



A thematic analysis of the intersection of engineering judgment and student writing practices

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ABSTRACT

CONTEXT

Engineering judgment is one of the defining characteristics of engineering practice and identity. Despite the prominence of engineering judgment in shaping engineering education and practice, the definition of engineering judgment as embodied communication processes and practice is under explored. Most studies of engineering judgment view judgment as something an individual does, however, engineering judgment also emerges from communication and work practices among team members. Moreover, engineering judgments are also communicated when work products, including a range of written documents, are disseminated to target audiences.

PURPOSE OR GOAL

The objective of this study is to explore the ways that undergraduate engineering students' engineering judgments are embodied and communicated in and through writing practice and processes. Specifically, our work addresses the question, "What is the interplay between engineering judgment and communication practices involved in completing a capstone systems engineering project?"

APPROACH OR METHODOLOGY/METHODS

This study employs the academic literacy and discourse identity frameworks. Semi-structured interviews were collected with 5 systems engineering undergraduate students at a US mid-Atlantic private engineering school. The interview protocol involved two 60-90 minute interviews with each participant: one after initial scoping of the project, and one after the project was completed. This paper analyzes data obtained from the first of the two interviews. The data will be analyzed using thematic analysis.

ACTUAL OR ANTICIPATED OUTCOMES

This research yields four themes that may help engineering educators understand how students' engineering judgments emerge from praxis and writing processes: framing and positioning, audience awareness, analysis, and synthesis. Engineering judgments are both conveyed in writing through documents produced and also emerge from writing processes represented by these themes. These judgments are forged by complex interplay between students' engagement with their engineering knowledge base, the technical nature of the engineering work, and the communication requirements perceived by the students as they are confronted with various rhetorical scenarios and stakeholders.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The findings of this project will inform pedagogical interventions aimed at developing students' engineering judgment and professional identity formation.

KEYWORDS

Engineering judgment, academic literacy, discourse identity

1 Introduction

This paper explores the ways students convey engineering judgments in written communication processes and products. Engineering judgment is foundational to the practice of engineering where judgment is required to identify a societal or technical need that can be addressed through engineered artifact. Judgment is used to formulate and encode engineering problems, and to determine technical and economic feasibility. It is also involves learning from experience. This understanding is critical to effective engineering pedagogy due to engineering judgment's central role in engineering practice.

Concurrently, engineering judgment is not clearly defined. Some researchers and practitioners define engineering judgment as activity undertaken by individuals when faced with making difficult tradeoffs (Pantazidou & Nair, 1999; Shaw et al., 2006). Others define engineering judgment as the practice of making decisions under uncertainty, ambiguity, or incomplete information (Douglas et al., 2012; Wait et al., 2013). Still others define engineering judgment as embodied communication processes engaged by teams of engineers to perform engineering work (Weedon, 2019). This paper builds upon these views through exploration of the following research questions:

1. How do students construct engineering judgments through writing processes?
2. How does the construction of engineering judgment shape writing processes or products?

These questions distinguish our efforts from those reported in prior research. First, our investigation frames judgment that occurs by an individual and among individuals. Second, our approach implies that engineering judgment is both situated in and constituted by the communication processes used to construct and convey judgments. To explore our research questions, we interviewed five 4th year undergraduate systems engineering students at a middle point of their year-long senior project. In the US, where this research was conducted, the senior project is a common culminating experience intended to replicate the expectations and tradeoffs students might face in professional practice. The next section of this article describes the theoretical frameworks we have selected for framing this work. The following section describes our use of the instrumental case study method and thematic analysis method for this work. We then present our results and discuss some of the key findings.

2 Theoretical Framework

Our research employs the academic literacies framework of Lea and Street (2006) as well as closely related discourse identity framework of Berkenkotter et al. (1988). Lea and Street (2006) observe that academic literacies are "concerned with meaning making, identity, power, and authority," and that this meaning making occurs within institutions which value particular forms of knowledge. This perspective guides our investigation as the senior projects are designed to initiate students into professional practices of knowledge production within sub-fields of engineering. Pembridge and Paretto (2019) highlight this focus on the workplace orientation of senior capstone projects, indicating the centrality of these project experiences to students' transition to work. One aspect of this transition is the shift from students' academic experiences with meaning making in their classwork to practice-based meaning making situated in design, confronting them with new perspectives on authority. While most classrooms involve the professor as the clear authority, the senior project adds additional layers of complexity depending on whether students' projects are completed primarily for intimately involved external stakeholders and/or are responding primarily to the demands and criteria placed by the supervising professors. The students' perception of the "institutional nature of what counts as knowledge" (Lea and Street 2006) can shift considerably while completing the senior project, as the institutional lines blur based on the number and types of stakeholders involved in their work.

The academic literacies model also attends to the contexts in which student writing is applied, viewing literacy practices as not residing entirely in discipline and subject-based

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communities (Lea and Street 2006). The participants described multi-disciplinary contexts that required students to carefully select literacy practices in various stages of their projects to be responsive to their specific audiences and expectations. Thus, the academic literacies framework helps understand how participants used judgment to engage in a range of literacies and communication practices in their work.

3 Methods

3.1 Data

The data analyzed in this paper are drawn from five semi-structured interview with undergraduate systems engineering students during the first half of their final semester. The students studied at a U.S. mid-Atlantic private institution. These interviews were collected as part of a larger study whose goals and objectives are described in Francis et al. (2020). Relevant methodological details are as follows. At each interview, the participant was asked to bring an example of a past writing sample they believed represented good engineering writing as well as writing samples related to their senior research project that could show how they have made engineering judgment choices in writing. The questions used during the semi-structured interviews were designed to investigate students' responses to the broad ideas: "What is Engineering and Writing?" and "How are Engineering Judgments and Process Expressed in Writing?" The questions were intended to understand students' backgrounds with and dispositions towards writing, then build on this understanding to explore how students understand the role of writing in engineering practice.

Each interview was between 45 and 75 recorded minutes in length on zoom and was manually transcribed prior to coding in Atlas.ti 9 qualitative analysis software. While the participant and interviewer were able to share screens and audio connection, no video was coded during analysis. During parts of the interview, participants used the screen sharing feature to show the interviewer specific choices made in their writing, or to explain specific aspects of their work during the interview. After the manual transcription was obtained, all three members of the writing team conducted first-cycle coding of one interview transcript to clarify coding objectives and assess consistency of the segments coded as judgments. Two additional transcripts were coded by two members of the writing team to inform further development of the final codes. The interviewer coded all five interview transcripts using thematic coding methods.

3.2 Thematic Analysis

We orient this study as an instrumental case study following Stake (2000). The goal is to identify themes that could lead to avenues of research yielding potential generalizations about the intersection of judgment and writing practices. Descriptive coding was used to develop themes. Descriptive coding summarizes in a word or short phrase the basic topic of a passage of qualitative data (Saldana, 2016). A preliminary codebook of approximately 23 codes reflecting themes or processes related to writing practice and engineering judgment was created based on prior literature and a review of the audio recording and interviewer field notes. Each transcribed interview was then coded by the interviewer using descriptive codes and in vivo coding. Additional descriptive codes were generated through a combination of interviewer judgment, in vivo coding, and cross-comparison with the codes obtained by the other members of the writing team. The interview transcript was coded a second time employing the expanded codebook. Ultimately, 65 descriptive/in vivo codes were obtained. These codes were then evaluated to recognize potential patterns and organized into four high-level themes.

4 Thematic Analysis of Judgment Processes in Student Writing

In this section, we present the results of our thematic analysis. Four major themes have been identified after analysis of the interview transcripts: Framing and Positioning, Audience Awareness, Analysis, and Synthesis.

4.1 Framing and Positioning

The first major theme, framing and positioning, is derived from several sub-codes used in analyzing the data, including 'assessing relevance or societal need' and 'framing and problem formulation'. Framing and positioning refers to actions related to framing or conceptually formulating the problem to be analyzed. The student makes judgments about what their reader needs to know in order to effectively communicate with them. Once the student decides what the reader needs to know, the student formulates and conceptualizes the scope and definition of the problem. This step is framed and potentially constrained by the student's understanding of their audience's needs. Therefore, framing and positioning involves an assessment of their conceptual problem's relevance or societal need. Students make judgments about the importance or motivation for a problem they are constructing, analyzing, or interpreting. The goal is to make judgments related to positioning the work that is to be completed in reference to the student(s) stakeholders' needs or expectations. The term 'stakeholders' should be viewed broadly: these could be clients directly involved in the construction and evaluation of their work or the students' conceptual representation of their external audience. Assessing relevance or societal need involves students deeply understanding their stakeholders' concerns while wrestling with how their work is responsive to these concerns.

Assessing relevance is closely related to other sub-themes employed in analyzing the interviews, including: 'thesis formulation', 'audience awareness', and 'framing and problem formulation'. From the students' point of view, these themes may overlap. Nonetheless, there are subtle distinctions. For example, the distinction between framing and problem formulation and assessing relevance or societal need is the internal vs. external orientation. With framing and problem formulation, attention shifts from explicit focus on stakeholder concerns to an internal (to the student or group) focus on deciding what the problem is. Assessing relevance could happen before problem formulation, as students survey the range of concerns present in the audiences they hope to engage with. Consider the following excerpt:

... one thing that I had noticed...was that the analysis was good for a lot of the papers that I had read, but they - to me it seemed like they weren't fully acknowledging that... A lot of people came to the conclusion that... Airbnb is raising rental prices and they show that by saying... look at... these neighborhoods and they're all... growing superfast in terms of rental prices and look how many Airbnb's are here. [T]hat's... where I thought they stopped. And my problem with that was there's...reasons why you might see that correlation, but I don't know if the causation exists...You could say Airbnb's tend to pop up where tourists want to stay. [T]ourists probably want to stay in...nicer areas and those...areas probably have their rents growing fast...

First, notice the student's emphasis on the audience. This student's full attention is on the conclusions of the authors whom they hope to engage. Second, the sentence beginning with "[T]hat's...where I thought they stopped" indicates that while this student is clearly questioning the conclusions made, this student is also crafting an opening for their own contribution. This interaction indicates a transition from an external focus on stakeholder concerns to an internal focus on defining or re-defining the problem. The next three sentences provide a prologue to this student's problem formulation by proposing potential alternative reasons to explain the observations reported by the members of the student's audience. Nonetheless, this segment stops just short of problem formulation because the student does not explicitly articulate their own thesis or conceptual problem for analysis.

4.2 Audience Awareness

The second theme, audience awareness, addresses how the students conceptualize their audience and how the students conceptualize their position within the intersecting communities the audience represents. Notably, audience awareness guides the students' participation in the discourse of their community of practice. This involves their ability to understand the types of knowledge and knowledge representations accepted by members of the community, appropriate methods of knowledge production, and their ability to convey the knowledge and methods of knowledge production in forms that will be readily recognized by

the community of practice and its peripheral stakeholders. These peripheral stakeholders may not be members of the engineering community of practice, but their understanding and acceptance of the work products is a critical concern directing engineering work.

In sum, the interview transcripts include reflective attention to the students' understanding of an audiences' background knowledge and needs. Audience awareness clearly influences the aforementioned 'assessing relevance or societal need' and 'framing and problem formulation' sub-themes. The distinction here is that while those codes refer to the assessment and formulation of the content of what is to be communicated, audience awareness involves a focus on audience expectations around not only the content but also on how the information can be effectively communicated. Thus, the transcripts describe how the students made judgments concerning word choice, oral vs. written communication, or even document design based on what they thought their audience considered most appropriate or easiest to understand.

Another dimension of audience awareness involves potential authority claims around the students' work products. The students each expressed concern about their ability to engage with their audiences authoritatively based on their work products, especially how to best communicate the results of their work products so that they would be well received by the authority. One strategy described by the students is the use of prior work as a model. Here is an example:

... these studies that were run were run pretty close to the proposal being due, and were..a last minute thing. Parts of it were – I looked at what we had, and read it, and then I looked at what other teams had done before. ... there was also another writing sample that had been sent to me by our adviser from a separate competition but similar type of analysis. And I read those, and realized.. here's ten things that we need to address, and seven... we didn't. We need to go run these studies to figure that out. ...I pushed it off to them, and they went and thought about it, and then brought it back.

This student is describing an experience with an extra-curricular aeronautics club where they submitted a design to a flight competition. In the passage, the student is looking at examples from other student teams who had previously submitted designs to the competition. The student observes and reads these prior reports to familiarize themselves and their team with the rhetorical forms used for this situation. Since each of these submissions were judged by the same criteria, the forms observed in these reports presumably possess the rhetorical moves required to authoritatively convey their proposed design to the judges because the judges would likely be expecting similar form and style from the student's report. We also observe the student using their familiarity with these documents and the rhetorical strategies used to communicate authoritatively to their team about what work needed to be completed before their design could be completed.

In several of the interviews, the students described a struggle with a crisis of authority, e.g., (Berkenkotter, 1984), where their work products needed to be responsive to multiple, potentially conflicting audience members. One way this crisis could arise is if two or more important audience stakeholders expressed demands that the students found difficult to reconcile. For example, this occurred if the supervising faculty imposed a demand on a student group that obfuscated an objective expressed by their group's client. Another possible source of the crisis of authority is ambiguity. Some participants reported concerns that their clients could be unresponsive or unclear about project objectives. This could lead to frequent changes in project scope as student groups struggled to assimilate client feedback while simultaneously satisfying the supervising faculty's requirements. A third way this crisis could arise is when students question their expertise relative to practicing engineers or academic experts.

4.3 Analysis

The analysis theme reflects students' efforts at formulating and conducting analysis. One sub-theme is 'assessing available resources and capabilities' dealing with students' efforts to

assess their own and their team's available resources, capabilities, and interests. Resources include tools such as computers or computing power, data availability, and access to suitable experts or professorial advice. Capabilities refer to the students' technical capacities. Students' interests provide intrinsic motivation to the work; thus, the interview data include student assessments of the types of problems available to their groups within the articulated interest areas of the group members. Other relevant sub-themes include 'constructing and conducting analysis' and 'making assumptions' or 'questioning assumptions'. These codes are derived from students' descriptions of tasks related to constructing their analyses using appropriate modeling techniques while making assumptions and tradeoffs within model form or parameterization. The students also describe their teams' internal discussions and strategies for organizing teamwork.

Constructing and conducting analysis refers to computational tasks immediately required in the course of producing the analyses subject to the project goals and objectives. Although one might consider this central to engineering work, it is worth noting that the students' interviews do not foreground the arcane technical details of their projects. Rather, where methods and techniques are mentioned, they are discussed at a relatively high level as if stating the technique alone is sufficient shorthand for an informed individual (e.g., a systems engineering professor from the same department). Instead, the students carefully describe representative scenarios or models, their assumptions, and tradeoffs required to keep the work manageable. Student descriptions of their analytical processes are quite lengthy in the interview transcripts. This relatively compact excerpt describes one student's approach to making assumptions and tradeoffs prior to computation:

... it went from I know that I want to stop people from trespassing in general on the metro system. ... we looked up [how]...people in..the literature talk about the topic. And then they said [well there are different types]. You could stop it by a physical barrier, or you could stop it by having more police people around that area, or...there were other ways. Like you could put up signs and tell them not to trespass....So we had to decide, first of all, what kind of barrier we're looking at, or deterrent, [from trespassing]....[W]e found out there were different types of trespassers. So that makes it not equally – like, for example, signs would maybe deter common citizens from accidentally going on it, so accidents would be prevented by having signs.

Note that this student's thesis has already been formulated. We see this in the phrase "I know that I want to stop people from trespassing..." Thesis formulation, described below, is distinct from constructing and conducting analysis because analytical choices depend on the type of questions or objectives that are chosen. Next, we see this student iterating between engaging the discourse (e.g., "how people in general in the literature talk about the topic") and making assumptions (e.g., "...we had to decide, first of all, what kind of barrier we're looking at..."). The judgments about the key assumptions and tradeoffs that must be made interact with the student's participation in the discourse. Indeed, the computational or technical aspects of engineering work that are commonly emphasized are situated within accepted discursive practices. More importantly, students generally use models present in the literature as points of departure for their own work. Thus, their modeling judgments are contingent on the types of examples they have seen modeled for the scenarios they encounter. Finally, the student's description of their assumptions indicates early stages of a mental model of the phenomenon the student's group is studying (e.g., "...signs would maybe deter common citizens from accidentally going on it, so accidents would be prevented by having signs.") This step is similar to Weedon's (2019) description of students' embodied cognition when seeking to make sense of measurements during group work. In the example, the student envisions the scenario that needs to be modeled while also creating a mental representation that can be modified to represent different types of trespassers or barriers. While the student is familiar with the barriers or signage from their experience riding trains, the student must struggle to convert this embodied experience to the mathematical and conceptual representations required for analysis. Thus, the embodied representations created by the student are prerequisite to the student's judgment of which scenario models are most critical to their ultimate communication task.

4.4 Synthesis

Synthesis is a crucial judgment theme in the transcripts and is involved before, during, and after analysis. Before the students enter the analysis stage, synthesis involves the sub-theme “thesis formulation”. Thesis formulation highlights the choices students make when selecting the main ideas to focus on and communicate through their work. This theme is related to the “discourse and authority”, “audience awareness”, and “framing and problem formulation” themes referred to in earlier sections because students must engage with the corpus of the discourse (i.e., knowledge base) and become familiar with the frames and ideas used by their audience. Once the students are familiar with these frames and ideas, they can create a niche that can be occupied by their thesis. For example, students reflect this point in their interviews by using phrases such as “one of the main tenets” and “bring out the point” indicating that they selectively emphasize or de-emphasize some ideas to the exclusion of others. In addition, thesis formulation is fundamentally creative. While in many other themes discussed in this paper the students refer to, and claim authority from, the ideas of others, thesis formulation proceeds from the students’ own ideas. At the same time, it is not “problem formulation” because the students are not yet constructing problems for analysis. Thesis formulation precedes problem formulation because the problems selected depend on the thesis. Another way of thinking about this is to keep in mind that a thesis can be approached using multiple problem frames, implying multiple possible modeling or computational techniques that might be responsive to those frames. Therefore, thesis formulation—identification of a key question or idea that will be the subject of subsequent analysis and inform action related to a problem frame—is distinct from audience awareness, framing and positioning, and analysis. This excerpt that illustrates thesis formulation:

... [O]nce we realized that...if you introduced more electric vehicles it doesn't necessarily mean that your planet is getting greener as you're using... fossil fuels to make those cars. We were thinking what if we... created a policy to decommission these coal plants and instead put that money into renewable energy sources to then use.

First, take note of the fact that this student prioritizes their team’s own realizations (e.g., “...once we realized that...”). In thesis formulation, the students’ own ideas are foregrounded. Second, notice that this student describes their niche by foregrounding a perceived gap or shortcoming in the knowledge base (e.g., “... if you introduced more electric vehicles it doesn’t necessarily mean that your planet is getting greener...”). Finally, the students’ focal idea emerges (i.e., “We were thinking what if we...created a policy to decommission these coal plants and instead put that money into renewable energy sources to then use?”)

After the analysis stage, synthesis involves interpretation. This step takes place after some computational or technical work has been completed and the students are considering how to understand and advocate for their work. Once a student has results, before they can make additional judgments about how best to communicate with their audience, they must determine what their results say and how best to use those results in persuasive communication tasks (Winsor, 1996). While students often consider quantitative results to “speak for themselves,” Winsor demonstrates how students must determine how best to use their results in their own rhetorical tasks. This excerpt demonstrates this dynamic:

... [O]ur research shows that until you get the grid, green electric vehicles are actually worse. I think our results show – we did the heavy electric vehicle push and then we said, OK, let's delay electric vehicles for so many years, increase grid renewability and then it showed a big decrease in greenhouse gas emissions. And you're thinking, OK, well, it's not really worth it until we get our grid clean, and so hashing out that.

This student must determine what their work’s most salient features are. They focus on showing “...that until you get the grid green electric vehicles are actually worse.” Next, this student describes the most important reasons why this is the case and what can be done to change their findings (e.g., “...increase grid renewability and then it showed a big decrease in greenhouse gas emissions.”). Of course, this judgment about selecting which causal factors should be emphasized takes place in the context of audience awareness. It is

possible the student's audience awareness conditions their interpretive judgments, potentially leading to a re-evaluation of the work performed, the audience addressed, their understanding of the corpus, or the original formulation of the problem. Consequently, it is important to note that the interpretation and thesis formulation stages are iterative. A good way of thinking about this is viewing them as mutually interacting together in cycles as students and their teams create a thesis based on their understanding of the knowledge base. They then formulate problems and conduct analysis, interpret their results and potentially revisit their original thesis, problem formulation, analysis techniques, or a combination of these as a result of their judgment about what their work products say. Together, thesis formulation and interpretation are synthesis, because this process describes the cyclical and iterative processes through which knowledge and their appropriate representations are created.

5 Discussion and Conclusions

Our results support the idea reflected in Cristancho's (2017) investigations on biomedical decision-making that judgment emerges from the interaction of complex components of a decision context. Judgment is not an isolated step in 'problem solving' but emerges as the expert's conceptualization and understanding of the problem evolves. In the interviews, student descriptions of the formulation of their projects indicates that judgments emerge at different stages in their writing processes as their understanding of both the discourses and their audiences evolves. The four themes described—framing and positioning, audience awareness, analysis, and synthesis—interact and intersect as each theme supports the emergence of judgment.

Our observations are a useful point of departure for investigating the ways students make writing decisions as they interact with both the knowledge base and the set of interpretive practices engineers draw on when making decisions. Our results support the idea that writing practices can help to support how engineering students learn to apply and interpret that knowledge in specific contexts. For example, our observations of students using 'embodied' cognition to construct and conduct analysis echoes Gainsburg's (2015) observations that engineering judgment ties deep domain and mathematical knowledge about physical phenomena to physical interpretations. Student writing practices may help to deepen these connections by strengthening students' understanding of the phenomena they are engaging as they seek to convey their understanding persuasively to their audiences.

Finally, our research suggests that in engineering education, investigators and instructors seeking to strengthen students' engineering judgment capacities could use intentional design of writing assignments to help develop these reasoning capabilities. For example, Swenson et al.'s (2019) use of open-ended mathematical modeling problems to develop the ability to determine the reasonableness of the analysis or design could be augmented with carefully designed writing assignments that foreground the themes of framing and positioning, audience awareness, and synthesis alongside the analysis. Moreover, our work extends Claris and Riley's (2012) work where reflective and metacognitive practices aid in developing engineering judgment. At the reflective and meta-cognitive levels, students use multiple observations and experientially informed reasoning to make connections and achieve knowledge transfer across conceptual areas. Our work shows that students writing projects engage them in making these connections across concepts, courses, and sub-disciplines to foster this quasi-rational combination of analysis and intuition.

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