Board 410: Thematic Maps of Interdependent Engineering Judgment Processes in Undergraduate Systems Engineering Capstone Projects

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Thematic map of interdependent engineering judgment processes in undergraduate systems engineering capstone projects

Abstract

Our NSF Research Initiation (RIEF) grant focuses on the role of professional engineer identity formation in the construction and communication of engineering judgments in writing. This paper reports the preliminary results of this research as a thematic map obtained from the analysis of 10 semi-structured interviews obtained from five senior systems engineering students in the capstone project at the lead author's institution. First, our research indicates the interdependence among cognitive processes, discursive identity, and the students' work context. Second, our research explores the interdependence among the various judgments students must make in order to construct the knowledge constituting their senior projects. These judgments are classified within three broad themes—assumptions and model building judgments, rhetorical and discursive judgments, and framing and positioning judgments. Our thematic map illustrates the role of social practice in the creation and re-creation of engineering knowledge. Our thematic maps suggest a need for greater integration of social and professional praxis in fundamental engineering curricula in order to better prepare students with an awareness of the embodied and enacted communicative practices involved in professional engineering work.

Introduction

The NSF Research Initiation in Engineering Formation (RIEF) project described in this paper is based on our emerging understanding of engineering judgment. Our project explores the ways students construct and convey engineering judgments in and throughout their writing projects. This investigation is situated in the experiences of five systems engineering undergraduates at the lead author's institution.

Most researchers view engineering judgment as something an individual does (Baybutt, 2018). For example, researchers may consider judgment as the capacity to bring one's professional experience and knowledge base to bear on the problem or design situation at hand (Bruhl et al., 2017). However, recent work has begun to re-conceptualize engineering judgment as the emergent property of a group of individuals working together to make sense of the work context and act within that context (Francis et al., 2022b; Weedon, 2019). As part of the broader investigation into engineering judgment in the literature, it is important to understand what types of decision situations are faced by designers and how they might apply judgment within those decision situations to act. Our research attempts this through analysis of interview data from 5 systems engineering seniors enrolled in their capstone projects at the time of being interviewed. The focus of the preliminary work reported in this paper is the elucidation of key themes related to judgment and decision making in student projects uncovered during our analysis.

The originally proposed objective our project was to investigate the ways students produce engineer identities in written artifacts through which they expect to be recognized as engineers. The subsequent investigation has been guided by the research question "How do students interact with the writing process, and particularly the need to articulate and justify engineering judgments, to produce engineer identities?". The project was divided into two phases. Phase I involved an exploratory thematic analysis of semi-structured interview data collected from an interview protocol designed to explore students' general perceptions of technical writing and specific experiences during their unfolding senior projects. Phase II, which is ongoing, involves

the integration of our findings into classroom practice. Our goal during Phase II is to adapt best practices reported in the literature that may help students actively participate in engineering judgment practices and processes. The results reported in this paper are from activities in Phase I.

Theoretical Framework

Our project is a constructivist thematic analysis investigating the ways student writers participate in and construct engineering judgments while they produce engineering identities through their written work. According to Chism et al. (2008), constructivism examines the meanings individuals create to describe the world around them. Constructivism assumes meaning is socially constructed through interaction of individuals with the world and their own particular viewpoints and experiences. Additionally, our understanding of judgment and decision making is grounded in the interconnected frameworks of naturalistic decision making (Klein, 2008; Mosier et al., 2018), identity production (Tonso, 2006a; Tonso, 2006b), and the engineering work context (Trevelyan, 2010).

Approach to Research

Our research approach has been more extensively described elsewhere in (Francis et al., 2020; Francis et al., 2021a; Francis et al., 2022a; Francis et al., 2021b). Figure 1 summarizes our research approach.

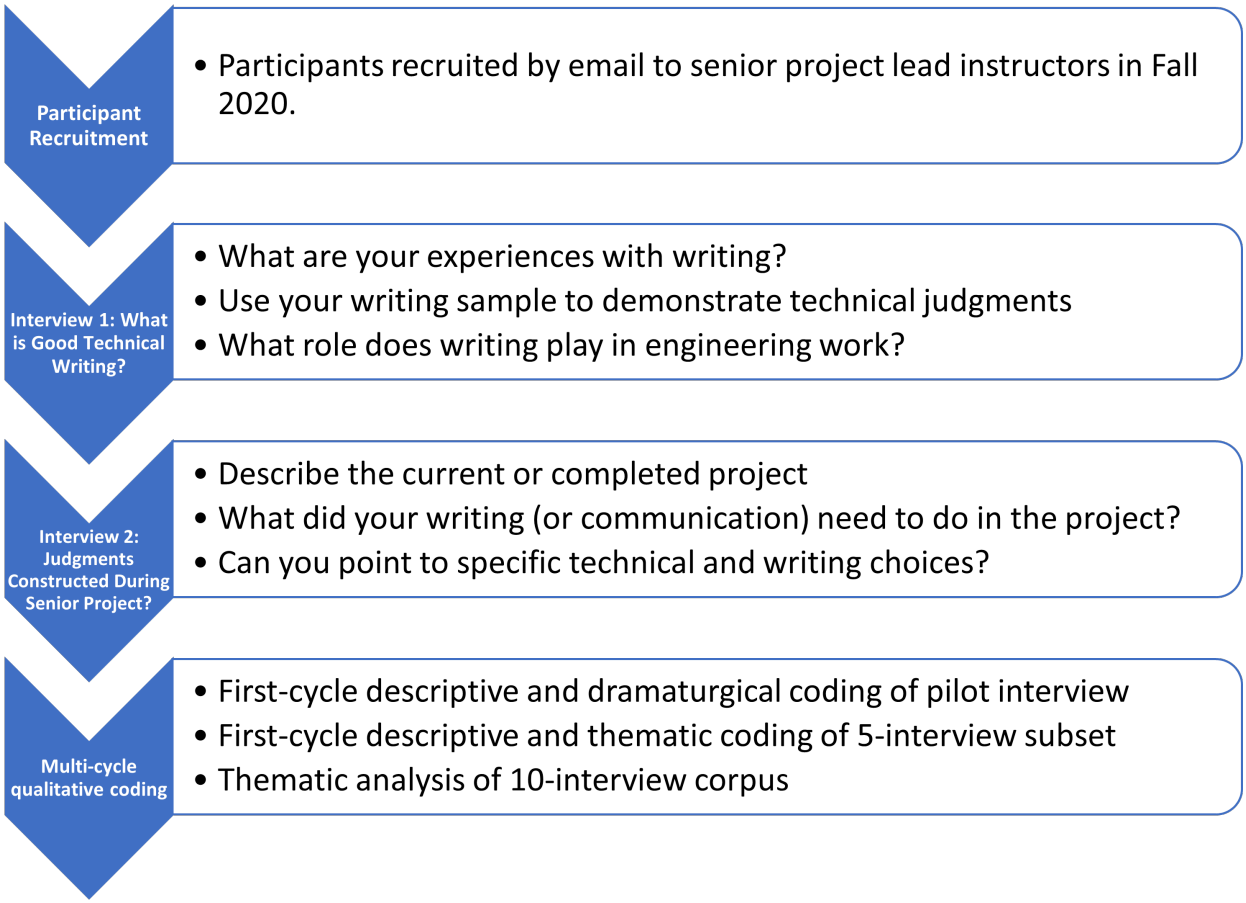

Figure 1. Study data collection and analysis overview.

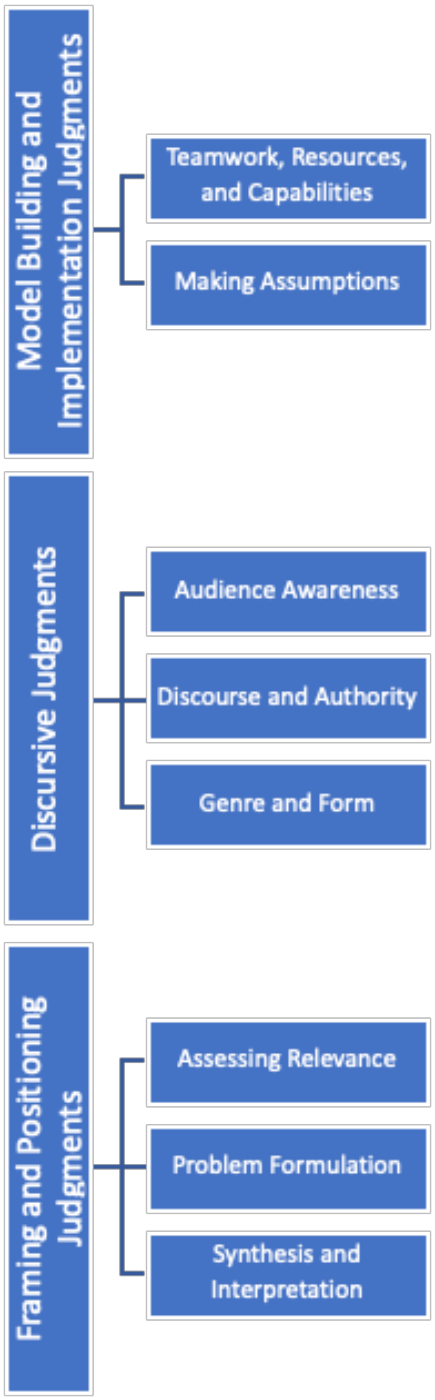

Figure 2. High-level themes and sub-themes used to analyze the data corpus.

Recruitment of participants after a 2-part pilot interview yielded 5 student participants. We conducted two semi-structured interviews with each student designed to investigate students responses to the ideas "What is good technical writing?" (Interview 1) and "How are engineering judgments and processes expressed in writing?" (Interview 2). Our interview protocol is described in more detail elsewhere (Francis et al., 2020). To analyze the data we collected, we used exploratory thematic analysis. A first pass of *a priori* codes was obtained through a two-part process. First cycle descriptive codes were identified from a combination of literature review, review of interviewer field notes, and dramaturgical coding of the pilot interview. Next, descriptive and thematic coding of the first interview with each of our five participants yielded additional descriptive themes. These themes were condensed through a multi-cycle approach involving the research team, and thematic analysis of the 10 interview corpus was completed after a final codebook was agreed upon. Our approach to data analysis was described in more detail elsewhere (Francis et al., 2021a; Francis et al., 2022a). Three high-level themes were identified through this process, and were decomposed into 8 themes shown in Figure 2. The themes are defined in Table 1 in the appendix at the end of this paper.

Results and Discussion: Thematic Map

The role of engineering judgment in engineering communication is critical to the success of engineering program graduates in their careers. In fact, in considering communication and professional skills "not engineering work" as the participants in Trevelyan (2010) indicated, one can limit their professional effectiveness since our study of engineering judgment in student writing clearly indicates that technical work is clearly mediated through communication practice. This finding is also reflected in Wilde and Guile's (2021) use of the concepts of situated judgment and immaterial activity. They note that material production includes interprofessional teams' idea generation and digital exchanges of ideas, suggestions, and recollections that can then be used to create new products and processes. Consider the thematic map of our eight themes, illustrated in Figure 3.

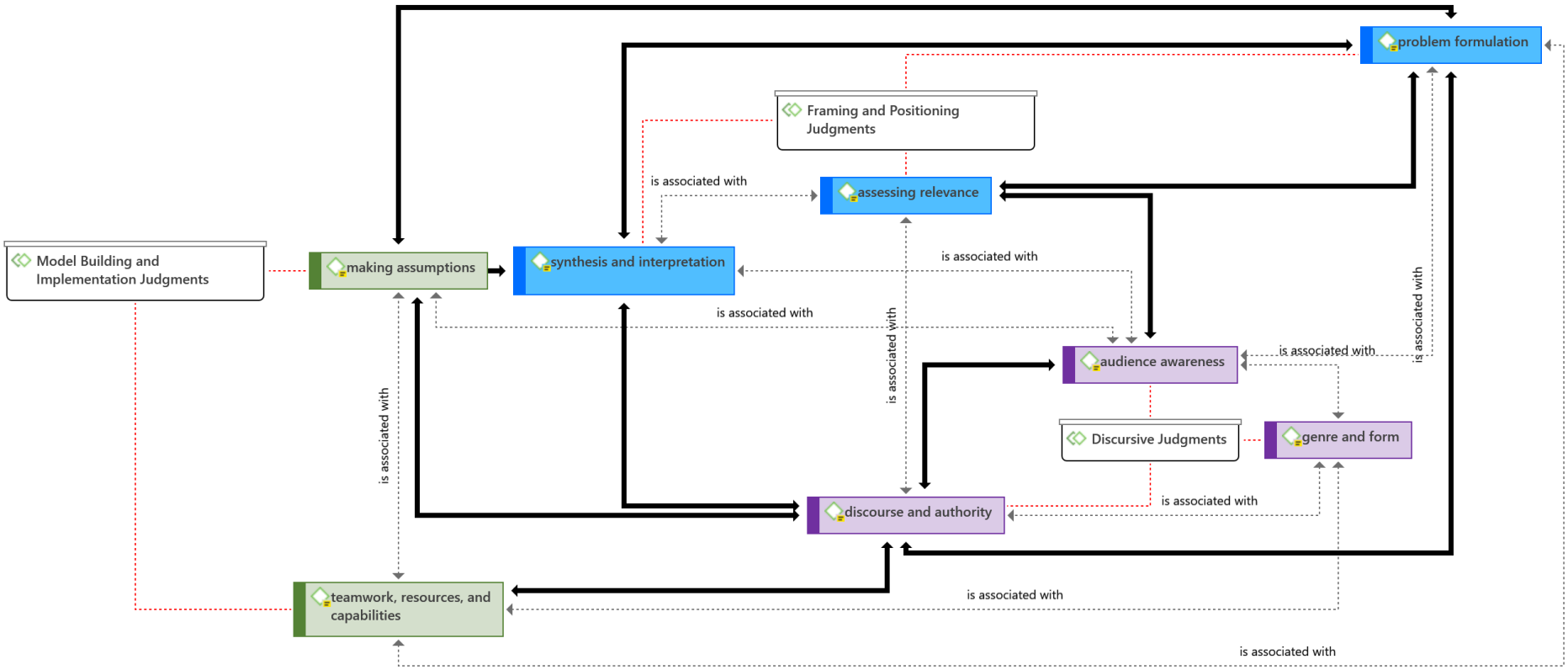

Figure 3. Thematic map indicating strong (bold, black) and weak (dotted gray) relationships among the 8 themes identified.

The nodes in the thematic map in Figure 3 are color-coded according to the three high-level themes identified: framing and positioning judgments, discursive judgments, and model building and implementation judgments. To obtain the thematic map, an undirected network was created from the co-occurrence of themes in the corpus. The details of the occurrence patterns and the network matrix are presented in Supplementary Information. The dark black lines are “strong” linkages, where codes co-occurred in the data 10 or more times; while dotted black lines are “moderate” linkages, where codes co-occurred in the data between 5 and 10 times. The code network clearly shows the considerable inter-linkages between framing and positioning judgments (blue) and rhetorical and discursive judgments (purple), while these are both intermediate to the assumptions and model building judgments (green).

This code network confirms that the three main themes—framing and positioning judgments, model building and implementation judgments, and discursive judgments—cannot be separated, as each remains interconnected through their sub-elements. For example, the model building and implementation judgments are modified by the discursive judgments, while also mutually informing the discursive judgments and positioning. Moreover, the students’ assessment of internal capacities is intimately connected to the students' individual and collective understanding of their participation in the discourse. The work processes reflected by the students' interviews and captured in this code network suggest that attempts to assist students in practicing the judgments identified in this study require an integrative approach. In other words, courses that focus on technical skills must do so mediated through intentional application of professional skills in that immediate context, while courses that focus on professional skills must integrate technical skill application into that immediate instructional context. While some researchers have explored the use of open-ended problems to develop engineering judgment skills (Johnson & Swenson, 2019; Magana et al., 2019; Swenson et al., 2020; Swenson et al., 2019), it is critical to engage students in team-oriented and unstructured contexts so that students can engage in a broader range of problem formulation, framing, and positioning judgments (Hamilton et al., 2008; Moore, 2008).

Considering only “strong” connections, discourse and authority, and problem formulation are the most highly connected themes. Including “moderate” connections, several themes are also highly inter-connected, including synthesis and interpretation, making assumptions, and audience awareness. The thematic map seems to hint at certain judgments being involved in some processes or activities together, while some judgments—based on the way the data are coded—do not seem to be involved in the same processes or activities. For example, looking only at the strong connections, the way that the data are coded suggests that assessing relevance or societal need is most strongly involved in the activities that also involve framing and problem formulation, and audience awareness. Since assessing relevance is not co-coded with judgments such as making assumptions or discourse and authority via strong relationships, this could suggest that assessing relevance is indicative of the stages of judgment that relate to the students bringing their prior and embodied knowledge to bear on the work at hand. Since these judgments may be based on prior knowledge, the students may feel less strongly the need to refer to discursive traditions or practices to justify or validate their judgments about relevance or societal need. Similarly, assessing relevance or societal need may contribute to synthesis and interpretation indirectly via problem formulation. If the problem formulation judgment is not necessary in a given circumstance, then assessing relevance or societal need may be directly linked to the synthesis and interpretation judgment. However, as predominantly described in our

data, synthesis and interpretation may be linked to assessment of societal relevance conditional on the nature of the problem framing and the type of problem formulated.

Conclusion

In conclusion, our thematic maps provide support for further investigation into the relationships between engineering judgment and engineering communication processes. Our thematic maps illustrate the intimate relationship between the construction of technical knowledge at various stages and levels of a project and the execution of communication tasks related to that technical knowledge. Moreover, the extant literature contains limited investigation into the types of judgments and choices students make during their engineering projects. Our findings indicate the need for additional research into these important processes to better understand how curricula or courses can be designed to facilitate undergraduate students' acquisition of the important participatory capacity of engineering judgment.

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Appendix: Definition of Themes

Table 1. Descriptions of themes identified in analysis.

Theme	Theme Description	Judgments or Choices Observed in Interview Data
Model Building and Implementation Judgments		
teamwork, resources, and capabilities	• Evaluation of students' and student teams' own internal interests, resources, and capabilities. • Logistical or operational concerns that must be resolved to complete the work.	Writing vs. analysis; sense-making team discussions; write what you built; account for interests, capability and understanding; team dynamics and conflict resolution; project management and work organization
making assumptions	• Building a quantitative (or qualitative) model intended to represent some real-world phenomenon. • Representations of the world that involve some simplification, tradition, and calibration. • Justification of their selection of modeling or analytical techniques. Judgments related to model parameterization and implementation, or problem or project scope, size, or complexity.	Selection of model technique; model parameterization; model implementation
Discursive Judgments		
audience awareness	• Assessment of their audiences' background knowledge, expectations, and/or needs.	Audience representativeness; simulated audience response; fitness for use; audience understandability
discourse and authority	• Students' perception of the academic and non-academic discursive practices that bear on acceptance of their work products. • Authority refers to those standards, traditions, gatekeepers, or practices that give validity to the students' work products. • 'Conversation' with external sources • Awareness of their positionality and the dimensions of identity they hope to convey through their work.	Awareness of methodological practices or traditions; conversations with clients; conversations with professors; conversations with professionals; consultations of discursive practices
genre and form	• Judgments about audience expectations of document form and convention. • Expectations of style, readability, and flow.	Understandability; procedural content; document or communication type; imitating successful models; persuasive tasks; time constraints

	• Judgments about word choice and understandability.	
	Framing and Positioning Judgments	
assessing relevance	• Assessment of societal, technical, economic, or business relevance.	Relevance from embodied experience; relevance from business needs; relevance from societal needs or patterns
problem formulation	• Judgments about both the features of background that make a problem compelling. • Judgments about what students include or exclude.	Creating real-world representations; modifying real-world representations; feasibility; responsiveness to anticipated demands; co-production of project objectives; work processes imply sub-problems
synthesis and interpretation	• Judgments about how best to understand the results of their analyses. • Decisions about what potential problems should be prioritized for further development.	Significant scenario creation; determining significance or meaning of results; prototyping solutions