A New STEM Teaching Practice Program: Training the Engineering Faculty of Tomorrow

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Abstract

Effective training of STEM graduate students requires preparation beyond technical expertise, including skills in teaching, communication, and mentoring. However, few graduate programs provide structured pedagogical development. This work-in-progress paper describes the design and early implementation of a STEM Teaching Pedagogy Apprenticeship Program in the Department of Chemical and Biomolecular Engineering (CBE) at the University of Pennsylvania. The one-year program integrates a discussion-based pedagogical seminar with a mentored teaching apprenticeship, allowing graduate students to connect learning theory with classroom practice. Participants engage in curriculum design, assessment, student engagement, and reflective teaching under faculty supervision. Using qualitative analysis of participant reflections, seminar discussions, and surveys from the pilot cohort, we examine changes in teaching confidence, pedagogical understanding, and professional identity. Preliminary findings suggest the program effectively supports graduate students' development as educators and provides a scalable model for graduate teaching preparation in engineering.

1. Introduction

Graduate education in Science, Technology, Engineering, and Mathematics (STEM) has traditionally prioritized the development of deep disciplinary expertise, with the implicit assumption that professional skills such as teaching, mentoring, and communication will be acquired informally or on the job. However, a growing body of research suggests that this model leaves many graduate students underprepared for the multifaceted roles they will assume in academic, industrial, and public-sector careers [1, 2]. These roles increasingly require not only technical mastery but also the ability to teach effectively, mentor diverse learners, collaborate across disciplines, and communicate complex ideas to varied audiences. Recent empirical work highlights persistent gaps between graduate training and professional expectations. National analyses of doctoral education emphasize that structured preparation for teaching and mentoring remains uneven across STEM disciplines and institutions, despite the centrality of these responsibilities in faculty and leadership roles [3]. Many graduate students enter instructional roles with limited formal preparation in pedagogy, assessment, or inclusive teaching practices, relying instead on observation or informal guidance. This lack of systematic preparation can negatively affect both graduate instructors and the undergraduate students they teach, while also slowing the development of professional identity and confidence as educators.

Education research further demonstrates that professional learning is most effective when it is sustained, practice-based, and supported through mentorship. Studies examining apprenticeship-style and embedded professional development models show that participants benefit most when pedagogical theory is integrated with authentic teaching practice, feedback, and structured reflection [4]. Rather than short-term workshops or isolated training sessions, these models emphasize learning through guided participation and iterative improvement, leading to more durable changes in professional practice. Evidence from broader workforce and education policy research reinforces these findings. Analyses of mentoring and professional development initiatives indicate that programs emphasizing long-term engagement, mentor-mentee relationships, and contextualized learning opportunities are more effective than episodic or compliance-driven training models [5]. These findings suggest that professional growth particularly in complex skill domains such as teaching requires intentional program design that aligns learning experiences with real-world responsibilities. Within engineering education, there is increasing recognition of the need to apply these principles to graduate teaching development. Yet many existing initiatives remain extracurricular, optional, or disconnected from disciplinary teaching contexts, limiting their impact and accessibility. As a result, graduate students who are interested in academic or teaching-focused careers often lack department-embedded pathways that support pedagogical development alongside research training.

In response to these challenges, the Department of Chemical and Biomolecular Engineering (CBE) at [institution] developed a STEM Teaching Pedagogy Apprenticeship Program designed to bridge teaching theory and practice through a structured, mentored experience. Drawing on evidence from apprenticeship and professional learning research, the program integrates a discussion-based pedagogical seminar with a year-long teaching apprenticeship embedded within undergraduate and graduate CBE courses. Graduate participants are paired with faculty mentors and engage in progressive instructional responsibilities while participating in guided reflection and feedback (Figure 1).

Figure 1: *The Pedagogical Apprenticeship Learning Cycle adapts Kolb's model to integrate theory, practice, and reflection in developing reflective engineering educators.*

This work-in-progress paper describes the design and early implementation of the CBE Teaching Pedagogy Apprenticeship Program and examines how participants articulate changes in their teaching philosophies, confidence, and pedagogical practices. Using qualitative data from written reflections, seminar discussions, and end-of-semester surveys, we explore how a discipline-embedded apprenticeship model can support graduate students' development as reflective educators. By situating this program within established evidence on graduate professional preparation and mentorship-based learning, we aim to offer a scalable model for engineering departments seeking to strengthen pedagogical training for PhD students.

2. Materials and Methods

2.1 Participants

Participants comprised of 3 graduate students who expressed interest in academic, teaching-focused, or education-adjacent career paths. Participation was voluntary and selected through an application process that considered teaching interests, prior instructional experience, and faculty mentor availability. Faculty mentors were tenure-track or teaching-focused faculty members teaching undergraduate or graduate CBE courses during the academic year. Each participant was paired with a faculty mentor whose course aligned with the student's interests and expertise. The program spans one academic year and consisted of two integrated components: (1) Biweekly Pedagogical Seminar and (2) Apprenticeship Experience.

2.2 Pedagogical Seminar Design

The pedagogical seminar is a discussion-based course offered during semester and facilitated by faculty with expertise in engineering education and teaching pedagogy. Seminar sessions were structured around core domains of effective teaching, including

a. Learning theory and evidence-based pedagogy [2, 6]
b. Curriculum, lesson design and Active Learning [7, 8]
c. Assessment, feedback, and grading practices [9, 10]
d. Mentorship as Teaching [11, 12].

Sessions incorporated paper readings, case studies, peer discussion, and reflective prompts. Participants were encouraged to connect seminar topics directly to their apprenticeship teaching experiences. Structured reflection activities, including written teaching journals, were used throughout the semester to support iterative learning and self-assessment.

2.3 Apprenticeship Experience

The apprenticeship component functioned as a guided, face-to-face teaching practicum embedded within existing undergraduate or graduate CBE courses. Apprentices initially observed their faculty mentor's teaching and course organization, followed by progressively increased responsibility over the semester. Responsibilities included assisting with lesson preparation, facilitating classroom activities, leading discussion sections or lectures, designing instructional materials, and providing formative feedback to students.

Faculty mentors provided regular feedback through informal check-ins and scheduled mentoring meetings. This scaffolded approach allowed participants to apply pedagogical concepts from the seminar in authentic instructional contexts while receiving ongoing guidance and support.

2.4 Data Collection

Data for this work-in-progress study were drawn from multiple qualitative sources generated as part of normal program participation. These included:

- Written student reflections completed throughout the semester in response to guided prompts associated with seminar readings.
- Teaching reflection narratives describing application of pedagogical strategies during the apprenticeship
- Peer teaching observation feedback from fellow participants
- End-of-semester written reflection focused on teaching confidence, pedagogical understanding, and professional identity development.

All data were collected with informed consent prior to analysis.

2.5 Data Analysis

A qualitative thematic analysis approach was used to analyze written reflections. As this is a work-in-progress study, the analysis focuses on descriptive insights and early trends rather than comprehensive outcome evaluation.

3. Results and Discussion

Qualitative analysis of graduate student reflections, seminar discussions, peer observations, and end-of-semester written reflection revealed consistent patterns in how participants developed pedagogical understanding, teaching practices, and professional identity as educators. Analysis focused on identifying cross-participant themes rather than individual teaching narratives. Full student reflections and extended excerpts are provided in the Appendices.

3.1 Student reflections from the Pedagogical Teaching Seminar

Reflections from the pedagogical seminar revealed a shift in how participants conceptualized engineering education, moving from a content-centered model toward a human-centered and skills-integrated framework. Across seminar modules, teaching skills, active learning, assessment, and mentorship participants emphasized that technical rigor alone is insufficient to prepare students for modern engineering practice.

Participants repeatedly identified the importance of addressing volatility, uncertainty, complexity, and ambiguity (VUCA) in engineering curricula. Reflections highlighted the need to integrate non-technical skills such as communication, ethical reasoning, decision-making under uncertainty, and systems thinking alongside foundational technical concepts. Rather than viewing these as competing priorities, participants described them as complementary: technical fundamentals provide the cognitive tools for problem solving, while contextual dialogue and reflection help students understand why and how those tools are applied.

Active learning emerged as a particularly influential theme. Participants described learning that even minimal strategies such as intentional pauses, restating student responses, or low-stakes formative checks can substantially improve student engagement and understanding. Reflections also demonstrated increased awareness of structural barriers to active learning, including time constraints, course size, and institutional norms, and emphasized the need for departmental and institutional support to sustain these practices.

Assessment discussions prompted participants to critically examine traditional exam-based evaluation, particularly considering widespread access to generative AI tools. Reflections emphasized designing assessments that prioritize reasoning, synthesis, and explanation over recall, and framed AI not solely as a threat but as a catalyst for rethinking assessment practices. Participants consistently argued that assessment should reinforce learning rather than merely certify correctness.

Finally, mentorship discussions reframed mentoring as a skill requiring intentional development rather than an assumed faculty competency. Participants articulated that effective mentorship must be adaptive, empathetic, and context-dependent, and that no single mentoring style fits all students. These reflections suggest that the seminar fostered a broader understanding of teaching as relational, reflective, and developmental rather than transactional.

3.2 Connecting Pedagogy to the Teaching Apprenticeship

A central outcome of the program was participants' ability to transfer pedagogical theory directly into teaching practice. Reflections demonstrated that the concurrent structure of seminar participation and teaching apprenticeship enabled rapid iteration between learning and application.

Participants described intentionally integrating dialogue, active learning, and formative assessment into recitations, lectures, and laboratory instruction. Common strategies included structured group problem-solving, guided board work led by students, think-pair-share activities, and deliberate pauses to allow for cognitive processing. Rather than viewing these techniques as add-ons, participants described them as reshaping the role of the instructor from content deliverer to facilitator of learning.

Importantly, reflections indicated that active learning was not implemented uniformly but was adapted to context. In recitations, participants emphasized collaborative problem solving and student-guided solutions. In lectures, where time and scale posed challenges, participants embedded shorter active learning moments such as polling, visualization tools, and guided questioning. In laboratory settings, participants leveraged the inherently active nature of lab work while supplementing it with mini-lectures, decision-making prompts, and reflective questions to promote higher-order thinking.

Participants also described intentional changes to assessment design informed by seminar discussions. These included incorporating open-ended reasoning questions, situational decision-making prompts, and synthesis-based exam problems designed to reduce reliance on memorization or AI-generated responses. Reflections emphasized that designing such assessments required careful alignment with learning objectives but was perceived as more authentic and educationally meaningful.

Across contexts, participants reported increased teaching confidence and a stronger sense of ownership over instructional decisions. Many reflected that pairing pedagogical learning with real-time teaching was more impactful than prior teaching experience without structured reflection, suggesting that experiential integration is a key strength of the apprenticeship model.

3.3 Peer Review and Teaching Observation

Peer observation and feedback functioned as a critical mechanism for reflective growth. Participants consistently described peer review as both affirming and developmental, providing concrete insights into instructional strengths and areas for improvement. Observed strengths included clear pacing, effective use of board work alongside slides, purposeful questioning, and successful integration of active learning strategies. Reviewers noted that student-guided problem solving and intentional wait time enhanced engagement and supported diverse learning styles. Participants also reported that receiving feedback from peers with shared pedagogical vocabulary allowed for more nuanced and actionable reflection.

Equally important were areas for growth identified through peer review. Common themes included the need for clearer transitions between topics, explicit articulation of learning objectives, stronger motivation through real-world examples, and greater variation in group formation. Feedback also highlighted the importance of physical presence and classroom movement, particularly in large or hybrid teaching environments.

Participants emphasized that observing peers' teaching was itself a powerful learning experience. Reflecting on others' instructional choices helped participants identify alternative approaches and recognize habits in their own teaching that might otherwise go unnoticed. These findings suggest that peer review served not only as an evaluative tool but as a collaborative learning process that reinforced reflective teaching practice.

3.4 Final End-of-Semester Reflections

End-of-semester reflections synthesized participants' experiences across the seminar, apprenticeship, and peer review components. Participants consistently described a transformation in how they understood teaching from an informal skill acquired through experience to a scholarly and reflective practice grounded in evidence and intentional design. Reflections emphasized increased confidence, clarity of teaching philosophy, and stronger professional identity as educators. Participants articulated greater comfort experimenting with instructional strategies, adapting to student needs, and iterating based on feedback. Many described the experience as more impactful than prior teaching roles, citing the structured integration of pedagogy, practice, and reflection as the distinguishing factor. Participants also acknowledged ongoing challenges, including time constraints, institutional norms, and uncertainty around scaling pedagogical innovations. Rather than viewing these as deterrents, reflections framed them as areas for continued growth and advocacy. Several participants expressed motivation to carry these practices forward into future teaching roles and to contribute to broader conversations around engineering education reform.

4. Conclusion

This work-in-progress paper describes the design and pilot implementation of a STEM Teaching Pedagogy Apprenticeship Program in a Chemical & Biomolecular Engineering Department and examines its impact on graduate students' pedagogical development. Findings from qualitative analysis indicate that integrating structured pedagogical discussion with mentored teaching practice supports meaningful growth in teaching confidence, instructional decision-making, and professional identity as educators.

Participants consistently demonstrated increased awareness of teaching as a human-centered practice, reported immediate transfer of pedagogical strategies into classroom settings, and articulated more intentional approaches to assessment and feedback. The apprenticeship model enabled graduate students to connect theory to practice through iterative reflection and mentorship, highlighting the value of learning pedagogical principles alongside authentic teaching responsibilities. This study contributes to the growing body of literature on graduate teaching development by offering a scalable, discipline-embedded model that requires minimal curricular restructuring while providing sustained pedagogical support.

As a pilot study with a small cohort, this work is limited in scope and does not aim to generalize outcomes broadly. Future iterations will expand participation, incorporate longitudinal follow-up, and examine how pedagogical training influences teaching practices over time. Additional work will also explore how structured mentorship and assessment design can further support inclusive and effective engineering education.

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Appendices

Appendix A. Pedagogical Seminar Reflection Excerpts

This appendix presents selected excerpts from graduate student reflections generated during the semester-long pedagogical seminar. Reflections were written in response to assigned readings and guided prompts and are organized by seminar module.

A.1 Teaching Skills for Engineers

"Engineering education needs to be reframed to focus not only on technical knowledge, but also on transferable skills and the human side of learning. Learning is emotional and identity-driven, and students need to feel safe being wrong." (Participant 1)

"Incorporating dialogue about real-world applications before and after technical content helped motivate topics and reduced how overwhelmed students felt during lectures." (Participant 2)

"Humanizing chemical engineering courses does not mean reducing rigor; it changes how rigor is experienced by students." (Participant 3)

A.2 Active Learning in STEM

"Even small active learning strategies, such as structured pauses or restating student answers, made a noticeable difference in engagement." (Participant 1)

"Active learning allowed me to see student thinking in real time and adjust pacing, rather than realizing misconceptions only after an exam." (Participant 2)

"The biggest barrier to active learning is not effectiveness but time and institutional support for instructors." (Participant 3)

A.3 Learning Assessment

"Assessment should prioritize reasoning and synthesis rather than factual recall, especially given widespread access to AI tools." (Participant 1)

"Situational and open-ended questions better reflect real engineering decision-making and are more resistant to superficial or AI-generated responses." (Participant 2)

"The goal should not be to 'AI-proof' assessments, but to design assessments that genuinely support learning." (Participant 3)

A.4 Mentorship as Teaching

"Mentorship is often assumed to be intuitive, but it is a skill that needs to be intentionally developed." (Participant 1)

"Effective mentors adapt to individual student needs rather than applying a single mentoring style." (Participant 2)

"Feedback that combines high standards with explicit belief in students' ability to improve was especially powerful." (Participant 3)

Appendix B. Teaching Apprenticeship Reflection Excerpts

This appendix includes selected excerpts describing how participants applied pedagogical concepts during their teaching apprenticeships. Excerpts span recitations, lectures, laboratory instruction, and assessment design.

B.1 Application of Active Learning Strategies

"Using group problem-solving and having students guide me through solutions shifted my role from lecturer to facilitator." (Participant 1)

"Active learning strategies discussed in seminar were immediately transferable to recitations and lectures." (Participant 2)

"Giving students time to think and discuss before answering improved both participation and confidence." (Participant 3)

B.2 Assessment and Exam Design

"Designing exam questions that combined multiple concepts forced deeper thinking and reduced reliance on memorization." (Participant 1)

"Free-response and explanation-based questions encouraged students to articulate reasoning rather than focus on final answers." (Participant 2)

B.3 Development of Teaching Confidence and Identity

"Applying pedagogical concepts in real time had more impact on my teaching than years of prior experience without structured reflection." (Participant 1)

"I began to see myself not just as a teaching assistant, but as an educator responsible for student development." (Participant 3)

Appendix C. Peer Observation and Feedback Excerpts

This appendix presents summarized excerpts from peer teaching observations conducted as part of the apprenticeship. Feedback focused on instructional clarity, engagement, pacing, and alignment with learning objectives.

C.1 Observed Strengths

"Clear pacing and intentional pauses helped maintain student engagement." (Peer Reviewer)

"Students were actively involved in problem-solving rather than passively observing solutions." (Peer Reviewer)

"Combining slides with board work addressed multiple learning styles effectively." (Peer Reviewer)

C.2 Areas for Growth Identified Through Peer Feedback

"Clearer transitions between topics and explicit learning outcomes would further support student understanding." (Peer Reviewer)

"Providing brief summaries at the end of lectures could reinforce key takeaways." (Peer Reviewer)

"Varying group composition across sessions may further enhance collaboration." (Peer Reviewer)