The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41982

Students' Use of Engineering Judgment on Undergraduate Student Project Teams

Jack Boomer Perry, University of Michigan

Boomer is a graduate student completing his master's degree in aerospace engineering at the University of Michigan. His focus in engineering education research has been towards bridging the gap between the undergraduate engineering curriculum and engineering industry practice.

Emily Buten, University of Michigan

Emily (she/her) is a Ph.D. student in the Engineering Education Research program at the University of Michigan and received her B.S. in Mechanical Engineering from University of Dayton. Her research focuses on individuals' development from students to professional engineers. She is particularly interested in studying co-op/internship programs, experiential learning opportunities, professional skills development, and diverse student experiences in experiential learning settings.

Dr. Aaron W. Johnson, University of Michigan

Aaron W. Johnson (he/him) is an Assistant Professor in the Aerospace Engineering Department and a Core Faculty member of the Engineering Education Research Program at the University of Michigan. His lab's design-based research focuses on how to re-contextualize engineering science engineering courses to better reflect and prepare students for the reality of ill-defined, sociotechnical engineering practice. Their current projects include studying and designing classroom interventions around macroethical issues in aerospace engineering and the productive beginnings of engineering judgment as students create and use mathematical models. Aaron holds a B.S. in Aerospace Engineering from U-M, and a Ph.D. in Aeronautics and Astronautics from the Massachusetts Institute of Technology. Prior to re-joining U-M, he was an instructor in Aerospace Engineering Sciences at the University of Colorado Boulder.

Students' Use of Engineering Judgment on Undergraduate Student Project Teams

Introduction

The undergraduate engineering curriculum is made up of mostly engineering science classes, which are classes heavy in mathematical content with little to no application. As a result, students rarely get to improve their *engineering judgment* skills, which we define as the ability to develop and use mathematical models for analysis and design. Our research team's focus has been on implementing open-ended modeling problems (OEMPs) into the engineering science curriculum in efforts to elicit engineering judgment. OEMPs bring real-world engineering examples into courses and leverage the use of active learning that has shown to be so beneficial to students in STEM [1]. McNeill et. al found that undergraduate students themselves acknowledge that they needed more experience to develop engineering intuition, which is related to engineering judgment at a high level [2], [3]. Students are simply not used to, nor comfortable with, solving the ill-defined problems that professional engineers face, as they haven't been exposed to them in their typical classroom settings. In this paper we shift our research focus a step further than classroom learning: to students working on engineering project teams.

We define student project teams as co-curricular, student-run activities that complete an engineering task, whether for a national competition or for accomplishing their self-set goals. We view these project teams as a midpoint between engineering undergraduates and practicing engineers. The projects that students work on are inherently open-ended and ill-defined, with fewer guidelines than a course assignment but more guidelines than a professional engineering project. Jonassen et. al emphasized that things like working with others, dealing with environmental constraints, and managing projects all made problems more ill-structured [4], and all of those aspects are abundantly present for project teams to deal with. A lot of research effort has been put into understanding project based learning in the curriculum itself (similar to our work with OEMPs) [5], [6], [7], and on individual student extracurricular learning (such as internships and co-ops) [8], [9], [10], yet there hasn't been much attention put into student project teams specifically. For these reasons, we believe that project teams are an impactful setting in which to study engineering judgment.

A big interest for our group is bridging the gap between professional engineers and the engineering curriculum. It has been found that students and engineering professionals approach and solve ill-structured problems differently [11]. Understanding how student project team members approach ill-structured problems reveals the step between students solving OEMPs and professional engineers, which is valuable to understand both what is possible for students to learn and how to properly teach them. As Weedon noted [12], the use of engineering judgment was recently added in ABET accreditation outcomes [13] suggesting the need for universities to begin explicitly inculcating it into their classes and curriculums. This type of research helps to inform others to construct more formalized definitions of engineering judgment, specifically for the use of engineering educators [14]. Through this research we are interested in asking the following questions about engineering judgment on student project teams: 1) *Do students on project teams exhibit engineering judgment while working on their teams?* And 2) *How do students on project teams practice engineering judgment similarly and differently from students working on open-ended classroom assignments?*

Framework

Our conceptualization of engineering judgment originates from ethnographies performed by Gainsburg [15], [16], where she examined structural engineers in a working environment and identified eight engineering judgment skills they exhibited during their work. Our research has centered around qualitatively coding transcripts from students recalling their OEMP assignments and the decisions they had to make when faced with ill-structured problems. Through these interviews we were able to adjust Gainsburg's eight codes into the *productive beginnings* of engineering judgment (PBJ), meaning the ways in which a student can show signs of engineering judgment on a lesser scale than how professional engineers would. This coding framework has been developing over the past four years [17], [18], its basic outline is described in Table 1. The more detailed current iteration of the PBJ framework is available in the Appendix.

The productive beginnings of engineering judgment framework centers on four main categories: making assumptions (PBJ1), assessing reasonableness (PBJ2), using technology tools (PBJ3), and overriding calculated answers (PBJ4). This codebook was first developed through retroactive interviews of students solving OEMPs in engineering static courses, then it was transferred to similar data of students in engineering dynamics courses [17], and later applied to group discourse data [18]. Now we would like to investigate the transferability of this code to engineering project teams and examine how students on these teams use engineering judgment differently from what our framework has seen before.

Table 1. Productive Beginning of Engineering Judgment (PBJ) Framework Outline

PBJ Code	PBJ Description
PBJ 1a – 1h	Making assumptions to create a more realistic model, obtain a simpler representation, make the problem solvable, consider the users, etc.
PBJ 2a – 2c	Assessing reasonableness of the provided model, assumptions made, or model output
PBJ 3a – 3b	Using a technology tool or assessing its use in analysis or computation
PBJ 4	Deciding to override a calculated mathematical answer

Methods

We conducted 11 interviews total with 12 students across 9 different project teams during the winter semester of 2022 and the fall semester of 2023. 11 interviewees were male and 1 was female. All students and project teams were from the same large, public university located in the Midwest. Participants were recruited via mass emails to project team leadership. Interested students filled out a Qualtrics survey that asked about their project teams and for them to briefly describe a mathematical model they worked on or developed for their team. Interviews were performed by the third author, with the first or second author accompanied to take notes and ask additional questions. These interviews lasted up to 90 minutes, were conducted over Zoom, and were recorded. Participants were compensated $15 for their time. Our interview protocol was broken into four main categories: *Introductions*, where we asked for a pseudonym, a description of the project team, and the interviewee's role on the team; *Engineering Judgment*, where we asked for a more in-depth explanation of the model they described in the Qualtrics survey and additional, pointed questions aimed at engineering judgment; *Professional skills*, where we asked for examples on how they learn and use professional skills on their project teams; and *Personal background*, where we collected data on the interviewee's background and self-reported identity.

A semi-structured interview protocol was developed based on the PBJ framework. After each interview, the transcript was collected from Zoom's automatic transcript generator and then corrected and de-identified by either the first or second author (whichever was not in the interview). Then the first author coded the four interview transcripts of the participants, listed in Table 2, via Dedoose software. The transcripts were coded for engineering judgment using the framework laid out in the Appendix. Additionally, the first author remained open to occurrences that could lead to new categories of the PBJ framework or any interesting trends that appeared in the interview data. Findings from the initial coding will be verified by additional research in the next stage of the study. This paper includes data from four of the interviews (randomly chosen), with four different participants across three project teams. Pseudonyms are used for the participants (chosen by the participant) and their team names (chosen by the researchers). Information on their year in college and pronouns were self-reported by the participant. Table 2 outlines the four participants we interviewed, along with a short description of them and their model.

Table 2. Interview Participants Information

Pseudonym	Pronouns	Year in College	Project Team	Model Discussed
Chase	he/him/his	Third Year	Airplane Team	Aircraft sizing model
Brenden	he/him/his	Fourth Year	Car Team	Gear loading/sizing model
Sheldon	he/him/his	Second Year	Rocket Team	Injector efficiency model
Samson	he/him/his	Third Year	Rocket Team	Flight simulation model

Results

The preliminary results of this research comes in two forms: the qualitative trends noted by the first author while coding and the quantitative metrics of the codes. These results help shape the next direction of our research and will be presented by looking at each research question postulated previously.

<u>RQ1</u>: *Do students on project teams exhibit productive beginnings of engineering judgment while working on their teams?* Table 3 provides the number of occurrences of each PBJ type coded per interview. 135 occurrences were coded and each interview consisted of at least 26 occurrences. All of the PBJ codes were found at least once throughout the interviews except for the PBJ 2c code "Assessing reasonableness of the model provided by the instructor." This makes sense as this code is specific to the OEMPs, where the instructor provided students with a model, and may suggest the need for a code definition change.

The data coded so far does show that the existing engineering judgment codebook can overall be applied to project team work and that students do exhibit the productive beginnings of engineering judgment on their project teams. Furthermore, the analysis identified three potential new codes that will be further investigated in future coding of the additional 8 project team interviews.

Table 3. Number of PBJ Code Occurrences per Interview

	1a	1b	1c	1d	1e	1f	1g	1h	2a	2b	2c	3a	3b	4a	**total**
Chase	2	4	0	0	4	2	0	2	7	8	0	5	2	4	**40**
Brenden	1	3	1	0	1	0	1	1	9	10	0	4	2	1	**34**
Sheldon	2	5	1	1	0	1	0	0	4	6	0	4	1	1	**26**
Samson	1	3	0	2	5	0	0	0	8	8	0	5	3	0	**35**
Totals	**6**	**15**	**2**	**3**	**10**	**3**	**1**	**3**	**28**	**32**	**0**	**18**	**8**	**6**	**135**

- *Potential New Code 1: Assessing the reasonableness of previously made assumptions in a model.*

An example of this potential new code was when Brenden described a situation with the steering system model and said "I ran the calculations and it's like I can't get these calculations to work, they're showing everything will fail. Let's check the calculations from last year." This is similar to what the PBJ 2c code is designed to capture, but changing the wording to PBJ 2c could generalize the framework further to capture instances of this type of engineering judgment.

- *Potential New Code 2: Assessing the reasonableness of making a design change.*

An example of this potential new code was when Brenden talked about the need to consider the impacts of a design change versus the time and effort the change will take, stating "So this case it was like doing a lot of testing showing that it works and, in general, if it's something that helped the performance of the car, whether that be lightweight, more capability, easier to build, something like that, then in general people will be down to make that." This is interesting because they aren't looking at the reasonableness of the assumptions or model output like codes PBJ 2a and PBJ 2b would capture, presumably they believe that those assumptions are well made. Instead they are debating whether this design change will be worth it to implement. We do see a connection to PBJ 1b, in which the student makes an assumption considering a client or user (in this case, their team). However, PBJ 1b does not capture the assessment of the reasonableness we see in Brenden's quote. This type of engineering judgment is also noted by Weedon, who discussed the role of rhetoric in persuasion and timing when applying engineering reasoning to a deliverable [12].

- *Potential New Code 3: Assumption considers how the model will interact with other systems.*

An example of this potential new code was when Samson described how he had to work with other systems while creating his model, saying "It has masses of every component, sizes of every component, everything like that, and it links to a whole bunch of other spreadsheets that we use. Just kind of a systems engineering approach to make sure everyone's on the same page about stuff." The topic of considering how a model interfaced with other models came up throughout these interviews, suggesting the possibility of a code to include systems thinking. Armstrong and Wade wrote about the importance of developing systems engineering expertise due to systems becoming more and more complex [19], which may suggest an emerging type of engineering judgment that we can only see when examining students who are solving larger, more intertwined problems than an OEMP.

RQ2: How do students on project teams practice engineering judgment similarly and differently from students working on open-ended classroom assignments? Figure 1 shows the frequency of PBJ coded for in these four project team interviews versus the frequency of codes for our OEMP static assignments [6].

From this plot we can see that students on project teams use technology tools (PBJ 3a & PBJ 3b) more than students solving OEMPs and make assumptions based on two main justifications (research/experimentation and to simplify) versus a more even justification spread for students solving OEMPs. Also, both project team students and students solving OEMPs assess the reasonableness of their outcomes (PBJ 2b) more frequently than their assumptions (PBJ 2a). Although we see these differences and similarities now, we may need to wait until the rest of the interviews are coded to hypothesize the reasoning behind these trends.

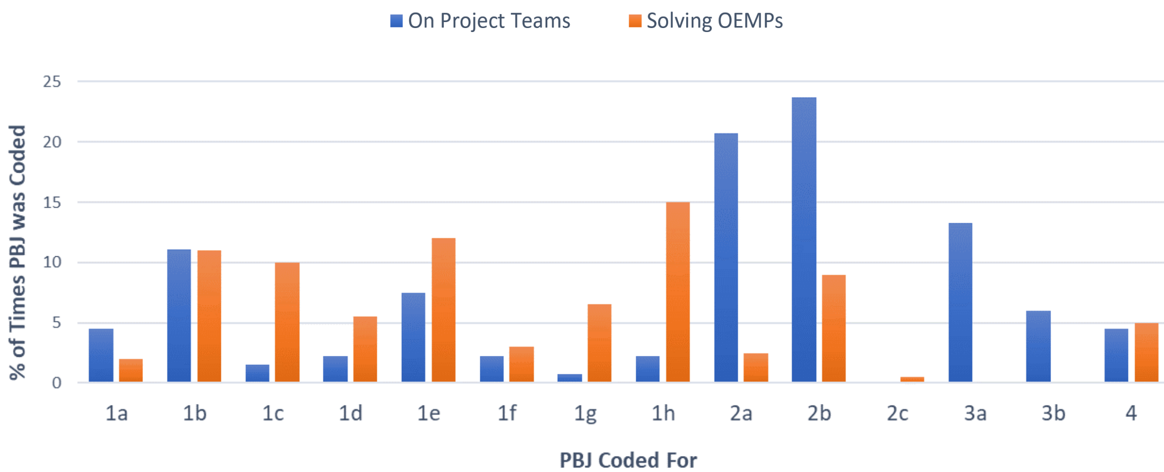

Figure 1. Frequencies of PBJ on Project Teams vs OEMP Statics Assignments

Discussion

These results show that our engineering judgment framework is on the right track to capture productive beginnings of engineering judgment from a diverse set of undergraduate students' work. We were able to find instances of engineering judgment being used on student project teams. Although this data set did have differences from our typical retrospective OEMP interview data, we now know that we can continue to study the use of engineering judgment on project teams with this framework. In the future we will collect more of these project team interviews, and further compare it to how students show instances of engineering judgment in the classroom in an attempt to answer the second research question in this paper.

It should be noted that the diversity of the teams could have played a factor in the current results, and when we code the seven remaining transcripts new trends could come about. Project team cultures can vary drastically, and as a result impact who is on them and what is being learned [20]. Similarly there are many differences in the ages of these project teams and how their knowledge gets shared from student-to-student, which can also impact the performance of the teams and what is learned [21]. These teams are each completing their own engineering challenges that perform very dissimilar tasks, which leads to difficulties but also a lot of value when it comes to comparing them to each other. This research could help us better see the steps in which engineering judgment is developed, and what is needed to learn it – giving great potential for engineering education and curriculum impact.

References

[1] S. Freeman *et al.*, "Active learning increases student performance in science, engineering, and mathematics," *Proc. Natl. Acad. Sci. U.S.A.*, vol. 111, no. 23, pp. 8410–8415, Jun. 2014, doi: 10.1073/pnas.1319030111.

[2] N. J. McNeill, E. P. Douglas, M. Koro-Ljungberg, D. J. Therriault, and I. Krause, "Undergraduate Students' Beliefs about Engineering Problem Solving," *J. Eng. Educ.*, vol. 105, no. 4, pp. 560–584, Oct. 2016, doi: 10.1002/jee.20150.

[3] Miskioğlu, E. E., Aaron, C., Bolton, C., Martin, K. M., Roth, M., Kavale, S. M., & Carberry, A. R. "Situating intuition in engineering practice," *Journal of Engineering Education*, vol. 112, no. 2, pp. 418–444, Mar., 2023, doi: 10.1002/jee.20521

[4] D. Jonassen, J. Strobel, and C. B. Lee, "Everyday Problem Solving in Engineering: Lessons for Engineering Educators," *Journal of Engineering Education*, vol. 95, no. 2, pp. 139-151, Jan. 2013, doi: 10.1002/j.2168-9830.2006.tb00885.x

[5] I. D. L. Ríos, A. Cazorla, J. M. Díaz-Puente, and J. L. Yagüe, "Project–based learning in engineering higher education: two decades of teaching competences in real environments," *Procedia - Social and Behavioral Sciences*, vol. 2, no. 2, pp. 1368–1378, Jan. 2010, doi: 10.1016/j.sbspro.2010.03.202.

[6] Servant-Miklos, V. F. C., & Kolmos, A., "Student conceptions of problem and project based learning in engineering education: A phenomenographic investigation," *Journal of Engineering Education*, vol. 111, no. 4, pp. 792–812, Jul. 2022, doi: 10.1002/jee.20478

[7] C. Jiang and Y. Pang, "Enhancing design thinking in engineering students with project-based learning," *Comput. Appl. Eng. Educ.*, vol. 31, no. 4, pp. 814–830, Feb. 2023, doi: 10.1002/cae.22608

[8] Marsono, M. Sugandi, Tuwoso, and Purnomo, "Study the impact of internship on improving engineering students' competency," in *Proceedings of the Green Construction and Engineering Education (GCEE) Conference*, East Java, Indonesia, pp. 1-5, Sept. 2017, doi: 10.1063/1.5003547.

[9] M. Goller, C. Harteis, D. Gijbels, and V. Donche, "Engineering students' learning during internships: Exploring the explanatory power of the job demands-control-support model," *Journal of Engineering Education*, vol. 109, no. 2, pp. 307–324, Apr. 2020, doi: 10.1002/jee.20308.

[10] L. Y. Y. Luk and C. K. Y. Chan, "Students' learning outcomes from engineering internship: a provisional framework," *Studies in Continuing Education*, vol. 44, no. 3, pp. 526–545, Sep. 2022, doi: 10.1080/0158037X.2021.1917536.

[11] S. Akinci-Ceylan, K. S. Cetin, B. Ahn, A. Surovek, and B. Cetin, "Investigating Problem-Solving Processes of Students, Faculty, and Practicing Engineers in Civil Engineering," *J. Civ. Eng. Educ.*, vol. 148, no. 1, pp. 1-14, Jan. 2022, doi: 10.1061/(ASCE)EI.2643-9115.0000054.

[12] S. Weedon, "The Role of Rhetoric in Engineering Judgment," *IEEE Trans. Profess. Commun.*, vol. 62, no. 2, pp. 165–177, Jun. 2019, doi: 10.1109/TPC.2019.2900824.

[13] ABET, "Criteria for Accrediting Engineering Programs, 2022 – 2023." *ABET [Online]*, Available: http://www.abet.org/

[14] D. Chadha and K. Hellgardt, "A case of conceptualisation: using a grounded theory approach to further explore how professionals define engineering judgement for use in engineering education," *European Journal of Engineering Education*, vol. 49, no. 2, pp. 348-369, May 2023, doi: 10.1080/03043797.2023.2210517.

[15] J. Gainsburg, "The Mathematical Modeling of Structural Engineers," *Mathematical Thinking and Learning*, vol. 8, no. 1, pp. 3–36, Jan. 2006, doi: 10.1207/s15327833mtl0801_2.

[16] J. Gainsburg, "The Mathematical Disposition of Structural Engineers," *Journal for Research in Mathematics Education,* vol. 38, no. 5, pp. 477-506, Nov. 2007, doi: 10.2307/30034962

[17] J. Swenson, A. Johnson, and M. Magee, "Investigating the Transferability of the Productive Beginnings of Engineering Judgment Framework from Statics to Dynamics," in *2022 ASEE Annual Conference & Exposition*, Minneapolis, MN, pp. 1-18, Jun. 2022, doi: 10.18260/1-2--41140

[18] C. Kimberlin, J. Perry, A. W. Johnson, and J. E. S. Swenson, "Investigating the Transferability of the Productive Beginnings of Engineering Judgment Framework from Interview Data to Group Discourse Data," in *2022 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden, pp. 1–7, Oct. 2022, doi: 10.1109/FIE56618.2022.9962516.
[19] J. R. Armstrong and J. Wade, "Development of Systems Engineering Expertise," *Procedia Computer Science*, vol. 44, no. 1, pp. 689–698, Dec. 2015, doi: 10.1016/j.procs.2015.03.026.
[20] L. Hirshfield, J. Coller, E. Madden, and R. Fowler, "Assessing the Culture of Engineering Student Project Teams," in *2020 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual Online, pp. 1-18, Jun. 2020, doi: 10.18260/1-2--34180.
[21] L. Zhang and J. Cheng, "Effect of Knowledge Leadership on Knowledge Sharing in Engineering Project Design Teams: The Role of Social Capital," *Project Management Journal*, vol. 46, no. 5, pp. 111–124, Oct. 2015, doi: 10.1002/pmj.21525.

Appendix

Productive Beginnings of Engineering Judgment (PBJ) Framework

PBJ Code	PBJ Description	PBJ Code	PBJ Description
PBJ1: Making Assumptions		**PBJ2: Assessing Reasonableness**	
PBJ 1a	Assumption with no justification	PBJ 2a	Assessing reasonableness of assumptions the student made
PBJ 1b	Assumption makes model more realistic based on student's research for the class	PBJ 2b	Assessing reasonableness of the model output
PBJ 1c	Assumption considers user/client/manufacturer	PBJ 2c	Assessing reasonableness of model provided by instructor
PBJ 1d	Assumption makes the model solvable	**PBJ3: Using Technology Tools**	
PBJ 1e	Assumption simplifies the model	PBJ 3a	Use of a technology tool to help with analysis/computation
PBJ 1f	Assumption doesn't affect the output of the model	PBJ 3b	Assessing use of a technology tool
PBJ 1g	Assumption models student's perceived worst-case scenario	**PBJ4: Overriding Answers**	
PBJ 1h	Assumption makes model more realistic based on student's lived experiences	PBJ4	Deciding to overriding a calculated answer