ACTIVATING STUDENT-CENTERED LEARNING AND BELONGING IN THE ENGINEERING CLASSROOM

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This teaching resource invites students to search beyond the limited offerings of a set course curriculum to find, cite, and share a source that helps them clarify a difficult concept. In its initial design, this teaching resource is intended for STEM classrooms but can be adapted to learning contexts that are heavily dependent on standardized textbooks or otherwise rigid curricular structures. These contexts have the tendency to reinforce dominant voices and ways of knowing and to position students as passive recipients in what Paolo Freire termed "the 'banking' concept of education" [1]. This activity represents one way of intervening in that model by encouraging students to seek out and justify alternative pathways to knowledge and see themselves as empowered agents of knowledge creation.

The occasion for use of this teaching resource is when students are introduced to a concept that is likely to be unfamiliar or confusing for them, i.e., a concept that constitutes a key learning objective for a given course. At the same time, this resource will help students achieve *citation*-specific learning objectives, which include:

1. Identifying gaps in standard curricula that assume a certain learner and reinforce canonical structures of knowledge production.
2. Locating extracurricular sources that can serve as examples in aid of learning transfer.

By helping students achieve this latter pair of learning objectives, instructors will also facilitate a greater sense of student belonging and active participation in the STEM classroom.

Context

As a teaching assistant for a lecture-based undergraduate engineering course cross-listed between Aerospace and Electrical Engineering at the University of Minnesota Twin Cities, I initially relied on the course textbook and lecture notes. As I gained awareness of students' different interests and backgrounds during office hours, I asked them to identify examples of systems that they have experienced that track reference values. In the context of engineering, a

"system" may be defined as components that interact to achieve an overall purpose. For example, one student had worked with an uncrewed aerial vehicle, which is a system with components such as motors and sensors and a goal of flight with small payloads such as cameras. This particular vehicle had a human operator that tracked a reference trajectory. The student felt comfortable extending the idea to the algorithm-based trajectory tracking we discussed in class. My intent was to help students connect their theoretical knowledge from course lectures to familiar systems so that they could identify gaps in their knowledge and demonstrate its application.

This experience encouraged me to reflect on how the limited number of authors of textbooks and course notes as well as the time between curricular updates can pose barriers to student identification of material that cultivates their sense of belonging. Further, some of these sources fail to acknowledge the specific efforts of research assistants and other contributors.

Discussions during "Teaching Citational Practice: A Critical Feminist Approach," organized by Diana Rose Newby and Cat Lambert and offered through the CIRTL series Teaching & Learning in the Diverse Classroom in 2021, helped me associate these challenges in my instruction with the vocabulary of canon formation ("overrepresentation" of certain voices [2]) and labor erasure (lack of acknowledgement's "negative impact on…grants and fellowships, … promotion" and other areas of participation in a discipline [2]). Making these connections in turn inspired me to identify an opportunity to invite students to cite and share the sources that help them connect with course material. This resource is also an invitation to students to address issues of canon formation and labor erasure.

"Teaching Citational Practice" encouraged me to learn more about the connections between cited course materials and student belonging. Researchers have identified broad associations between students' sense of belonging in the classroom and grade performance [3], retention [4], identities [5], and persistence [6] in Science, Technology, Engineering, and Mathematics (STEM). Christman and Yerrick report discussions among U.S. female undergraduate engineering students regarding course examples "that are more geared towards guys" [7], which draws attention to how citation of canonical examples can pose a barrier to belonging for students with one or more "othered" identities in engineering. In the conference paper, two students shared how car systems were commonly used as examples in their coursework, with one student noting "if you raise…a question like, 'Hey what is

the whatever of a car? What does that do? I don't understand the analogy.' You probably will get laughed at" [7].

I sought additional discussions to develop this resource. My mentees in a research-based undergraduate engineering course at Cornell University were surprised to learn that they could be authors of engineering publications; they were also unfamiliar with citation conventions favored by engineering professional societies such as the Institute of Electrical and Electronics Engineers. Therefore, I formulated the activity in my resource to prepare students for citational practice in internships and research experiences as well as to invite students to consider their role as contributors to knowledge in engineering. The activity is suitable for both lecture- and discussion-based engineering courses at the beginning of undergraduate aerospace, electrical, and mechanical engineering curricula.

Fellow graduate teaching assistants Aditya Bhaskar and Elise Eckman also furthered my development of this resource when they shared how they identified citations for engineering discussion/recitation sessions to help with my examples of sources in this resource. Aditya Bhaskar reinforced the value of recognizing undergraduate students as knowledge creators. He provided an example of the undergraduate research by Neeraj Kayal and Nitin Saxena, which led to a breakthrough in theoretical computer science. Their mentor, Manindra Agrawal, worked with them to amplify their work to field-recognized publication with subsequent award recognition [8], [9].

Discussions with Diana Rose Newby, Cat Lambert, and Ashley B. Heim during the editing of this resource helped clarify language and instructions such that the resource may be applicable to other disciplines in which early undergraduate curricula tend to focus on knowledge acquisition rather than positioning students as participants in the creation of knowledge through citational practice.

IMPLEMENTATION

This resource invites students to locate and share sources that help them complete a particular learning objective for the given course. The format of the assignment is a post to an online discussion board or forum outside of a course meeting. In my own instruction, I plan to implement this activity in the following ways:

- as part of an assignment that encourages students to practice working with and to clarify topics that are commonly confusing for students
- to encourage students to actively participate in broader applications of the course material

Table 2, which appears in the Appendix following the student-facing instructions, presents a hypothetical example, based on my own learning experiences, of how this activity might unfold for students and instructors. The student-facing instructions ask for a citation in the form of a link. This choice reflects my past students' lack of exposure to professional societies' citation conventions for engineering documentation. Instructors whose course learning objectives include teaching these conventions may choose to use this as an opportunity for students to practice conventional forms of citation.

Because each student brings different experiences to the classroom, the success of this exercise requires instructors to cultivate an open environment so that students feel comfortable sharing broad types and contexts of sources that resonate with them. One way that instructors can cultivate this open environment is to incorporate a diverse range of sources into their own instruction via memes, social media posts, demonstration videos, etc., that are not part of canonical English language engineering curricula.

I recognize that time and other resources can determine the capacity of instructors to create course materials that actively respond to changing student experiences. Further, accreditation agencies such as ABET (the Accreditation Board for Engineering and Technology) [10] shape the engineering curriculum and learning objectives in the U.S. and other countries, which could create obstacles for instructors who want to leverage this teaching resource toward curricular transformation. Therefore, I want to highlight opportunities to connect citational practice with professional program requirements in engineering. These opportunities may also be applicable to other disciplines in which national and international accreditation boards shape curricula. Below I also include a discussion of how to connect the activity in this resource with methods in teaching practice to motivate instructor applications for course development funding.

Instructors may choose to discuss with their department mentors opportunities for temporal and financial support to incorporate this activity and prevent erasure of their efforts. Department mentors can help instructors identify department, university, and external grants for teaching innovation

that may facilitate formal allocation of time and funding for preparation and training. Professional organizations may also have relevant grant opportunities.

Instructors may motivate and provide context for requested funding and other forms of curricular support by linking this teaching resource to instructional tools that have gained acceptance in some engineering communities. For instance, several undergraduate teaching and research institutions [11]–[17] emphasize the revised Bloom's taxonomy [18] for learning objectives and the Research Skills Development Framework for development of skills in knowledge creation [19] in undergraduate education. Table 1 below summarizes how instructors can integrate a tool such as Bloom's taxonomy into citational practice teaching activities that address learning objectives in the Research Skills Development Framework as well as related ABET criteria for student outcomes. I acknowledge the limitations of these tools [17], [20], [21], including the limited number of national academic systems in which they have been tested, and encourage instructors to find tools that are relevant to their students.

The table below presents a framing of learning objectives in citational practice that may help instructors motivate support from other stakeholders. Each column of this table lists a learning objective for citational practice and associates it with a specific level of Bloom's taxonomy. The rows reflect how the instructor may connect the learning objectives with research skills (Row 1) and ABET Criteria for Student Outcomes (Row 2).

Table 1. Connections with Learning Objectives for Citational Practice

	Revised Bloom's Taxonomy Level [18]	
	Understand	Evaluate
Research Skills Development Framework [19] Autonomy Level: Prescribed Research Research facet: Communicate and Apply	Students identify patterns that reinforce or help dismantle canon formation/labor erasure in the selected sources such as author affiliation and acknowledgement.	Students identify opportunities to improve course sources that they value and determine how limitations on the span of course sources may influence their perception of knowledge creation.
Related ABET Criteria for Student Outcomes [10]	"an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts"	"an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives"

Finally, instructors might extend the activity in this resource by more broadly modeling diverse and inclusive citational practice across course material. Citations of shared videos, summary diagrams from blog posts, etc., can help instructors demonstrate how to credit a wide range of authors and types of media in one or more citation styles common to the discipline. Instructors may choose to create an ongoing reference list and have students consider the sources and gaps in how their references span authorship and types of media in the discipline. Kim's "'The Paths We Were Told To Follow': A Citational Practice Worksheet for Students" [22] provides another example of how instructors might facilitate a similar assignment. By broadening the sources of materials from which they draw, instructors provide multiple perspectives from which students can learn and achieve continuous growth in citational practice.

TEACHING RESOURCE

Student-facing Instructions

[To be presented in the form of an assignment prompt. Instructor-specific notes are included in brackets.]

The textbooks and lecture notes that instructors provide in this course reflect a limited number of authors and perspectives. Therefore, they only highlight specific individuals and institutions that create and communicate knowledge in this field. This activity asks you to create a discussion post about a source beyond instructor-provided course materials that helps you learn the following: [Instructors place the selected learning objective here]

The goals of this activity are twofold:

- to cite a source that can help you and your classmates better understand this topic
- to reflect on how the source you share shapes your understanding of canon formation and the labor that makes up this field.

You may want to start by considering sources of information that you have used to understand material in past courses. Examples include topic pages in open-access encyclopedias and illustrations through online videos. Use these pathways to spend about 15 minutes to identify a resource that helps you to better understand the learning objective. If you want to discuss starting points or ideas for sources, we encourage you to speak with us during office hours.

Once you have identified a source, we ask you to spend about 15 minutes responding to the following prompts through an online discussion post.

1. Please generate a citation for your resource in the form of a link. For sources that are offline, please provide the following information as it is available so that other students can find them: resource type (e.g., book or poster), author names, creation date, and location (e.g., poster presented at the on-campus undergraduate research conference).
2. How does your resource connect with the learning objective? What aspects of the presentation of information help with your understanding beyond the textbook and course lectures?
3. Does your resource credit any authors or contributors? Whose work is credited via authorship, and whose work is relegated to acknowledgments? Whose work might be omitted altogether?
4. Considering your responses to Question #3, how does your resource support labor erasure? How does it mitigate it?
5. How do you think that your resource relates to canon formation? To what extent does it support dominant voices in engineering? How do you think it omits or diminishes these voices?

APPENDIX

In my past role as a student in and teaching assistant for the cross-listed linear control systems course, I wanted to bridge interests in aerospace and electrical engineering applications with the objective of mapping transfer functions to state space models. The first row of Table 2 below shares examples that I might have identified as an undergraduate student if I were tasked with this same assignment. The second row of Table 2 reflects how I would identify the type of resource, authors, and affiliations in response to the prompts in the student-facing portion of the resource.

Each column of this table gives an example response and its source. The first row gives the example and how it connects with the learning objective in the existing curriculum. The second row reflects how the instructor may connect the examples with learning objectives for citational practice in the form of forum responses or in class.

Table 2. Connections between citational practice and examples for a linear systems course

Learning Objective	Example from an English Language Textbook [23] Used Across Programs [24]–[27]	Example from a Peer-Reviewed Research Paper [28]	Example from a Web Resource [29]
Convert between state space and transfer function models	Examples 2-2 and 2-3 in Ogata ask for the transfer function and state-space model of a second order linear system equation. The text relates the equation to a series spring-mass-damper system.	Researchers may use quadrotors to illustrate concepts in robotics because of their ease of takeoff and landing. A paper by Hoffman, Huang, Waslander, and Tomlin uses a linear model for small changes in attitude (i.e., orientation) of a quadrotor [28]. The student may practice writing the state-space model for the following transfer function $\frac{\Phi(s)}{U_{\phi}(s)} = \frac{1/I_{\phi}}{s^2(\tau s+1)}$ ϕ indicates the roll component u_{ϕ} is the control input moment about the roll axis I_{ϕ} is a constant and represents the inertial component in the body frame τ is a constant and represents the time delay for the thrust command to the motors	Cruise control is a precursor to additional autonomous capabilities for vehicles. The student may practice writing the state-space model for the following transfer function for cruise control $\frac{V(s)}{U(s)} = \frac{1}{ms+b}$ v is the velocity of the vehicle u is the control input the force m is a constant and represents the mass of the vehicle b is a constant and represents the effects of wind drag and rolling resistance
Description of the type of resource, authorship, and acknowledgements to facilitate discussion of how the resource may challenge and reinforce dominant (i.e., canonical) voices and labor valuation (e.g., erasure).	***Type of resource*** assigned course textbook ***Author*** Katsuhiko Ogata (University of Minnesota professor) ***Acknowledgements of fifth edition reviewers in order of appearance*** Mark Campbell (Cornell University	***Type of resource*** a peer-reviewed journal, Control Engineering Practice ***Authors in order of appearance*** Gabriel M. Hoffmann (Stanford University graduate student), Haomiao Huang (Stanford University graduate student), Steven L. Waslander (University of Waterloo	***Type of resource*** a website falling under a non-attribution Creative Commons license, Control Tutorials for MATLAB and Simulink ***Authors in order of appearance*** [30] Dawn Tilbury (University of Michigan, UM, professor), Bill

Table continued on following page

	professor), Henry Sodano (Arizona State University professor), and Atul G. Kelkar (Iowa State University professor)	postdoctoral scholar), Claire J. Tomlin (University of California Berkeley professor) ***Acknowledgements*** "The authors would like to thank Jung Soon Jang, David Shoemaker, David Dostal, Dev Gorur Rajnarayan, Vijay Pradeep, Paul Yu, Justin Hendrickson, and Michael Vitus, for their many contributions to the development of the STARMAC testbed. We would also like to thank Mark Woodward for the image processing program used for the USB camera system."	Messner (Carnegie Mellon University, CMU, professor), Luis Oms (CMU undergraduate student), Joshua Pagel (UM undergraduate student), Yanjie Sun (UM undergraduate student), Munish Suri (CMU undergraduate student), Christopher Caruana (UM undergraduate student), Dai Kawano (UM undergraduate student), Brian Nakai (CMU undergraduate student), Pradya Prempraneerach (CMU undergraduate student), Jonathon Luntz (CMU graduate student), Rick Hill (University of Detroit Mercy, DM, professor), JD Taylor (CMU graduate student), Shuvra Das (DM professor), and Mike Hagenow (University of Wisconsin graduate student)

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