Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47964

BOARD # 442: RIEF: Elicitation of epistemic practices during engineering laboratory activities in different modes

Dr. Jeffrey A Nason, Oregon State University

Jeff Nason is a professor of environmental engineering and associate head for graduate programs in the School of Chemical, Biological and Environmental Engineering at Oregon State University.

Samuel Gavitte, Tufts University

A PhD student at Tufts University working with Dr. Jeff Nason and Dr. Milo Koretsky to research engineering epistemic practices in the context of virtual and physical lab activities.

Sarah Simmons, Tufts University
Dr. Milo Koretsky, Tufts University

Milo Koretsky is the McDonnell Family Bridge Professor in the Department of Chemical and Biological Engineering and in the Department of Education at Tufts University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley,

RIEF: Elicitation of epistemic practices during engineering laboratory activities in different modes

Project Overview

The answer to the question "what does it means to be an engineer?" can depend on the setting. In the university classroom, for example, being an engineer typically means having the ability to solve well-defined, idealized problems quickly and accurately. On the other hand, in the workplace, engineering involves solving complex problems using *practices* often underemphasized in the university setting such as collaborating in teams, learning from failure, and making trade-offs [1], [2], [3], [4]. In this project, we developed an *industrially situated* physical and virtual laboratory which engages students in practices more representative of the engineering workplace.

We take a sociocultural orientation that positions student learning as participation in valued disciplinary practices as opposed to the more traditional stance which positions learning as the acquisition of discrete knowledge and skills [5], [6], [7], [8]. This framing follows the 'practice turn' in the learning sciences which calls for students to engage in the practices of the discipline they are learning instead of acquiring a set of canonical knowledge [2], [9]. Emphasis on practice in science and engineering education provides a framing to students that aligns better with the complex, messy nature of these disciplines and can potentially make the field compelling to people with more diverse backgrounds by valuing a wider range of competencies [2], [3].

To analyze how students engage in the disciplinary practices of engineering, we utilize two theoretical frameworks – engineering epistemic practices and practical epistemology analysis. First, we characterize the *engineering epistemic practices* that are elicited during the laboratory task. Engineering epistemic practices are the socially organized and interactionally accomplished ways engineers develop, justify, and communicate ideas when completing engineering work [1], [10], [11]. Second, we identify the gaps student teams encounter as they progress through the laboratory task. The idea of gaps comes from the framework of *practical epistemology analysis* (PEA) [12]. In the case of our study, gaps are the salient points in their understanding and task design that groups socially acknowledge as needing attention. These frameworks are combined to both characterize the practices that groups demonstrate and understand what they sought to accomplish with those practices.

Currently, we ask the following research questions:

1. What epistemic practices do engineering student groups demonstrate while completing an industrially situated laboratory task? How are these practices influenced by:
    a. Instructional design (e.g.: physical or virtual mode, inclusion of a planning day)
    b. Students disciplinary background
    c. The interface of the virtual laboratory environment
2. What gaps do students identify and fill during the task? How do students use epistemic practices in support of filling these gaps?

Laboratory Design

The laboratories that were developed for this project are on the topic of drinking water treatment. Jar testing is a common procedure used in drinking water treatment plants. The test simulates the coagulation, flocculation, sedimentation procedure of drinking water treatment on a small scale to calibrate chemical additives used to remove water contaminants at the municipal scale. We developed separate virtual and physical laboratories for jar testing and investigated student participation through several combinations of these laboratories.

The physical and virtual laboratory designs are described in detail in past work [13]; however, improvements are being made to both based on those prior investigations. A new version of the virtual laboratory is being developed in the video game engine Unity. A screenshot is shown in Figure 1. In this version, students are placed in a 3D environment where they must interact with modeled lab equipment to complete the jar test. In contrast to the html virtual laboratory where a single button press provided groups with data, students will have to select the right equipment and measurements for each step of the process. Once groups have selected their inputs and initialized the test, an animation will play, showing the treated water change color and opacity to represent the removal of contaminants. Then, student groups will need to measure the turbidity, organic carbon content, and pH of each jar. Upon reflection of their experience completing the html version of the laboratory, students reported wanting visuals or animations of the procedural steps when completing the activity; therefore, a goal of the Unity Jar Test was to include these representations of the laboratory procedure for students.

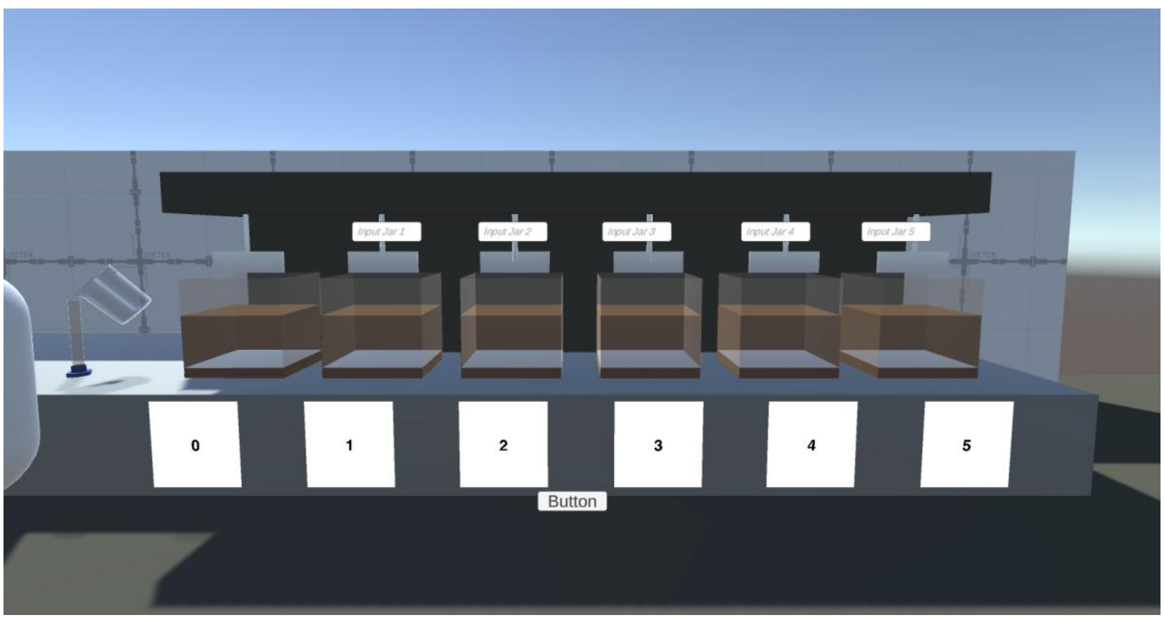

Figure 1: The jar testing apparatus from the Unity Jar Test as shown while selecting the input parameters. After selecting the button at the bottom of the screen a time-accelerated animation will play depicting the process.

The physical laboratory was originally designed with a prescribed procedure that told students which doses of chemicals to add. This choice ensured that students would obtain useful data but also limited student agency. To address this, we revised the instructional design to include a planning day where groups developed the chemical doses they would use in the physical jar test. During this planning day, students were given a set of incomplete sample data and had access to their virtual laboratory data from the week before. The sample data provided were from tests performed on the same water source students were provided in the physical laboratory. However, the characteristics of this water were intentionally different from the water simulated in the virtual laboratory.

Methods

Data Collection

Two rounds of data collection have been completed with a third planned. During each round of data collection, student groups have completed both the physical and virtual laboratory. The specifics of the instructional design have been adapted each round based on data gathered in the previous implementations. Participants complete the laboratories in groups of three while being video-recorded the entire time they work. Group work artifacts (laboratory reports prepared by each group) were also collected. After completing all assignments for the jar test, students participated in individual semi-structured about their experiences and actions in the laboratories.

Chemical engineering students in an upper-level laboratory class at a large public land grant university completed the laboratories in the first round of data collection. Four groups of three students participated, for a total of twelve participants. Two groups completed the physical laboratory first and the virtual laboratory second, while the other two groups completed the laboratories in the opposite order. Three groups of environmental engineering students at the same university completed the laboratories in the second round of data collection. This design had groups completing the virtual laboratory in the first week and the physical laboratory in the third week with the planning day described above in between. The planned third round of data collection will follow the same pattern as the second round, but will utilize the Unity-developed version of the virtual laboratory described above.

Data Analysis

Video recordings were transcribed verbatim and split into thematic episodes of one to four minutes in length. Episodes were bounded by student groups changing the topic or focus of their discussion. These episodes were qualitatively coded using discourse analysis [14], [15] to identify the engineering epistemic practices that students were engaging in each episode. The codebook was based on past work [16] but was amended throughout the project as needed. Practices were grouped into three larger categories: conceptual, material, and social. Analysis using PEA was done similarly with video transcripts being coded for when groups identified and closed gaps. These gaps were described and arranged into timelines showing what gaps were being addressed at different points in time. The authors met regularly to discuss the coding process and develop the timelines which was done iteratively until all authors agreed.

Results and Discussion

To date, we have found that the virtual and physical laboratories target different subsets of epistemic practices as described in [13] and that the use of a particular epistemic practice is connected to group-identified gaps as described in [17]. Initial findings from coding the second round of data collection have shown promising results for the redesign that included a planning day prior to the physical laboratory. Without a planning day, groups minimally engaged with conceptual epistemic practices while completing the physical laboratory. In contrast, during the planning day, groups used the virtual laboratory as an experience to draw upon to develop their experimental plan. We conjecture the planning day design positions the virtual laboratory as a source of *case-based knowledge*, similarly to how practicing engineers use their case-based experience in their practice [18]. Groups needed to account for differences in the water conditions and problem constraints between the virtual and the physical laboratory cases, eliciting their conceptual engagement. The planning days led to students identifying gaps that required both conceptual and material practices to address, compared to the round one physical laboratory where physical practice dominated. We are currently further developing this line of inquiry.

A preliminary version of a timeline from one group's virtual laboratory is presented in the appendix, Figure A1. Timelines serve as a tool to extend previous analysis [17] across all gaps from a laboratory and work on developing the timelines is ongoing. In the current version (Figure A1), gaps are listed in three categories which were identified during coding: overall goal, strategy for next run, and data analysis. This timeline uses O and C to denote when gaps are opening and closing, meaning the group either acknowledges the existence and need to fill a gap (opening) or that suitable relations have been built to fill a gap and proceed in their work (closing). Sometimes, the group will be unable to fill a gap but change topic anyway, this is denoted on the timeline with L to mean the gap is lingering. The opening and closing of gaps are a social phenomenon, meaning it depends on the state of group discussion and not any external assessment of correctness. Consequently, any individual gap could open and close numerous times as work progresses, and new information and ideas become available. For instance, in the timeline, gap 1.3 considers how much total organic carbon (TOC) is needed to be removed from the treated water. This gap was addressed three separate times, at the beginning of the laboratory, after the group had struggled to achieve it, and later when discussing with the instructor. We are interested in ways the recursive analysis of a phenomena such as this influences learning.

The Unity virtual laboratory will provide students with more visual feedback about the jar testing process. It is anticipated that this will lead to groups having more salient experiences in connection to the real jar testing process while completing the virtual laboratory. Research has shown that more visually immersive virtual laboratories increase student motivation to engage with the task [19]. The enhanced virtual laboratory will likely also assist groups during the planning days given they will know more about the physical jar test procedure and equipment.

Acknowledgments

The work reported here was supported in part by a grant from the National Science Foundation (EEC 2204885 and EEC 2204933) and the Oregon State University Center for Research in Engineering Education Online (CREEdO). We would like to acknowledge Dr. Skip Rochefort and Dr. Tyler Radniecki for their assistance and for allowing us to implement these laboratories in their classes. Thank you also to Nicolette Maggiore and Dr. Ira Caspari-Gnann for their invaluable support in our application of PEA in this work.

References

[1] C. M. Cunningham and G. J. Kelly, “Epistemic Practices of Engineering for Education,” *Sci. Educ.*, vol. 101, no. 3, pp. 486–505, May 2017, doi: 10.1002/sce.21271.

[2] E. Forman, “The Practice Turn in Learning Theory and Science Education,” in *Constructivist Education in an Age of Accountability*, 2018, pp. 97–111. doi: 10.1007/978-3-319-66050-9_5.

[3] C. C. M. Mody, "Scientific Practice and Science Education," *Sci. Educ.*, vol. 99, no. 6, pp. 1026–1032, 2015, doi: https://doi.org/10.1002/sce.21190.
[4] D. Jonassen, J. Strobel, and C. B. Lee, "Everyday Problem Solving in Engineering: Lessons for Engineering Educators," *J. Eng. Educ.*, vol. 95, no. 2, pp. 139–151, Apr. 2006, doi: 10.1002/j.2168-9830.2006.tb00885.x.
[5] S. Wörner, J. Kuhn, and K. Scheiter, "The Best of Two Worlds: A Systematic Review on Combining Real and Virtual Experiments in Science Education," *Rev. Educ. Res.*, vol. 92, no. 6, pp. 911–952, Dec. 2022, doi: 10.3102/00346543221079417.
[6] T. de Jong, M. C. Linn, and Z. C. Zacharia, "Physical and Virtual Laboratories in Science and Engineering Education," *Science*, vol. 340, no. 6130, pp. 305–308, Apr. 2013, doi: 10.1126/science.1230579.
[7] S. E. Muilwijk and A. W. Lazonder, "Learning from physical and virtual investigation: A meta-analysis of conceptual knowledge acquisition," *Front. Educ.*, vol. 8, 2023, [Online]. Available: https://www.frontiersin.org/articles/10.3389/feduc.2023.1163024
[8] A. Sfard, "On Two Metaphors for Learning and the Dangers of Choosing Just One," *Educ. Res.*, vol. 27, no. 2, pp. 4–13, Mar. 1998, doi: 10.3102/0013189X027002004.
[9] C. Passmore, J. S. Gouvea, and R. N. Giere, "Models in Science and in Learning Science: Focusing Scientific Practice on Sense-making," 2014. [Online]. Available: https://api.semanticscholar.org/CorpusID:59812136
[10] M. Koretsky, E. J. Nefcy, S. B. Nolen, and A. B. Champagne, "Connected epistemic practices in laboratory-based engineering design projects for large-course instruction," *Sci. Educ.*, vol. 107, no. 2, 2023, doi: 10.1002/sce.21769.
[11] G. J. Kelly and P. Licona, "Epistemic Practices and Science Education," in *Science*, in Science: Philosophy, History and Education. , Springer Nature, 2018, pp. 139–165. doi: 10.1007/978-3-319-62616-1_5.
[12] P.-O. Wickman and L. Östman, "Learning as discourse change: A sociocultural mechanism," *Sci. Educ.*, vol. 86, no. 5, pp. 601–623, Sep. 2002, doi: 10.1002/sce.10036.
[13] S. B. Gavitte, M. D. Koretsky, and J. A. Nason, "Connecting affordances of physical and virtual laboratory modes to engineering epistemic practices," *J. Comput. High. Educ.*, Jun. 2024, doi: 10.1007/s12528-024-09403-7.
[14] N. Fairclough, *Analysing Discourse: Textual Analysis for Social Research*. in Analysing Discourse: Textual Analysis for Social Research. Routledge, 2003. [Online]. Available: https://books.google.com/books?id=V4SOkoy2vEIC
[15] M. Handford and J. P. Gee, *The Routledge Handbook of Discourse Analysis*, 1st ed. Routledge, 2012. [Online]. Available: https://doi.org/10.4324/9780203809068
[16] K. Chindanon and M. Koretsky, "Group Practice in Engineering: Productive Interactions during a Realistic, Open-ended Task.," *Stud. Eng. Educ.*, 2023, doi: https://doi.org/10.21061/see.112.
[17] S. B. Gavitte, M. D. Koretsky, and J. A. Nason, "Discourse Moves and Engineering Epistemic Practices in a Virtual Laboratory," 2024.
[18] W. G. Vincenti, *What Engineers Know and How They Know It*. John Hopins University Press, 1990.
[19] V. Potkonjak *et al.*, "Virtual laboratories for education in science, technology, and engineering: A review," *Comput. Educ.*, vol. 95, pp. 309–327, Apr. 2016, doi: 10.1016/j.compedu.2016.02.002.

Appendix

											R1										R2													
	Gap	**Time ->**	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
***1**	Overall goal																																
1.1	What resources they have and what do they mean			O~	C																												
1.2	What and how are we removing things				O~	~	~	~C																									
1.3	What is the TOC removal requirement					O~	~C							OC							OC												
***2**	Strategy for next run																																
2.1	Overall strategy for doses						O~	C																									
2.2	Range of doses for round 1								O~	C																							
2.3	Units of doses									O~	C																						
2.4	Should we change pH and how?													OL			O~	~	C						OC								
2.5	How to consider economics?																	OL															
2.6	Lower or raise pH																										O	~	~	C			
2.7	Strategy for changing pH																														O~	~	~C
2.8	Error in spreadsheet?																															OC	
2.9	Third run values																																O~
2.10	What should we replicate/how do we improve past r																																
2.11	Should we do a 4th run																																
2.12	How does pH effect the process																																
2.13	Why are we doing another run?																																
***3**	Data analysis																																
3.1	What are the different data given?										O	~	~C																				
3.2	Does the simulation have variability?														O~	L					C												
3.3	Why did the pH change?																				O~	C								OC			
3.4	How to graph results?																						O~	~	~C								
3.5	Did we get better removal or																																
3.6	Whats our optimal dose?																																

Figure A1: A timeline of the gaps one group identified while completing the Jar Test Virtual Laboratory. Each box represents two minutes of time, light grey highlighting and tildes denoting that a gap is being addressed in that moment, with descriptions of each gap written on the left. Gaps opening, lingering, or closing are marked with O, L, and C, respectively. Gaps are grouped into three categories, that are marked with dark grey.

	Gap	60	62	64	66	68	R3 70	72	74	76	78	80	82	84	86	88	90	92	R4 94	96	98	100	102	104	106	108	110	112	114	116	118	120
***1**	Overall goal																															
1.1	What resources they have and what do they mean																															
1.2	What and how are we removing things																															
1.3	What is the TOC removal requirement			OC																												
***2**	Strategy for next run																															
2.1	Overall strategy for doses																															
2.2	Range of doses for round 1																															
2.3	Units of doses																															
2.4	Should we change pH and how?																															
2.5	How to consider economics?																															
2.6	Lower or raise pH																															
2.7	Strategy for changing pH	~C																														
2.8	Error in spreadsheet?																															
2.9	Third run values	O~	~C		O~	~C																										
2.10	What should we replicate/how do we improve past r			O	~C																											
2.11	Should we do a 4th run						O~	~L				~	~		C																	
2.12	How does pH effect the process								O	~	~	~	~	~	~L															O~	~L	
2.13	Why are we doing another run?																	OC														
***3**	Data analysis																															
3.1	What are the different data given?																															
3.2	Does the simulation have variability?																															
3.3	Why did the pH change?																															
3.4	How to graph results?							O~	~	~	~C																					
3.5	Did we get better removal or						OC																									
3.6	Whats our optimal dose?																					O~	~	~C								

Figure A1 (cont.): A timeline of the gaps one group identified while completing the Jar Test Virtual Laboratory. Each box represents two minutes of time, light grey highlighting and tildes denoting that a gap is being addressed in that moment, with descriptions of each gap written on the left. Gaps opening, lingering, or closing are marked with O, L, and C, respectively. Gaps are grouped into three categories, that are marked with dark grey.