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Applying the See One, Do One, Teach One (SODOTO) Framework in Traditional and Laboratory-Based Chemical Engineering Courses

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1. Introduction

Chemical engineering education is characterized by a dual emphasis on technical rigor and professional preparation. Laboratory courses are designed to reinforce theoretical concepts through experimentation while developing competencies in data analysis, process understanding, and engineering judgment [1], [2]. Similarly, core lecture courses—particularly material and energy balances—serve as gateway experiences that strongly influence student persistence and progression within the major [3]–[5].

Despite these goals, both laboratory and lecture courses are often structured in ways that emphasize procedural completion over conceptual understanding [1], [6]. In laboratory settings, students may focus primarily on following prescribed procedures and producing reports, with limited engagement in the underlying experimental intent, assumptions, or sources of uncertainty [1], [7]. Similarly, in lecture-based courses, students may prioritize obtaining correct numerical solutions without articulating the reasoning processes or conceptual frameworks underlying those solutions [2], [8]. These patterns have motivated sustained interest in active learning strategies within chemical engineering education, particularly those aligned with ABET Student Outcomes related to problem solving, communication, teamwork, and professional responsibility [9].

This work explores whether a teaching-as-learning framework—specifically, See One, Do One, Teach One (SODOTO), which originates in medical education—can serve as a coherent pedagogical approach across both laboratory and lecture contexts in chemical engineering [10]. By explicitly positioning teaching as a learning activity rather than solely an assessment outcome, this study examines the adaptability of SODOTO across instructional modalities and its potential to support student engagement, reflection, and persistence.

2. Background and Related Work

2.1 Active Learning and Explanation in Chemical Engineering

Active learning strategies have been extensively studied in engineering education. Prince demonstrated that instructional approaches requiring students to actively construct knowledge are associated with improved conceptual understanding [8], and Prince and Felder further articulated the theoretical and empirical foundations of inductive teaching methods in engineering. Inductive teaching refers to instructional approaches in which students are first presented with problems, data, or experiences and subsequently derive underlying principles, rather than receiving principles prior to application [11]. Freeman et al. showed that active learning reduces failure rates across STEM disciplines, including engineering [12].

Within chemical engineering, several instructional approaches that fall under the umbrella of active learning have been widely adopted. These include flipped classrooms, in which students engage with core content prior to class and use class time for problem solving and discussion, and problem-based learning, which organizes instruction around open-ended, contextualized problems that require student-driven inquiry. Both approaches have been implemented in chemical engineering courses such as material balances, thermodynamics, and transport phenomena, with reported gains in engagement and conceptual understanding [2], [8], [18]. While these approaches emphasize active engagement, the ways in which students articulate reasoning and communicate problem-solving processes can vary depending on implementation. These approaches align directly with ABET Student Outcomes, particularly Outcome 1 (ability to identify, formulate, and solve complex engineering problems), Outcome 3 (ability to communicate effectively with a range of audiences), Outcome 5 (ability to function effectively on a team), and Outcome 6 (ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment) [2], [9].

Building on this engineering education literature, research in cognitive science provides insight into why explanation may play a critical role in learning. Studies suggest that explaining one's reasoning, particularly to others, promotes learning through elaboration, metacognition, and error detection [13]. Peer instruction models explicitly leverage these mechanisms by requiring students to articulate conceptual understanding during structured interactions [14]. While these principles align closely with ABET Student Outcomes related to communication and teamwork, they may be challenging to implement consistently within core chemical engineering laboratory and lecture courses due to constraints such as limited instructional time, content coverage expectations, and traditional assessment structures. This work builds on this body of research by exploring a structured teaching-as-learning approach that explicitly incorporates explanation and peer teaching into existing instructional contexts. Future work will examine how factors such as course level, class size, and instructional scaffolding influence the effectiveness and sustainability of such approaches in chemical engineering curricula.

2.2 Laboratory Pedagogy in Chemical Engineering

Chemical engineering laboratories have historically emphasized safety, reproducibility, and efficiency. While these priorities are essential, they can result in highly prescriptive experiences that limit student agency and opportunities for reflection on experimental intent, assumptions, and uncertainty [1]. In response, inquiry-based and project-based laboratory models have been developed to promote student-driven investigation, open-ended problem solving, and deeper engagement with experimental design and interpretation. These approaches have been shown to support higher-order learning outcomes, but they often require substantial curricular restructuring, increased instructional time, and significant faculty coordination, which can limit their scalability across programs and course sequences.

Prior work has demonstrated that elements of active learning can be integrated into chemical engineering laboratories without sacrificing technical rigor. For example, Koretsky et al. showed that incorporating targeted active learning strategies can improve student engagement and conceptual understanding within existing laboratory frameworks [7]. Building on this work, the central contribution of the present study is to examine a teaching-as-learning approach that can be layered onto traditional laboratory structures with minimal disruption. By embedding structured peer explanation and teaching activities into existing experiments, this approach seeks to support ABET outcomes related to experimentation, data interpretation, communication, and professional judgment while preserving established laboratory content and constraints.

2.3 Teaching-as-Learning and the SODOTO Framework

The See One, Do One, Teach One (SODOTO) framework originates in medical and clinical education, where it is used to scaffold procedural learning and professional identity development [10]. The framework emphasizes progression from observation (See One), to independent execution (Do One), to teaching others (Teach One), with teaching treated as a learning activity rather than merely an assessment artifact.

Although the specific SODOTO terminology is rooted in medical education, closely related instructional strategies—particularly those involving structured peer teaching and explanation—have been documented in the engineering education literature. Within ASEE conference proceedings, several instructional interventions share key pedagogical mechanisms with the Teach One phase of SODOTO. Hamel reported on a peer-teaching activity in an engineering creativity and innovation course in which students prepared and delivered short lessons to peers, promoting engagement and reflective knowledge sharing [15].

Similarly, Kim, Schubert, and Jacobitz described peer teaching in electric circuits laboratories, where student peer assistants led instructional activities and supported collaborative problem solving [16]. More recently, Ghanat et al. examined peer-teaching techniques implemented across both lecture and laboratory environments in geotechnical engineering, reporting enhanced student interaction and positive perceptions of learning [17]. These practices align with established research on peer instruction and cooperative learning, which demonstrates that requiring students to articulate reasoning to others promotes deeper understanding, metacognition, and retention [13], [14].

Despite strong theoretical alignment with engineering education goals and ABET Student Outcomes related to communication, teamwork, and lifelong learning, SODOTO has seen limited application specifically within chemical engineering. This study examines its adaptability across instructional contexts within the chemical engineering curriculum.

3. Instructional Contexts and Design

The University of Massachusetts Lowell is a public, research-active institution with a strong emphasis on undergraduate engineering education and broad access. The Francis College of

Engineering enrolls a diverse student population, including a substantial proportion of first-generation college students, transfer students, and students balancing academic responsibilities with employment. Chemical engineering students typically progress through a structured curriculum that includes foundational lecture courses, such as material and energy balances, followed by laboratory-intensive upper-division coursework.

Within this context, laboratory and core lecture courses serve multiple roles: reinforcing disciplinary fundamentals, supporting student persistence through key transition points in the curriculum, and developing professional skills aligned with ABET accreditation requirements. Class sizes in core courses are moderate, ranging from approximately 20–40 students, and laboratory sections are intentionally capped at 12 students to support hands-on experimentation while operating within standard instructional time and resource constraints. As a result, instructional innovations that can be integrated into existing course structures—without requiring major curricular redesign—are particularly valuable for supporting student engagement and learning across the program.

3.1 Junior-Level Chemical Engineering Laboratory Course

The laboratory course is a required junior-level chemical engineering course emphasizing experimental methods, data analysis, and process interpretation. Enrollment ranges from approximately 10–12 students per section (with laboratory sections capped at 12 students). Prior to this intervention, the course followed a traditional laboratory format consisting of instructor demonstrations, student experimentation, and written reports.

The SODOTO framework was integrated without altering experimental content by restructuring how students engaged with laboratory activities. Instructor-led demonstrations and preparatory discussions emphasized experimental objectives, assumptions, and expected outcomes (See One). Student teams then conducted experiments independently, collected data, and performed analysis (Do One). Finally, students explained experimental procedures, calculations, or conceptual insights to peers during structured but informal teaching interactions (Teach One).

In the laboratory course, the Teach One phase occurred during the scheduled laboratory period. After completing the experimental procedures and initial data analysis, student groups were assigned brief intervals (limited to 15–20 minutes) to explain a selected procedural step, calculation approach, or conceptual interpretation to another group. These interactions were structured but informal and were monitored by the instructor and teaching assistants to ensure technical accuracy. Feedback was provided verbally, focusing on clarity of explanation and conceptual reasoning rather than presentation quality. The SODOTO structure was implemented across multiple laboratory modules rather than limited to a single activity, allowing students repeated opportunities to practice explanation and peer teaching.

This design explicitly targeted ABET Student Outcomes related to experimentation, communication, teamwork, and professional responsibility.

3.2 Sophomore-Level Material and Energy Balances Course

A second implementation occurred in a sophomore-level core course introducing material and energy balances. This course serves as a gateway to the chemical engineering curriculum and has historically exhibited nontrivial attrition.

The course was redesigned using a flipped classroom model in which students engaged with instructional content prior to class and used class time for problem-solving workshops. To align with the Teach One phase of SODOTO, students completed intentional homework assignments requiring them to write explicit, step-by-step explanations of how they would teach a given problem to another student. In-class workshops reinforced this approach through verbal explanation, peer questioning, and collaborative reasoning. This instructional design emphasized ABET outcomes related to problem solving, communication, and self-directed learning.

4. ABET Alignment

The instructional approaches described in this study align with several ABET Student Outcomes as shown in Table 1. The emphasis on explanation and peer teaching supports Outcome 1 by requiring students to articulate assumptions, solution strategies, and engineering reasoning [9]. Structured peer interaction and teaching address Outcome 3 through written and oral communication and Outcome 5 through collaborative engagement. The laboratory implementation further supports Outcome 6 through engagement with experimentation, data analysis, and interpretation of results. Collectively, these outcomes position SODOTO as a pedagogical framework aligned with current accreditation expectations.

Table 1: Alignment of SODOTO Instructional Activities with ABET Student Outcomes

ABET Student Outcome	Instructional Activity	Evidence Collected
Outcome 1: Problem solving	Step-by-step explanation of material and energy balance problems or explanation of labs/equipment	Written explanations; peer discussion
Outcome 3: Communication	Peer teaching during lab sessions and workshops	Student reflections; instructor observation
Outcome 5: Teamwork	Collaborative explanation and questioning in groups	Qualitative survey responses
Outcome 6: Experimentation	(Only Junior Level Lab) Laboratory data analysis and interpretation	Lab activities; reflective responses

5. Methods

This study examined implementation of the SODOTO framework in two distinct required courses within the chemical engineering curriculum: a sophomore-level material and energy balances course and a junior-level unit operations laboratory course. These courses involved different student cohorts and were analyzed independently. The qualitative survey data reported in this study were collected from students enrolled in the junior-level laboratory course, while withdraw–fail (WF) rates were examined for the sophomore-level lecture course only. The survey component of the junior-level laboratory course was reviewed and approved by the institution's Institutional Review Board (IRB) under Exempt status. For the sophomore-level course, only aggregate, de-identified course outcome data (withdraw–fail rates) were analyzed. The IRB determined that this analysis did not constitute human subjects research and therefore did not require additional review. Accordingly, the present analysis does not evaluate longitudinal retention across courses but rather reports course-specific outcomes associated with instructional changes within each context.

5.1 Laboratory Course Survey Data

Post-course surveys were administered in the laboratory course to capture student perceptions of the instructional format. The survey included a combination of Likert-scale items and open-ended questions. Survey items were developed by the instructional team to align with the goals of the SODOTO framework and to elicit student reflections on engagement, learning processes, and implementation considerations.

Likert-Scale Items

Likert-scale items were measured on a five-point scale (1 = Strongly Disagree, 5 = Strongly Agree). The instrument included items across the following constructs:

- **Background and Self-Efficacy**
    - Confidence in performing laboratory calculations and data analysis
    - Prior laboratory experience
- **See One (Observation Phase)**
    - Clarity of instructor explanations and laboratory materials in conveying experimental purpose
- **Do One (Practice Phase)**
    - Connection between theory and practice during experimentation
    - Comfort operating equipment and collecting data
- **Teach One (Peer Learning Phase)**

    - Perceived learning gains from explaining procedures or results to peers
    - Confidence in communicating technical results within teams
- **General Engagement**
    - Comparative engagement relative to prior laboratory courses
    - Motivation to prepare before lab sessions
- **Overall Learning and Skill Development**
    - Perceived improvement in conceptual understanding
    - Confidence in troubleshooting laboratory issues
    - Development of teamwork and communication skills
    - Ability to connect laboratory observations to engineering theory
- **Perception of Teach One**
    - Perceived value of the Teach One component
    - Willingness to recommend the instructional approach for other chemical engineering courses

Likert-scale responses were exported numerically (1–5) for descriptive analysis.

Open-Ended Items

Open-ended questions were included to support qualitative analysis of student experiences. These prompts asked students to:

- Identify factors that supported their learning
- Describe challenges encountered with the SODOTO approach
- Provide examples of how teaching peers reinforced their understanding
- Compare the SODOTO format to prior laboratory experiences
- Suggest improvements for future implementation

Open-ended responses were anonymized and analyzed using inductive thematic coding.

Participation in the survey was voluntary, and responses were collected anonymously in accordance with approved human subjects research protocols. A total of n = 16 student responses were included in the analysis.

5.2 Sophomore Course Outcome Data

For the sophomore-level material and energy balances course, institutional records were used to calculate withdraw–fail (WF) rates across course offerings. In this study, the WF rate is defined as the proportion of enrolled students who either withdrew from the course or earned a failing grade. WF rates were selected as an exploratory outcome due to their relevance in gateway courses, with the understanding that they reflect multiple interacting factors and do not directly measure learning gains.

6. Qualitative Analysis Methods

Open-ended survey responses from the laboratory course were analyzed using an inductive thematic approach supported by Dedoose mixed-methods qualitative analysis software. This approach involves iterative coding, identification of recurring meaning units, and refinement of thematic categories grounded in participants' language [19].

6.1 Coding Process

The unit of analysis was a sentence or meaningful phrase. A hybrid inductive thematic analysis approach was employed, with parent codes and emergent subcodes developed iteratively. Code co-occurrence was permitted, and analytic memos were used to document code development and interpretation. Coding was conducted by a single author with iterative memoing and code refinement across two coding passes.

6.2 Rigor and Trustworthiness

To enhance analytic rigor, codes were iteratively refined rather than fixed a priori. Negative and ambivalent responses were retained and analyzed, and analytic memos documented interpretive decisions throughout the process. Given the limited amount of data collected in this study, results are presented descriptively.

6.3 Quantitative Analysis Methods

WF rates were calculated for three offerings of the sophomore-level material and energy balances course: two offerings prior to implementation of explanation-centered instruction and one offering following implementation. WF rates were compared descriptively; no statistical inference was conducted due to small sample sizes and cohort variability.

7. Results

7.1 Qualitative Findings from the Laboratory Course

To examine how students experienced the teaching-as-learning approach described in the Introduction, open-ended survey responses were analyzed using an inductive thematic approach. This analysis focused on identifying how students described their engagement with laboratory activities, their perceptions of peer teaching, and the practical challenges associated with implementation. Four dominant themes emerged from the analysis: increased engagement, teaching as learning, productive discomfort, and time constraints. The "Traditional vs. SODOTO" theme captured explicit student comparisons between prior laboratory formats and the SODOTO-based structure. While related to engagement, this theme reflects comparative framing rather than affective response, and therefore was treated separately. Together, these themes illuminate both the instructional affordances and the implementation considerations of the SODOTO framework within a chemical engineering laboratory context.

Increased Engagement.
Students frequently described the SODOTO-based laboratory format as more engaging than prior laboratory experiences. Responses associated with this theme emphasized active involvement, increased thinking during laboratory activities, and reduced perceptions of the laboratory as a purely procedural exercise. In contrast to traditional laboratories that students characterized as "cookie-cutter," several students noted that the requirement to explain concepts to peers prompted greater attention to underlying ideas rather than simply completing tasks. This theme aligns with the motivation outlined in the Introduction to move beyond procedural completion toward deeper conceptual engagement.

Teaching as Learning.
A central theme across responses was the novelty and cognitive demand of teaching peers. Many students explicitly noted that they had not previously been asked to teach others in a laboratory setting. Within this theme, students described how explaining procedures, calculations, or concepts required them to organize their thinking and reflect on their own understanding. Although not all students reported enjoying the teaching component, several acknowledged its instructional value, suggesting that peer teaching functioned as a meaningful learning activity rather than solely a communication exercise.

Productive Discomfort.
Closely related to teaching as learning, many responses reflected a sense of discomfort associated with explaining material to peers. Students described uncertainty, reluctance, or preference for working independently. Importantly, this discomfort often co-occurred with recognition of the value of teaching, indicating that discomfort did not necessarily signal resistance but rather engagement with an unfamiliar learning role. This pattern reflects what is described in the literature as productive struggle and supports the interpretation that teaching introduced a constructive challenge rather than a barrier to participation.

Time Constraints.
The most common implementation-focused theme concerned time. Students frequently suggested that additional time was needed for the teaching component, either through longer laboratory sessions or more structured teaching intervals. These comments suggest that while students perceived value in peer teaching, the pacing of laboratory activities constrained their

ability to fully engage in explanation and discussion. This theme highlights an important area for refinement in future implementations.

Traditional vs. SODOTO

Students frequently framed their responses through direct comparison between prior laboratory experiences and the SODOTO-based format. This theme captures how students contextualized their learning, often describing previous labs as procedural or "cookie-cutter" in contrast to the more interactive and reflective structure introduced by SODOTO. While related to engagement, this theme reflects comparative framing rather than an affective response and therefore was analyzed separately. These comparisons provide additional insight into how students perceived the relative value of the instructional change.

Figure 1 summarizes the frequency with which these themes appeared across student responses, illustrating their relative prominence. Representative excerpts corresponding to each theme are provided in Table 2 to demonstrate how students articulated these experiences in their own words.

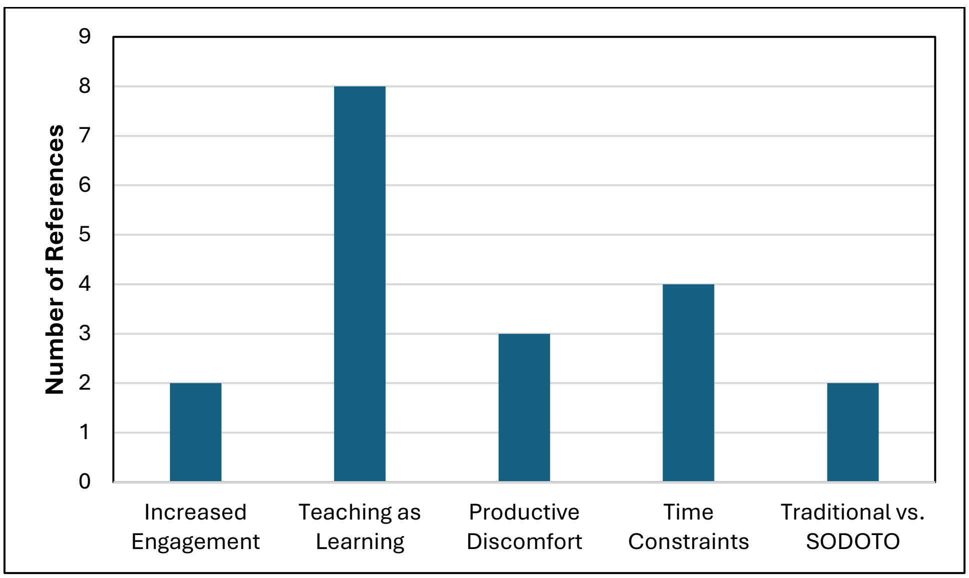

Figure 1: Frequency of emergent qualitative themes identified in student open-ended survey responses regarding the SODOTO-based laboratory format. Theme frequencies represent the number of responses in which each theme appeared; individual responses could be associated with multiple themes. Frequencies are presented to illustrate relative prominence rather than statistical significance.

Table 2: Representative Student Excerpts Illustrating Emergent Qualitative Themes

Theme	**Representative Student Excerpt**
Increased Engagement	"More involved, in a good way."
Teaching as Learning	"I never had to teach formally before."
Productive Discomfort	"I don't like the teaching, but I understand why it is valuable."
Time Constraints	"Maybe dedicate more time to teaching."
Traditional vs. SODOTO	"Other labs are cookie cutter and don't take too much thinking."

Taken together, these qualitative findings suggest that the SODOTO framework prompted students to engage with laboratory activities in ways that extended beyond procedural task completion. While peer teaching introduced moments of discomfort, students' reflections indicate that this discomfort was often accompanied by recognition of instructional value. The prominence of time-related concerns further suggests that implementation logistics, rather than resistance to the pedagogical approach itself, represent the primary area for refinement in future iterations.

Descriptive analysis of Likert-scale responses indicated consistently high levels of agreement across constructs, with total positive agreement (Agree + Strongly Agree) exceeding 90% for several items. In particular, items related to conceptual understanding, troubleshooting confidence, and connecting theory to practice each showed 91.7% total positive agreement. Similarly, 90.9% of students agreed or strongly agreed that explaining concepts to peers improved clarity of understanding. The strongest overall endorsement was observed for recommending the approach, with 100% of students selecting "Agree" or "Strongly Agree." While communication-related items showed slightly lower positive agreement (75.0%), the overall pattern indicates broad student support for the teaching-as-learning approach and reinforces the qualitative findings related to engagement and perceived learning gains. These data is summarized in Table 3.

Table 3: Summary of Likert-Scale Responses

Likert-Question	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree* (%)	Total Positive (%)
Understanding improved	16.7	75.0	8.3	0.0	**91.7**
Explaining improves clarity	54.5	36.4	0.0	9.1	**90.9**
Confidence in troubleshooting increased	58.3	33.3	8.3	0.0	**91.7**
Communication/teamwork was improved	25.0	50.0	16.7	8.3	**75.0**
Connecting theory to practice was more apparent	41.7	50.0	8.3	0.0	**91.7**
Value of "Teach One" as positive	63.6	9.1	9.1	18.2	**72.7**
Recommend approach	54.5	45.5	0.0	0.0	**100.0**

*Strongly disagree was not observed in any of the questions

7.2 WF Rate Trends in the Sophomore Course

Withdraw–fail (WF) rates, defined as the proportion of students who withdrew from or failed the course, were examined for a sophomore-level, lecture-based material and energy balances course taught by the same instructor across multiple offerings with consistent content coverage, learning objectives, and assessment structure. Enrollment in the lecture-based course ranged from approximately 30 to 46 students across offerings and primarily consisted of declared chemical engineering majors early in the curriculum. WF rates decreased from 16.7% (5/30) and 13.2% (5/38) in two offerings that used a traditional lecture format to 8.7% (4/46) in a subsequent offering following implementation of explanation-centered instructional practices aligned with the Teach One component of SODOTO.

For comparison, the junior-level laboratory course in which qualitative data were collected enrolled approximately 24 students across two sections and consisted of students who had progressed beyond the material and energy balances sequence. While the laboratory and lecture courses differ in structure and student population, both represent required components of the chemical engineering curriculum and were taught within similar institutional contexts. Although causality cannot be established and multiple factors may contribute to student persistence, the observed reduction in WF rates coincided with the introduction of structured opportunities for students to articulate reasoning and teach problem-solving approaches to peers. These findings reflect course-specific patterns rather than longitudinal tracking of individual students across the curriculum.

8. Discussion

Across both instructional contexts examined in this study, the findings suggest that teaching-as-learning strategies can meaningfully shape how students engage with core chemical engineering coursework. In the laboratory setting, qualitative analysis indicated that students experienced increased engagement and were prompted to move beyond procedural task completion toward reflection on underlying concepts, consistent with prior critiques of prescriptive laboratory instruction [1], [6]. The emergence of teaching as learning and productive discomfort as dominant themes aligns with research on active learning and peer instruction, which emphasizes explanation and articulation as mechanisms for deepening understanding [8], [12], [13]. Notably, students' expressions of discomfort frequently co-occurred with recognition of instructional value, supporting the interpretation that peer teaching introduced a constructive challenge rather than resistance to learning. This finding reinforces the potential of structured peer teaching to shift student focus from procedural completion toward conceptual articulation, a goal identified earlier in the literature on laboratory reform.

In the lecture-based material and energy balances course, the observed reduction in withdraw–fail rates coincided with the introduction of explanation-centered instructional practices that required students to articulate problem-solving strategies and teach reasoning to peers. While causal claims cannot be made, this trend is consistent with prior findings that active learning approaches can support student persistence in gateway engineering courses [3], [11]. Taken together, these results suggest that the SODOTO framework offers a coherent way to operationalize teaching-as-learning principles across instructional modalities. By embedding structured explanation and peer teaching into existing laboratory and lecture formats, SODOTO aligns with the active learning and cognitive science literature reviewed earlier while remaining compatible with common curricular constraints. These findings reinforce the importance of scaffolding, transparency, and intentional design when introducing peer-teaching practices in chemical engineering education.

9. Limitations and Ongoing Work

Limitations include single-institution implementation, modest sample sizes, and reliance on self-reported perceptions and WF rates. Ongoing work includes integrating quantitative survey measures, examining longitudinal impacts across cohorts, and refining instructional scaffolding to support diverse learner needs.

10. Conclusions

The goal of this study was to examine whether the See One, Do One, Teach One (SODOTO) framework could be adapted across lecture and laboratory contexts in chemical engineering to support engagement, learning, and skill development. Preliminary qualitative and descriptive quantitative results suggest that structured peer teaching may support engagement, reflection, and persistence while preserving technical rigor and aligning with ABET Student Outcomes.

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