Precisely how the coding space should map to the close *vs.* broad context categories (analogous to the mapping illustrated for Midwest Floods in Figure 1) is under discussion.

Preliminary Findings

As illustrated by the discs in Figure 2, analysis based on the preliminary coding indicated that the majority of the factors addressed the financial and logistical concerns directly related to the factory and the vicinity of the site. Factors such as availability and cost of qualified labor, accessibility for suppliers of production inputs, and transportation and utilities infrastructure accounted for a significant proportion of the factors. We also found that students less frequently mentioned some of the broader "strategic" considerations involving the corporation as a whole, as well as more global considerations of factory siting. At the same time, some students did express concerns regarding the demographics around the candidate sites, as well as the interests and attitudes of the local government and residents. Finally, our preliminary coding revealed a relative lack of discussion of the environmental aspects of facility siting. While experienced engineers, regardless of specialization, may be aware of the significant ecological footprint of high-tech manufacturing, it is unclear to what extent students in our sample considered such issues to be important for selecting a location for the new factory.

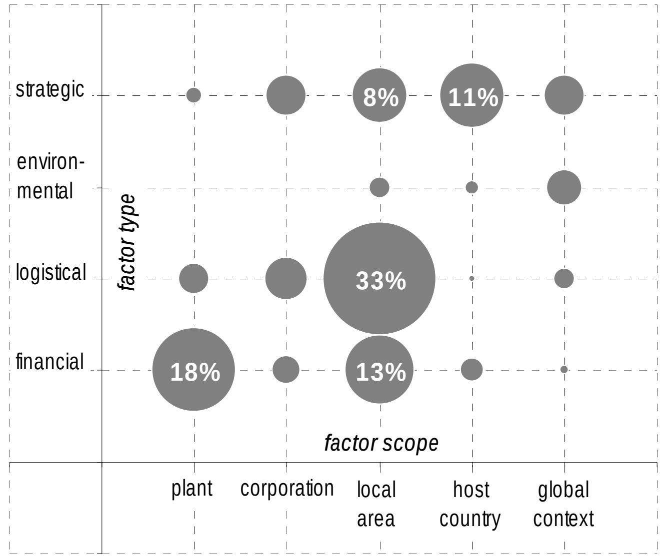

Figure 2. Distribution of coded Chip Factory statements across the coding space.

Analyses for Symposium Presentation

The Midwest Floods Design Task offers a longitudinal view of the development of engineering undergraduates' ability to consider contextual factors during engineering problem-solving, focusing on the comparison of close *vs.* broad context issues. As opposed to engaging students in design thinking to address a large-scale social issue, the Chip Factory Siting Problem elicited responses to a more business-oriented scenario. Through different framing, the problem provides opportunities for comparing students' problem-scoping approaches. As summarized in Figure 3, a complete analysis of the data will allow us to conduct some longitudinal, as well as comparative analyses, yielding a description of students' developmental trajectories and typologies of contextual thinking. In this presentation we will use case studies to illuminate how participants, whose context consideration developed exceptionally between Years 1 and 3, approached the Chip Factory problem in Year 4. We hope this research will inform assessment practice by showing how instruments such as those described here can produce insights into students' conceptualizations of engineering problems, and their ability to prioritize and clearly communicate important factors in analyzing the scope of the problem.

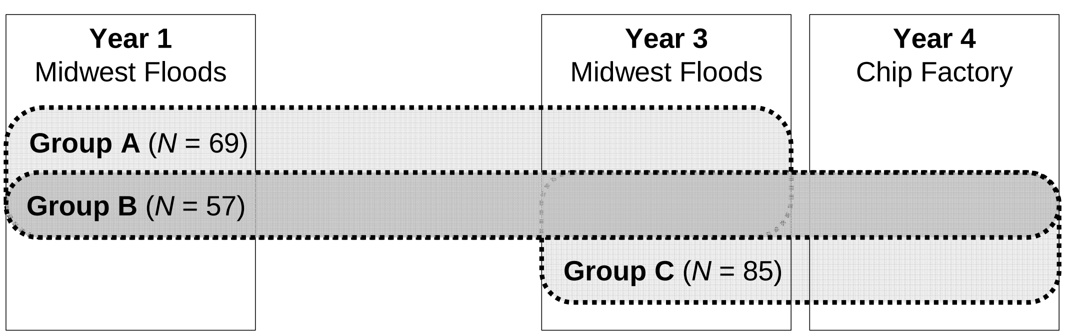

Figure 3. Summary of the administrations of Midwest Floods and Chip Factory problems, including the sizes of participant groups for whom we have responses to multiple administrations suitable for longitudinal analysis.

In addition to presenting further results of our longitudinal analyses at the Symposium, we are especially interested in input from researchers from other nations. We anticipate this will bring into clarity the extent to which our interpretations are uniquely products of our own national context, as well as identify issues that might be considered from other national perspectives.

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