Investigating the Transferability of the Productive Beginnings of Engineering Judgment Framework from Interview Data to Group Discourse Data

Chloe Kimberlin
Mechanical Engineering Department
University of Michigan
Ann Arbor, MI, USA
kchloe@umich.edu

Jack Perry
Aerospace Engineering Department
University of Michigan
Ann Arbor, MI, USA
boomerp@umich.edu

Aaron W. Johnson
Aerospace Engineering Department
University of Michigan
Ann Arbor, MI, USA
aaronwj@umich.edu

Jessica E.S. Swenson
Department of Engineering Education
University at Buffalo
Buffalo, NY, USA
jswenson@buffalo.edu

***Abstract*—Our research team has been working to understand how students develop and use mathematical models—the practice of *engineering judgment*—while completing open-ended modeling problems (OEMPs) during their undergraduate engineering science courses. We have used retrospective interviews, in which students review their work and discuss what they were thinking when they originally completed the problem, to develop a Productive Beginnings of Engineering Judgment (PBJ) Framework. This paper presents the transferability of our PBJ framework to a new data set—students' discourse as they complete an OEMP in a small group. Examining this discourse data confirms that the PBJ Framework applies to students' engineering judgment in-the-moment while working on an open-ended assignment. We also discuss three potential new codes for our PBJ Framework that need further exploring, and how students' written assignments do not fully capture the engineering judgment they used when completing the OEMP with their peers.**

Keywords—modeling, undergraduate, engineering judgment, transferability, discourse analysis

I. Introduction

For the past few years, our research team has been studying students' thinking as they complete open-ended modeling problems (OEMPs) in their undergraduate engineering science courses. In these OEMPs, students gain experience with the professional practice of *engineering judgment*. Engineering judgment has been defined in a number of different, yet related, ways throughout the engineering education literature. It has been studied generally as the cognitive processes that support engineering decision making in open-ended situations [1], and more specifically as the ability to apply learned technical knowledge to a novel situation [2], [3], the prediction of how a system will behave [3], [4], and the assessment of the analytical conclusions [5]–[7]. In our OEMPs and research we take a specific focus and define engineering judgment to be *the development and use of mathematical models in engineering design and analysis*. This framing comes from Gainsburg's ethnographic study of structural engineers, in which she developed a list of eight practices of engineering judgment focused on mathematical modeling [7]. We used this framework as a sensitizing concept to develop OEMPs designed to engage students in the productive beginnings of engineering judgment [8]. By *productive beginnings* we mean behaviors and thought processes that are like, but not as sophisticated as, professional engineers' judgment and prepare students to further develop engineering judgment later in their career [9]–[11].

In OEMPs, students model and analyze a real-world system, such as a playground slide, by making assumptions and simplifications in order to apply the canonical models learned in class to the system. Students also have to assess the reasonableness of their assumptions and model outcomes [12]. These actions reflect what practicing engineers do when faced with complex, ill-defined problems that need detailed solutions addressing technical and non-technical metrics [13]. Traditionally, students are given textbook problems that are closed-ended and solution focused. By presenting them with more realistic problems, they are encouraged to think more like a professional engineer.

Often, students complete the OEMPs in two steps. First, they complete an individual assignment in which they create an initial model of the system. Then, they meet in a small group of students to compare their initial models, create one "best" consensus model of the system, and complete additional modeling and analysis tasks. We have created this assignment structure because engineering judgment is a collaborative practice [7], [14], and making arguments about one's ideas allows students to "make sense" of concepts [15]. Having students work in a group gives them a chance to assess and challenge each other's assumptions and simplifications. This requires students to justify their choices, which is a way of making arguments.

Our research team has used retrospective interviews, in which students review their work and discuss what they were thinking when they originally completed the problem, to develop a thirteen-category Productive Beginnings of Engineering Judgment (PBJ) Framework [16], [17]. However, there are still limitations to these retrospective interviews. As students are recalling work they did up to a month ago, they may have inaccurate or incomplete memories of their thought processes. And, there are times when it is unclear whether students had certain thoughts in-the-moment when completing the problems, or if these are new thoughts spurred by specific interview questions. For example, one instance of engineering judgment is seen in the following response from a student who completed an OEMP in their sophomore statics course in which they modeled a pool lift. When asked by the interviewer, “Tell me why the way you modeled this problem is accurate enough,” the student responded:

> For a static analysis I think it's accurate. I mean there's some assumptions that we make as a group that I think weren't great or were more for the ease of the project itself, such as the two force members and neglecting weights which if it wouldn't have like tripled the time that it would have taken to do the calculations, I would have not wanted to neglect the weights just because I mean what if that is made out of something heavy? [...] I guess, I don't know—I mean, I feel good about it accuracy wise um… That's kind of a rough question, not gonna lie.

In this utterance, the student assesses their group’s assumption that the members of the pool lift were massless. While assessing assumptions is a productive beginning of engineering judgment, the uncertainty expressed by the student in saying “I guess, I don't know—I mean, I feel good about it accuracy wise um… That's kind of a rough question, not gonna lie.” suggests that this practice may have only occurred in the interview, spurred by the interviewer’s question. It is unclear if or how the student assessed this assumption when working on the OEMP with their group. We have also analyzed how students display their “in the moment” engineering judgment on the written assignments they turn in, but have found that (unsurprisingly), these data do not always fully capture students’ thought processes. Instead, they present a sanitized and linear picture of their assumptions.

In this paper we investigate the transferability of our PBJ Framework to another dataset—recordings of student discussions as they complete the group parts of an OEMP. Assessing this transferability will allow us to determine if our PBJ Framework truly captures the productive beginnings of engineering judgment, or if it only describes the productive beginnings expressed in retrospective interviews. This method builds off of the work of science education researchers who examined how students develop scientific ideas through creating explanations and arguments [15], [18]. Engineering education researchers have also analyzed student discourse to classify how students use the discourse and practices of engineering [19]; co-construct knowledge with their peers [20]; develop conceptual knowledge by making connections between equations and physical scenarios or by reasoning about the underlying processes of a phenomenon [21]; make decision in a group during design [22]; and weigh, balance, and choose between criteria when problem scoping [23]. The common thread in all this prior work is that analyzing student discourse gives insight into their thinking “in the moment” in a naturalistic setting. In this study, we look at how students propose assumptions and assess their reasonableness in real time while working with their peers. In particular, this discourse shows all of students’ verbalized ideas, whether they make it into the final model or not.

Specifically, our research team asks three questions from the student discourse data:

1. *How well does the existing PBJ Framework capture the productive beginnings of engineering judgment seen in students’ group discourse?*

Fig. 1. Local playground slide modeled by students in the Slide OEMP.

2. *Are there productive beginnings of engineering judgment seen in students' group discourse that are not captured in the existing PBJ Framework?*
3. *Are there productive beginnings of engineering judgment seen in students' group discussions that are not detailed on their written assignment?*

II. METHODS

A. Study Context

The data in this study come from a sophomore-level statics course in the aerospace engineering department of a large, public, research-intensive university in the Western United States. The data were collected in Fall 2020, when the course was co-taught by the third author and 324 students were enrolled. Due to the COVID-19 pandemic, the course was conducted completely online. Lecture videos were posted online for students to watch, and the university-set lecture times were used for online office hours and problem solving. The course also met for one online, synchronous, two-hour lab each Monday. Throughout the semester, students completed three open-ended modeling problems (OEMPs). The data in this study were collected during the second OEMP, which occurred during weeks 8-10 of the semester (out of 16) and was themed around a local playground slide (Figure 1).

The Slide OEMP was designed by the third author and his co-instructor. For more information about the design of OEMPs, please see [8], [24]. Students first completed an individual OEMP assignment in which they drew free-body diagrams (FBDs) of the slide with support reaction moments and forces only (no external loads). Doing this required them to make and justify assumptions about the types of supports on the actual playground slide. Students were provided with close-up photographs of the slide supports (Figure 1, right). Then, students had to determine a worst-case static loading scenario for the slide and draw additional FBDs that included these loads.

After this individual OEMP, students completed a group OEMP assignment. This was submitted and graded by the instructional team. Students were first asked to discuss each team members' approach to modeling the slide and select one model to use for the group assignment. Students then set up the equilibrium equations ($\sum F=0$, $\sum M=0$) but did not solve them because the model of the slide was statically indeterminate and the system of equations was unsolvable (i.e. the model was overconstrained). In the second part of the group OEMP, students designed a new straight slide that was static, statically determinate, and had at least one two-force member as part of the structure. Groups drew a FBD of their slide with support reactions and external loads, and then solved the system of equations for the support reactions and the normal stress in the two-force member. To calculate this stress, students were given a safety factor of 3 and told to choose a diameter and material for the two-force member. Lastly, students were asked to assess the reasonableness of their answer by answering the question, "Does this diameter make sense? Why or why not?"

Because the third author was both the instructor of the course and a researcher, the research was led by the fourth author, who is at a different institution. The research was approved by both the third and fourth authors' institutional review boards. The fourth author announced the research in class after the first OEMP and asked students to consent if they were interested in participating in the research. After students consented, the fourth author created groups for the Slide (second) OEMP and the third OEMP so that there were as many groups as possible in which all students had consented to the recording. The third author and his co-instructor were not aware which groups were participating in the study until final grades had been submitted at the end of the semester. Because these groups met on Zoom, they were asked to record any of their meetings in which they met to work on the OEMP. The groups then submitted these video recordings to the fourth author. Students were each compensated with a $25 Amazon gift card for their participation. Because students were given control over the recording, it is likely that the data do not include all meetings in which the groups worked on the OEMP. In total, we collected data on the Slide OEMP from five groups, and data on the third OEMP from five groups. The groups were rearranged between the two OEMPs, but many of the same students were recorded during both OEMPs.

In this paper we present an analysis of three of the groups as they completed the Slide OEMP. These three groups were selected from the five recorded because they displayed much of their work on screen while discussing the OEMP. This made it easier to understand students' actions and words during the analysis. Students' demographics were not collected with the data, and we do not want to make inferences based on their appearances. For these reasons, we do not report students' demographics in this paper.

B. Data Analysis

All previous coding for the productive beginnings of engineering judgment (PBJ) has been done with transcripts of retrospective interviews asking a single student questions about OEMPs they completed (e.g. [25]). This research has developed a 13-code PBJ Framework (Table 2, [16]). The first and second authors, who coded the student discourse data used in this paper, had previously coded retrospective interviews together. Each author coded the interview transcripts and checked the coding of the other author, resulting in them developing a common understanding and familiarity of the coding framework.

The recordings of the student groups were coded by using the existing PBJ Framework while also searching for new codes and different instances of engineering judgment that had not been seen in the interview data. The three videos analyzed featured 4-5 students completing their group assignment over Zoom, with their cameras and screen sharing on most of the time to better convey their ideas. The first and second author watched the videos and noted the timestamps where they found instances of students engaging in a PBJ code, instances of PBJ that were not currently captured in a code, and anything that seemed of interest to the overall research of engineering judgment. The timestamps were recorded along with the corresponding PBJ code in a spreadsheet. Utterance codes were only reviewed by another author if the initial coder was unsure. In these cases, the third author reviewed the utterance and had the final say of how they were coded.

TABLE I. ALL UTTERANCES OF THE PRODUCTIVE BEGINNING OF ENGINEERING JUDGMENT FOUND IN THE THREE GROUPS' DISCOURSE DATA

Productive Beginning Code	Productive Beginning Definition	Utterances Across All Groups	% of Total Utterances	Groups With at Least 1 Utterance
PBJ1.a	Assumption made with no justification	14	3.7%	3
PBJ1.b	Assumption made based on student's research or experimentation for the class	34	9.1%	3
PBJ1.c	Assumption considered the user, client, or manufacturer	21	5.6%	3
PBJ1.d	Assumption made the model solvable	22	5.9%	3
PBJ1.e	Assumption made the model easier to solve	67	17.9%	3
PBJ1.f	Assumption did not affect the output of the model	12	3.2%	3
PBJ1.g	Assumption modeled the perceived worst-case scenario	14	3.7%	3
PBJ1.h	Assumption made based on student's personal lived experience	39	10.4%	3
PBJ2.a	Assessed the reasonableness of	80	21.3%	3

III. RESULTS

A. Research Question 1

The results of the student group discourse coding are shown in Table I. These results address the first research question, *How well does the existing PBJ Framework capture the productive beginnings of engineering judgment seen in students' group discourse?*

Table I shows that our PBJ Framework works well to capture the engineering judgment seen in students' group discourse. All codes from the PBJ Framework were found in the group discourse data except for PBJ4. Also, the majority of codes, all except for PBJ3.a, PBJ3.b, and PBJ4 were found in all three groups' discourse. The lack of any PBJ4 utterances could be a result of the small data size analyzed, or may just be a function of the assignment itself. Many of the OEMP questions were worded to receive exact answers, such as asking for the "calculated diameter" of the two-force member. The OEMP had already asked students to consider a safety factor, so students did not have to decide to override their calculated answer to provide margin. Table I also shows that PBJ1.e and PBJ2.a were the most-coded utterances. This is consistent with what we have found while coding retrospective interviews, with the exception of PBJ1.e typically being more common than PBJ2.a in the retrospective interviews [17].

B. Research Question 2

The answer to the second research question, *Are there productive beginnings of engineering judgment seen in students' group discourse that are not captured in the existing PBJ Framework?*, is not quite as straightforward. We cannot say definitively that we have found new instances of the productive beginnings of engineering judgment, as we still need to examine more of the group discourse data. However, we did find three types of utterances that may be added to the PBJ Framework after further investigation:

1. Referencing past OEMPs, quizzes, or homeworks to help make an assumption or justify an answer.

2. Using visual cues, specifically the right-hand rule, to convey ideas or opinions.
3. Considering a potential assumption, and then explicitly not making that assumption to make the problem easier to solve.

All three of these potential PBJ codes had at least two instances seen throughout the group discourse data. The first potential PBJ was found in all three of the group discussions, while the second and third potential PBJs were found in two of the three group discussions.

The first potential PBJ code is related to PBJ1.b and PBJ1.h (defined in Table I), both of which relate to the knowledge students are using to complete the OEMP. PBJ1.b captures knowledge that students are developing because of the OEMP, and PBJ1.h captures knowledge that students had from their lived experience prior to the OEMP. Neither of these codes capture knowledge specifically from the course but not this particular OEMP. The second potential PBJ code was not found in our prior analysis of interview transcripts, which are written documents. This finding builds on previous research finding that physics students use gestures to convey their thoughts in a way that words cannot [26]. Lastly, the third potential PBJ code is related to our current definition of PBJ2.a because students are determining that an assumption is not actually useful. It is also related to PBJ1.e because the effect of leaving out the assumption makes the problem easier to solve. More research is needed to determine if these utterances belong to one of the existing categories or a new category.

C. Research Question 3

The answer to the third research question, *Are there productive beginnings of engineering judgment seen in students' group discussions that are not detailed on their written assignment?*, is "yes." Compared to the written assignments, student's group discussions give a more complete view into the entire *process* of engineering judgment in which students engage while developing their model. When examining the Slide OEMP group assignment, there were only 2 of 19 questions that led to written answers with any sign of engineering judgment. Question 18 asked "Is this diameter physically reasonable? Justify your answer," and question 19 asked "Name at least three other factors beyond strength that an engineer might consider when selecting the material and diameter for a bar that supports a slide." Furthermore, while students display engineering judgment in their responses to these questions, we cannot be sure if students engaged in these practices during the actual problem-solving process.

While questions 18 and 19 were not the only ones designed to engage students in the productive beginnings of engineering judgment, they were the only ones to explicitly ask students to describe their engineering judgment on paper. Many other questions asked on the Slide OEMP assignment gave rise to instances of engineering judgment during the group discussions, specifically questions about the worst-case loading of the slide, the chosen support material to hold up the slide, and the design of a new straight slide. However, on the student's written assignments there were no signs of this engineering judgment, just the required formulas and work to answer the question. This likely occurred because these questions did not ask for justifications—for example, question 1 just asked for the "worst case loading scenario."

While the written assignment questions do not require students to explicitly detail their engineering judgment, the group discussions force them to engage in these engineering judgment practices. When proposing an assumption to the group, we frequently saw students also providing a justification (PBJ1.b-h) in order to get the rest of their group to agree. As an example, one student suggested the use of stainless steel for the material of their support because they knew that most playground equipment was made of stainless steel. And if a student agreed or disagreed with an assumption being proposed or a final answer calculation, they needed to clearly state their assessment of the reasonableness (PBJ2.a-b) so their peers understood their point. As an example, one student did not want to model a slide on roller supports and asked the rest of the group if they had ever seen a slide in real life on rollers.

IV. Discussion

This research suggests that our Productive Beginnings of Engineering Judgment (PBJ) Framework does capture the productive beginnings of engineering judgment, and does *not* only describe the productive beginnings expressed in retrospective interviews. All of the existing PBJ codes except one were found in the student discourse data, and there are also three potential new codes that we are exploring. The discourse data gives important insight to the work being done by students as they complete the problem, and it shows students' "in-the-moment" thinking better than retrospective interviews or written assignments. The data is collected as students are expressing their thoughts and developing ideas together, and we also see students sharing more freely in their groups. Students contribute assumptions of varying detail as they converse and are more comfortable sharing even if they are not fully confident in what they think. They are happy to speak their own ideas and are willing to propose and immediately assess assumptions with their peers. This is different from the retrospective interviews, in which most reflection and assessment of assumptions seems to occur after a final solution has been developed.

Although discourse data is incredibly interesting and useful, there are a number of challenges in analyzing the data. Students often talk over one another, leaving some assumptions more explored than another. This also makes it difficult to code every PBJ utterance. We also struggle to identify which group member is sharing a particular idea. The data also takes a significant amount of time to analyze, as the videos are long. In the data presented here, each group had at least 5.5 hours of video. Lastly, because students are working in-the-moment and not explaining their model to an interviewer, there is some difficulty in identifying whether students are making an assumption or discussing a problem-solving method.

There are some additional limitations to our study that constrain the application of our results to other contexts. However, the focus of this study was a limited investigation of the transferability of our PBJ framework, so these limitations do not affect our findings. One primary limitation is that we were only able to analyze three groups and extract data from their discourses. This limits the scope of our analysis and also encourages us to continue to analyze discourse data. Furthermore, most utterances were only coded by one researcher. For the development of the PBJ Framework, at least two researchers coded each utterance to come to a consensus. However, as is described in the Data Analysis section, the first and second author had developed a common understanding and familiarity of the coding framework. We also found limitations in how and when students contribute to the group discourse. Differing group dynamics led to some groups where everyone shared equally and others where two members dominated the conversation. We also saw this occurring when some members had less-stable internet or different technology tools (e.g. having a tablet computer that the student could write on made it easier for them to share their thoughts with the group). If a student does not contribute to the discussion, then we are unable to analyze their discourse—and therefore their productive beginnings of engineering judgment. Lastly, students recorded their work themselves, so there is a possibility that students did not record all of their meetings or completed work outside of the meetings. From the data we analyzed it seems like the videos capture most of the group work, but there could have been some exceptions to this.

V. Conclusions

In this paper we found that we are able to identify the productive beginnings of engineering judgment in student group discourse and that our Productive Beginnings of Engineering Judgment (PBJ) Framework is transferable to this new group discourse data set. Also, we found that having the ability to examine student groups working on OEMPs in-the-moment provided great insight into their thoughts and assumptions. Witnessing the entire *process* of engineering judgment taking place allows for various PBJ utterances to occur that are never seen in students' written work, and are seen in a different light during a retrospective interview.

Because of the success of our initial study of student discourse, we plan on continuing to analyze discourse data and its relationship with the PBJ Framework. We also want to look more into the three potential new PBJ codes that were found and see if other discourse data supports these codes. Our future work will involve both furthering analysis of the data we have, as we have only coded three of the ten groups' recordings that were collected, and collecting further student discourse on both statics and dynamics OEMPs. This analysis of group discourse data will increase our knowledge of the productive beginnings of engineering judgment and also allow us to improve the OEMP scaffolding to better engage students in engineering judgment. By doing so, we can augment the closed-ended mathematics of undergraduate engineering science courses with more real-life engineering problems.

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