# Impacts of Inquiry-Based Learning on Chemical Engineering Undergraduates

**Dr. Francis Ledesma, Cornell University**

Dr. Francis Ledesma is a Postdoctoral Associate in Chemical and Biomolecular Engineering at Cornell University. His research focuses on incorporating active learning into the traditional core chemical engineering curriculum and studying the resulting effects on both students and faculty. He received his Ph.D. in Chemical and Biomolecular Engineering from the University of California, Berkeley and his B.S. in Chemical and Biomolecular Engineering from Cornell University.

**Cara Robertus, Cornell University**
**Prof. Allison Godwin, Cornell University**

Allison Godwin, Ph.D. is the Dr. G. Stephen Irwin '67, '68 Professor in Engineering Education Research in the Robert Frederick Smith School of Chemical and Biomolecular Engineering at Cornell University. She is also the Associate Director of the Cornell NanoScale Science and Technology Facility and a McCormick Teaching Excellence Institute Research Fellow. Her research focuses on how identity, among other affective factors, influences diverse groups of students to choose engineering and persist in engineering. She also studies how different experiences within the practice and culture of engineering foster or hinder belonging, motivation, and identity development. Dr. Godwin graduated from Clemson University with a B.S. in Chemical Engineering and Ph.D. in Engineering and Science Education. Her research earned her a National Science Foundation CAREER Award focused on characterizing latent diversity, which includes diverse attitudes, mindsets, and approaches to learning to understand engineering students' identity development. She has won several awards for her research including the 2021 Chemical Engineering Education William H. Corcoran Award, 2022 American Educational Research Association Education in the Professions (Division I) 2021-2022 Outstanding Research Publication Award, and the 2023 AIChE Excellence in Engineering Education Research Award.

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## Abstract

This research paper investigates the continued impacts of incorporating inquiry-based laboratory experiences into core chemical engineering courses on undergraduate students at a research-intensive university in the Northeast United States. Traditional chemical engineering curricula often begin by engaging students in instructor-centered, lecture-based courses to introduce the theory behind real-world processes, reserving the application of this theoretical knowledge for the canonical upper-level Unit Operations (UO) laboratory course. However, existing literature and our prior work suggest that redesigning the chemical engineering curriculum to allow students to learn theory and immediately apply it to real-world equipment through hands-on laboratory exercises benefits student motivation and knowledge retention. To achieve this goal, we are currently reconfiguring the existing Unit Operations course into self-contained experimental "inquiry labs" and integrating these inquiry-based labs into aligned courses in the Sophomore and Junior years of the curriculum. At this point, we have incorporated 10 inquiry labs into the core chemical engineering curriculum. To assess the longitudinal impact of these labs, we employed a concurrent mixed-methods study (IRB0148897) by implementing surveys after each lab to gather lab-specific feedback and conducting interviews with students at the end of each semester. Specifically, we present our findings on the positive impact of these labs on student learning, motivation, and an intelligence mindset. Future work will continue to assess the impact of continued participation in inquiry labs on students' beliefs through a longitudinal study. By understanding the effect of active learning implementation on students in this school, we can better understand the potential for curriculum redesign at other institutions and across all engineering disciplines.


## Introduction

The field of chemical engineering has consistently evolved to understand and address novel problems posed by society. From its beginnings in the petrochemical industry to current applications in areas such as biomolecular engineering, clean energy, and colloids, interfaces, and surfaces, chemical engineering has emerged as a discipline at the forefront of technological and industrial advancement [1]-[3]. Despite the ease and swiftness with which the field has transformed its content towards these novel applications, a similar evolution in chemical engineering pedagogy is sluggish in comparison [4]-[6].

Traditional chemical engineering curricula often feature instructor-centered, lecture-based classes that prioritize theory, followed by recitation sessions to practice solving closed-ended problems to reinforce knowledge. Student application of the theory learned in these core courses to real-world equipment and data analysis is usually reserved for the canonical upper-level Unit Operations (UO) laboratory. Knowledge across all core courses is integrated into UO, and as such, students are required to recall learning from prior years to successfully complete it. Because of this requirement, UO has a reputation for being particularly challenging while also serving an important role in the curriculum [7]. While recall of prior course material can improve knowledge retention, students can also struggle to connect and apply theory learned years ago to their present day, leading to higher levels of stress, frustration, and impeded learning [8]-[11].

The current curriculum structure could also be misaligned with what is known about how students learn. The learning theory of social constructivism contrasts with this canonical learning structure as it posits that learning is not a passive process of information absorption but rather an active process of collaboration and reflection [12]. From this framing, the traditional curriculum structure can lead to student demotivation by first passively teaching chemical engineering knowledge and skills, and reserving the challenge of application for years after these skills are gained [13]. By contrast, a curriculum that timely challenges students to apply their newly gained knowledge can push them into their zone of proximal development, motivating students and improving knowledge retention [10], [14]. Furthermore, social constructivism also asserts that student learning is contextual, where students are inspired by and learn better from applications of theoretical concepts grounded in real-world problems [15]. As such, students could benefit from more opportunities to apply their knowledge to solve applied and personally relevant problems throughout the curriculum rather than solely at the end. A redesigned curriculum with inquiry-based laboratories (inquiry labs) embedded in core classes would both contextualize course material and actively engage students with each subject, improving student motivation and learning retention [16], [17]. Therefore, adjusting the curriculum to provide opportunities to immediately apply course material could benefit students.

In this work, we answer the following research questions:

**RQ1**: How did participating in course-embedded inquiry-based laboratories impact our students?
**RQ2**: What aspects of inquiry-based laboratories were most influential in facilitating these impacts on our students?

**Theoretical Framework**

Dweck's [18] mindset theory posits that there are two general beliefs about the formation of intelligence. Fixed mindset is the belief that intelligence is innate and unchangeable, while a growth mindset is the belief that intelligence can be developed with effort. A person's mindset influences their learning by affecting their response to challenging situations. A person with high fixed mindset views difficult tasks as insurmountable, often disengages or avoids struggle, and views struggle as an assessment of their abilities rather than an integral part of the learning journey. By contrast, a person with high growth mindset views challenges as opportunities to improve and learn [19], [20]. Higher growth mindset has been shown to improve academic performance, which in turn improves growth mindset, forming a positive feedback loop [21]. As such, students participating in inquiry labs would respond to the challenging situations presented in different ways depending on their fixed and growth mindset tendencies. Growth and fixed mindset levels often differ among demographic groups, such as women, Black, Latiné, and Indigenous, and first-generation students having different mindsets compared to their counterparts. These differences are likely due to differences in structural supports, higher perceived consequences for negative learning outcomes, and often higher pressure to "prove" themselves in engineering spaces where negative stereotypes about marginalized groups exist [22], [23]. Interventions can improve engineering students' growth mindset, especially for women, which in turn, can reshape experiences of struggle, persistence on task, and academic outcomes [24], [25]. Therefore, inquiry labs could serve as an intervention that simultaneously improves student learning and growth mindset by providing opportunities to develop hands-on chemical engineering skills.

## Methods

This work is part of a larger study investigating several aspects of how incorporating active learning through hands-on, inquiry-based laboratories in core chemical engineering courses impacts engineering students and faculty. We focus this study on mindset as a student's tendency towards a fixed or growth mindset strongly impacts student motivation when faced with a difficult challenge, such as participating in our inquiry-based labs [26], [27].

We employed a concurrent mixed methods study (IRB0148897) to understand the impacts of participating in inquiry-based labs on our students. We administered attitudes and beliefs surveys to the entire undergraduate chemical engineering student body at the end of each semester in which labs were incorporated (Fall 2024, Spring 2025, and Fall 2025). We also collected lab-specific feedback from students who participated in inquiry labs via separate surveys. We then conducted interviews at the end of each semester with students who participated in inquiry labs and our survey. The interviews focused on, among other aspects, the participant's perceptions of their inquiry lab experience and their perspectives on the potential benefits and drawbacks of these inquiry labs for their learning. These data were collected simultaneously during each semester and integrated in data analysis to answer RQ1 and RQ2.

### *Institutional Context and Participants*

The student participants in this study are members of the School of Chemical and Biomolecular Engineering at a large, research-intensive university in the Northeast. Of the school's total students ($N = 271$), 157 submitted at least one response to the attitudes and beliefs survey. The participants were recruited based on their enrollment in an undergraduate chemical engineering course that included at least one inquiry lab during the semester. The courses that featured inquiry labs are core, required courses in the Sophomore and Junior Years of the curriculum: Chemical Process Design and Analysis (Fall 2024), Fluid Mechanics (Spring 2025), Physical Chemistry II for Engineers (Spring 2025), Analysis of Separation Processes (Spring 2025), Chemical Engineering Thermodynamics (Fall 2025), and Heat and Mass Transfer (Fall 2025).

### *Inquiry-Based Laboratory Implementation*

The labs were designed in a collaborative effort between an engineering education research postdoctoral scholar and the instructor of record, with consultation of an engineering education research faculty member. We chose the objectives of each lab based on the course instructor's preferences on key content to emphasize and reinforce, as well as the integration of existing equipment. As such, we adapted six existing UO labs into inquiry labs using the heat exchanger, distillation column, pump characterization, and membrane separation units. We also developed four new inquiry labs concerning process economics, dimensionless numbers, photolithography, and combined heat and power generation. We designed each inquiry lab's structure around Kolb's experiential learning model [28], [29], in which students engage in concrete experience, reflective observation, abstract conceptualization, and active experimentation to engage in learning.

Each cohort of students ranged from 47 to 71 students. For each lab, students were first formed into teams, either self-selected or randomly assigned, depending on the class, and presented with a challenging open-ended question. We modeled this team structure as if the students were members of an engineering consulting firm, mimicking their potential future work environments. As a team, they were then asked to plan their data-collection strategy, collect data using relevant equipment in a lab setting, analyze their data using chemical engineering theory, and communicate their results in written reports or oral presentations. We hypothesized that this structure would motivate students by encouraging them to connect their course knowledge to the problem and challenging them to collaborate, gain, and disseminate new knowledge, strengthening attention and memory consolidation [30]-[32]. Furthermore, the inquiry labs were conducted as close as possible to when the content was introduced in lecture, reinforcing course concepts immediately as opposed to two years later in the current UO lab structure. The details of the four inquiry labs implemented in Fall 2024 are discussed in our prior work [33]. The labs implemented in the 2025 calendar year are summarized below (Table 1).

**Table 1.** Descriptions of newly implemented inquiry labs in Spring 2025 and Fall 2025.

| Lab | Objective | Real-World Context | Deliverable | Reinforced Course Concept |
|---|---|---|---|---|
| Pump Curve Characterization (Fluid Mechanics, 2025SP) | Characterize the pump head curve and impeller diameter of an unknown pump | Engineering consulting firm finding and repurposing a pump from the lab basement without documentation | Written memorandum communicating experimental protocol, results, and recommended flow rates to operate the pump | Reynolds number, friction factor, and pump head loss |
| VR Photolithography (Physical Chemistry II, 2025SP) | Investigate the photolithography process for semiconductor manufacturing | Semiconductor manufacturing company seeking to optimize the current production process | Written memorandum communicating the features, purpose, and limitations of a selected piece of photolithography process equipment | Light wavelengths, photochemistry |
| Continuous Distillation (Separations, 2025SP) | Characterize the Murphree efficiency of each tray in an eight-tray distillation column operating continuously | Engineering consulting firm supporting a chemical company's separation of waste methanol and water for reagent recycling | Written memorandum comparing ideal and real-world column temperatures and calculating Murphree efficiency | McCabe-Thiele graphical analysis, column pinching, and Murphree efficiency calculations |

| | | | | |
|---|---|---|---|---|
| Membrane Separation (Separations, 2025SP) | Operate a polysulfone membrane apparatus in co-current and counter-current flow to separate oxygen from air | Engineering consulting firm characterizing new membrane materials for novel applications | Technical brochure outlining proposed oxygen separation product and intended market | Co-current versus counter-current flow, gas-phase separation, permeability |
| Combined Heat and Power Plant Analysis (Thermodynamics, 2025FA) | Analyze the efficiency of the campus combined heat and power plant, generate a "digital twin" of the process in ASPEN, and propose and characterize an improvement to the current process | Engineering consulting firm supporting the campus carbon neutrality initiative | Written memorandums communicating analysis, real-world efficiency, theoretical maximum, and simulated sensitivity analysis. Group poster presentation with power plant engineers | First Law, power generation cycles, enthalpy and entropy, carbon emissions |
| Heat Exchanger II: Thermal Battery Design (Heat and Mass Transfer, 2025FA) | Characterize the heat transfer coefficient of a concentric-pipe heat exchanger to inform the design of a thermal battery to store and release excess heat provided to the chemical engineering building | Engineering consulting firm supporting the campus carbon neutrality initiative | Annotated calculations detailing analysis of in-house heat exchanger for feedback, design memorandum communicating existing literature, proposed design, and capacity of thermal battery | Overall heat transfer coefficients, Sieder-Tate correlation, Nusselt number, Wilson method |

***Data Collection and Analysis***

*Lab feedback survey*

After each inquiry lab, we asked students to complete a lab feedback survey no more than 24 hours after the submission of their deliverables to promote accurate reflection on the activities. The survey asked for qualitative student feedback on the best and worst aspects of the lab, skills they gained from the lab, and main takeaways. Students also were asked to rate their agreement with various statements related to their perceptions of the lab's design, learning reinforcement, and their motivation (Table 2).

Students responded to these items on a 7-point anchored numeric scale, with 1 being the lowest value ("Strongly disagree") and 7 being the highest value ("Strongly agree"). We received a total of 521 responses to this survey from 114 different students over the course of the three semesters, and 60 of these students also submitted at least one attitudes and beliefs survey response. We used demographic information submitted by these students in the attitudes and beliefs survey to disaggregate the lab feedback data by gender, based on prior literature suggesting possible differences in engineering experiences [34]-[37]. We also collected race/ethnicity and first-generation status as demographic data, but the sample sizes in both groups were too small to disaggregate and maintain participants' anonymity. In this study, we chose to aggregate each participant's lab feedback data over time with an unweighted average for each item. This combination of data allowed us to assess whether there were differences among demographic groups in their overall perceptions of inquiry labs, rather than in perceptions of individual labs.

**Table 2.** Inquiry lab feedback survey questions.

| Question No. | Statement | Purpose |
|---|---|---|
| 1 | The problem statement for this lab was clear. | Design |
| 2 | The deliverable assignments for this lab were clear. | Design |
| 3 | I felt prepared to successfully complete this lab. | Design |
| 4 | This lab took too much time outside of class. | Design |
| 5 | I learned something new from this lab. | Learning |
| 6 | Concepts I learned in lecture were reinforced by this lab. | Learning |
| 7 | I see the value in participating in this lab. | Learning |
| 8 | I recommend this lab be instituted next year. | Learning |
| 9 | I felt confident while participating in this lab. | Motivation |
| 10 | I enjoyed this lab. | Motivation |
| 11 | I tried my hardest to do well in this lab. | Motivation |

To identify if perception of inquiry labs was different by gender, we used a nonparametric statistical test (Mann-Whitney U) for significance and calculated a nonparametric effect size of these differences using a point-biserial correlation ($r$) [38]. Small, medium, and large effect size thresholds are generally considered to be 0.1, 0.3, and 0.5, respectively [39].

*Attitudes and beliefs survey*

Over the three semesters we administered the attitudes and beliefs survey, we received a total of 177 responses ($n$ = 37 in Fall 2024, $n$ = 35 in Spring 2025, and $n$ = 105 in Fall 2025). We analyzed the participants' responses to the mindset questions shown below (Table 3).

**Table 3.** Survey items for mindset adapted from [40].

| Question | Item | Construct |
|---|---|---|
| Please indicate your agreement with the following statements. | I can become even better at solving engineering problems through hard work. | Growth Mindset (My_Growth) |
| | I am capable of really understanding engineering if I work hard. | |
| | I can change my intelligence in engineering quite a lot by working hard. | |
| | Even if I were to spend a lot of time working on difficult engineering problems, I cannot develop my intelligence in engineering further. | Fixed Mindset (My_Ability) |
| | I won't get better at engineering if I try harder. | |
| | I could never excel in engineering because I do not have what it takes to be an engineering person. | |
| | I could never become really good at engineering even if I were to work hard because I don't have natural ability. | |

Participants responded to these items on a 1-7 anchored numeric scale, with 1 being the lowest value ("Strongly disagree") and 7 being the highest value ("Strongly agree"). We calculated the construct scores for growth and fixed mindset as the unweighted average of responses. We present results disaggregated by the semester in which responses were submitted to track how inquiry-based labs may shape mindset over time. We used a nonparametric statistical test (Kruskal-Wallis) for significance and calculated an effect size of these differences (ordinal epsilon-squared, ${\varepsilon^2}_R$) [39]. Small, medium, and large effect size thresholds are generally considered to be 0.01, 0.06, and 0.14, respectively [39]. If the omnibus test was significant (indicating at least one group is different from the others), we used a Dunn's post hoc test to provide pairwise comparisons between each semester. We calculated the effect size of the differences between each semester pair using a point-biserial correlation ($r$) [39]. Small, medium, and large effect size thresholds are generally considered to be 0.1, 0.3, and 0.5, respectively [39].

*Interviews*

We conducted 60-minute semi-structured interviews with participants at the end of each semester. Participants were eligible for interviews if they submitted at least one lab feedback form and completed the attitudes and beliefs survey for that semester. Among other questions, we specifically asked each student in their interview about their previous experience with hands-on learning, their reactions to failure, and their perceptions of the labs for the semester. For students who completed multiple interviews, subsequent interviews featured the same questions, with additional questions regarding their perspectives on how these labs have impacted their belonging, engineering identity, and future career intentions, among others.

We transcribed the interviews verbatim, and at least one member of the research team proofread each transcript for accuracy before analysis. We coded the interviews with a two-cycle approach.

We used Values Coding for the first pass, identifying relevant quotes from each participant regarding their perceptions of hands-on learning and growth, or a fixed mindset, and attributing a value, attitude, or belief to each [41]. We chose Values Coding because we are interested in understanding how engagement with inquiry labs shaped students' beliefs about their learning, themselves, and their priorities in chemical engineering. For the second pass, we deductively grouped Values Codes into categories and themes for growth and fixed mindset using thematic analysis. We then mixed the quantitative and qualitative data streams by identifying which aspects of inquiry labs were most influential to growth mindset in interviews to corroborate and expand upon the general trends we observe in the quantitative data. All data procedures were approved by our university's IRB under protocol IRB0148897.

### *Author Positionality*

Author 1 holds undergraduate and Ph.D. degrees in chemical and biomolecular engineering. He worked directly with students, implementing labs, conducting interviews, and administering surveys. He presented findings at faculty meetings and consulted with co-authors throughout, as this was his first experience with lab implementation and engineering education research. Author 2 holds an undergraduate degree in chemical and biomolecular engineering and a Ph.D. degree in biomedical engineering. She worked directly with students, implementing labs, conducting interviews, and administering surveys. She presented findings at faculty meetings and consulted with co-authors throughout, as this was her first experience with lab implementation and engineering education research. Authors 1 and 2 analyzed anonymized interview transcripts in two passes, meeting with Author 3 to reach consensus. Author 3 has a Ph.D. in engineering education and an undergraduate degree in chemical engineering. She mentored Authors 1 and 2 on lab design and implementation and regularly uses inquiry-based labs in her own teaching. As a department faculty member, she engaged with study participants in her classes but refrained from data collection and data analysis due to these relationships.

## Results

We observed no significant differences in perceptions of lab design and learning between our women and men students. For the lab design questions, all median values were above 4, indicating a high degree of success regarding our delivery of the lab problem statements, deliverable assignments, student preparation, and time requirements. We observed significant differences in motivational items between women and men (Figure 1).

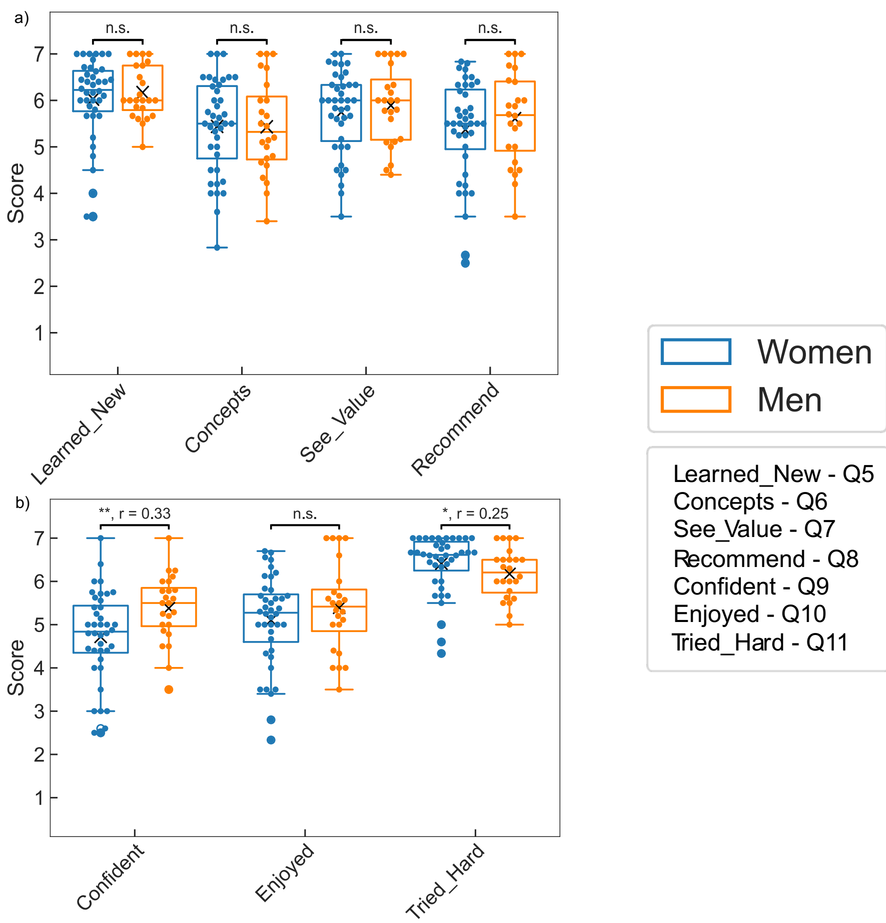


**Figure 1.** Quantitative survey results of average student responses to learning and motivation items disaggregated by gender. Individual students are represented as circles. Boxes represent the upper quartile, median, and lower quartile of responses for each item and outliers are represented as open circles. Response count $n = 39$ for women and $n = 21$ for men for all items. Mean values are plotted as "x" markers over their respective boxes. n.s., $p > 0.05$; *, $p < 0.05$; **, $p < 0.01$.

Over the course of three semesters, women ($M = 4.84$; where $M$ is the median) expressed a significantly lower median level of confidence during labs than men ($M = 5.5$) with a medium effect size ($U(39,21) = 292$, $p = 0.0092$, $r = 0.33$). Despite this lower feeling of confidence, women ($M = 6.61$) expressed a significantly higher median level of motivation to try their hardest during labs than men ($M = 6.21$) with a small effect size ($U(39,21) = 625$, $p = 0.044$, $r = 0.25$). As with the lab design questions, median student responses to the learning questions were high and not significantly different by gender.

We also observed a significant increase in growth mindset over the course of three semesters among our total student population, while fixed mindset remained low (Figure 2).

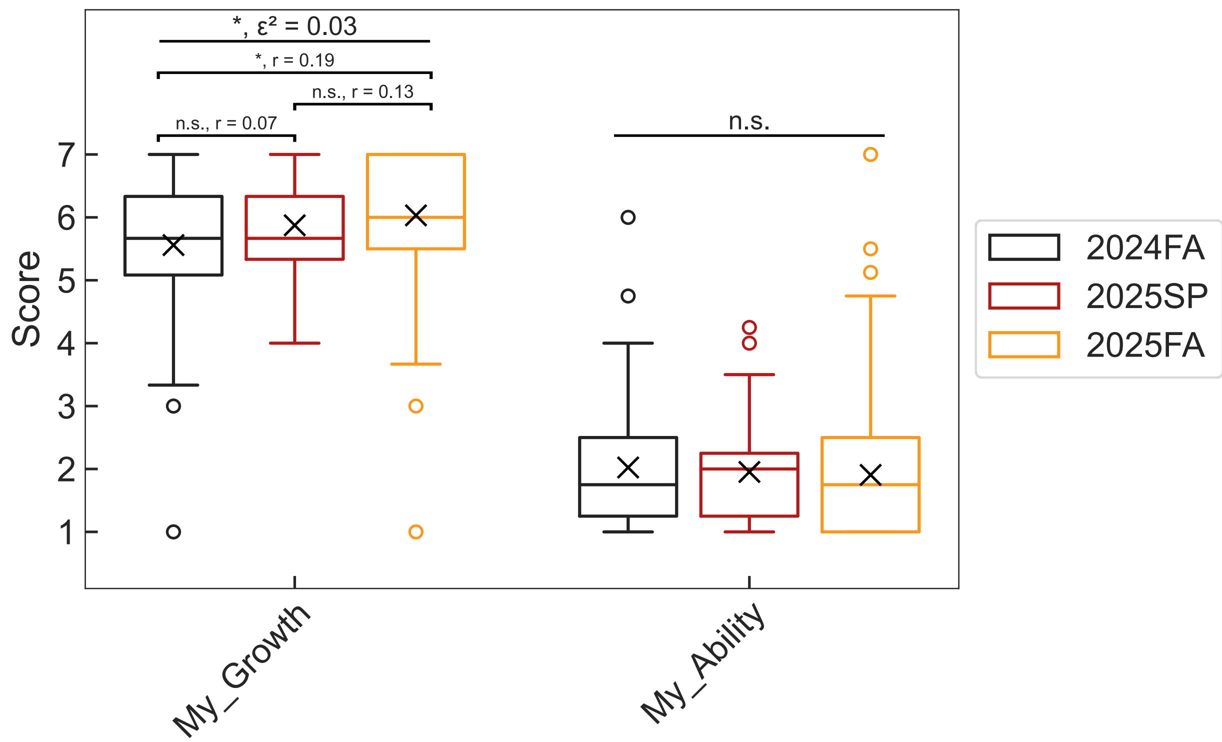


**Figure 2.** Quantitative survey results of participants' fixed and growth mindset constructs over time. Individual survey responses are omitted for legibility. Boxes represent the upper quartile, median, and lower quartile of responses for each item and outliers are represented as open circles. Response count *n* = 37 for Fall 2024 (2024FA), *n* = 35 for Spring 2025 (2025SP), and *n* = 105 for Fall 2025 (2025FA). Mean values are plotted as "x" markers over their respective boxes. n.s., $p > 0.05$; *, $p < 0.05$.

The median values of our student participants' growth mindset increased over time (Fall 2024, $M$ = 5.67; Spring 2025, $M$ = 5.67; Fall 2025, $M$ = 6.00) and this increase was statistically significant ($H(df = 2) = 6.11$, $p = 0.047$) with a small effect size (${\varepsilon^2}_R = 0.03$). From a post hoc comparison test, the only significant difference was between Fall 2024 and Fall 2025 ($p = 0.022$) with a small effect size ($r = 0.19$). Conversely, student participants' fixed mindset was low (Fall 2024, $M$ = 1.75; Spring 2025, $M$ = 2.00; Fall 2025, $M$ = 1.75) and did not significantly change over time ($H(df = 2) = 0.61$, $p = 0.74$).

When analyzing responses from women and men over time, we observe a significant increase in growth mindset among women (Figure 3a), while men remain unchanged (Figure 3b).

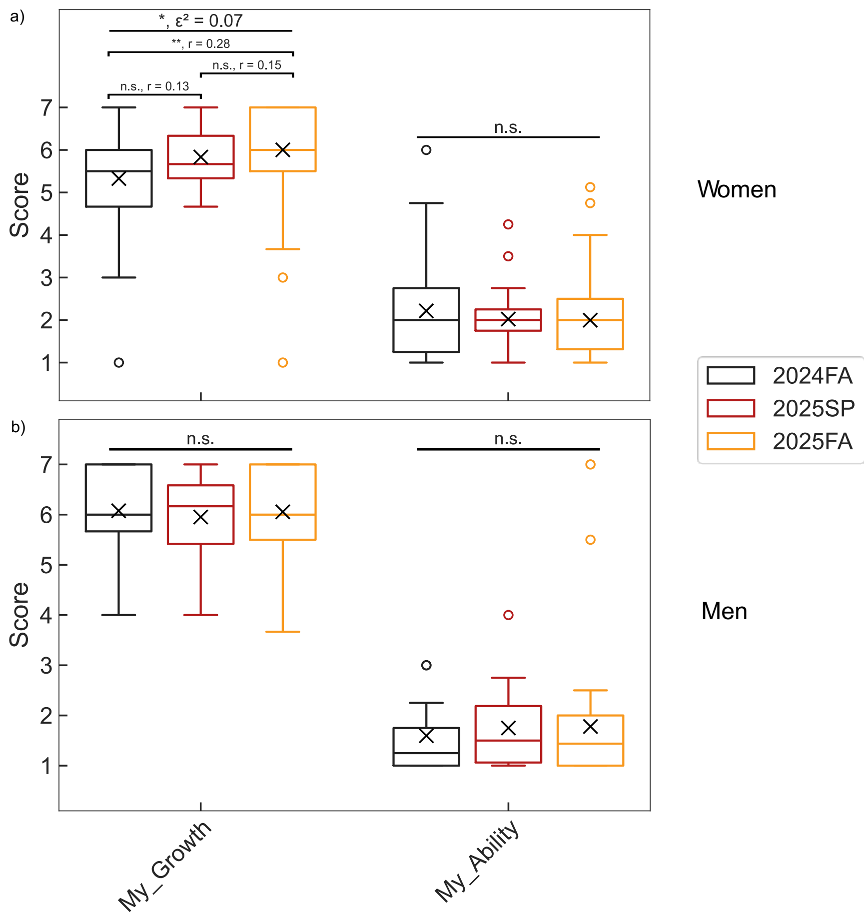


**Figure 3.** Quantitative survey results of (a) women's and (b) men's fixed and growth mindset constructs over time. Individual survey responses are omitted for legibility. Boxes represent the upper quartile, median, and lower quartile of responses for each item and outliers are represented as open circles. Response count for women is $n = 26$ for Fall 2024 (2024FA), $n = 21$ for Spring 2025 (2025SP), and $n = 65$ for Fall 2025 (2025FA). Response count for men is $n = 11$ for Fall 2024 (2024FA), $n = 14$ for Spring 2025 (2025SP), and $n = 40$ for Fall 2025 (2025FA). Mean values are plotted as "x" markers over their respective boxes. n.s., $p > 0.05$; *, $p < 0.05$; **, $p < 0.01$.

The median values of our women participants' growth mindset increased over time (Fall 2024, $M = 5.50$; Spring 2025, $M = 5.67$; Fall 2025, $M = 6.00$) and this increase was statistically significant ($H(df = 2) = 7.64$, $p = 0.022$) with a medium effect size ($\varepsilon^2_R = 0.07$). In contrast, the median values of our men participants' growth mindset remained high and constant (Fall 2024, $M = 6.00$; Spring 2025, $M = 6.17$; Fall 2025, $M = 6.00$) with no significant change ($H(df = 2) = 0.18$, $p = 0.92$). From a post hoc comparison test for our women participants, the only significant difference was again between Fall 2024 and Fall 2025 ($p = 0.0075$) with a small effect size ($r = 0.28$). This result suggests that the significant increase we observe for the overall population is driven predominantly by our women students. For both women and men, fixed mindset was low (Fall 2024: Women $M = 2.00$, Men $M = 1.25$; Spring 2025: Women $M = 2.00$, Men $M = 1.50$; Fall 2025: Women $M = 2.00$, Men $M = 1.44$) and did not significantly change over time (Women: $H(df = 2) = 0.26$, $p = 0.88$, Men: $H(df = 2) = 0.20$, $p = 0.91$).

Overall, our quantitative results suggest that participating in course-embedded inquiry labs improves growth mindset for our undergraduate students. This improvement is largely driven by our women students, which is consistent with prior literature that found that women in physics had lower growth mindset than their men peers [42]. Gendered differences in growth mindset also appear in our lab feedback results, with women showing lower levels of confidence than men. However, women expressed higher levels of motivation to try hard in labs, indicating that lower confidence and growth mindset did not hinder their motivation. The efficacy of our inquiry labs on improving growth mindset for only our women students also has precedent, with mindset interventions showing gendered effects [19], [43]; women improved through intervention efforts, while there was no effect on men. These trends indicate opportunities to scaffold learning to ensure equal starting attitudes, beliefs, and mindsets for all students, enabling similar academic outcomes for similarly prepared students. In other words, there is an opportunity to address negative psychological mechanisms that shape student outcomes (e.g., the belief that struggling is evidence that one should not be a chemical engineer and that a student cannot develop their abilities through effort) and create negative feedback loops on how struggle is interpreted in the moment. Disrupting these feedback cycles can enable all students to reframe struggle as a core part of learning, and reinforcing the effort and time spent on task can improve learning. This reframing has been shown through other efforts to change behaviors within classroom settings, and ultimately outcomes [44]. Although fixed mindset remained unchanged over time for both our men and women, the overall mean values for both populations remained low. This observation suggests that inquiry labs did not negatively affect participants' mindsets, despite the potential to increase fixed-mindset beliefs when students encounter a difficult situation and struggle during a lab.

To obtain a richer understanding of our quantitative results, we analyzed our 60-minute interviews with students to understand their perceptions of the most impactful aspects of inquiry labs on our participants' mindset beliefs.

***Inquiry Labs are Low-Stakes Growth Opportunities***

One of the most highlighted aspects of inquiry labs that students expressed as beneficial for their growth as engineers was the intentionally low-stakes nature of the assignments. For all inquiry labs, the teaching team intentionally lowered the impact on students' final grade. Most inquiry labs were graded as homework assignments, accounting for 10-20% of a students' final course grade. The highest percentage allotted to an inquiry lab was in Thermodynamics, which accounted for 25% of the students' final course grade. However, this larger percentage was split among three check-in deliverables, which lowered the stakes of each individual assignment. Students appreciated the shift away from the traditional high-stakes, summative exam and towards these low-stakes assignments, which allowed them to view inquiry labs as growth opportunities rather than assessments of their competence:

> So, it's very eye opening and, like, a little shocking when we actually do it for the first time. It's an opportunity for growth. It's like, the whole thing [is] basically, like, this is so low stakes. Come in and, like, try your best, and you'll, you'll get something out of it. – Student 1, Sophomore

> I felt like it made it easier to, like, be less serious about it. Obviously, we were still serious and trying our best, but like, we could be a little silly with it, and there was no consequence to our grade. So having, like, I think with the grade aspect, like, you have to be a bit more careful. And just that, since we are, like, most of us are Type A students, like, we're going to be very serious and like, "we have to get the grade," but just being, I think low stakes it's kind of like, it's kind of whatever. – Student 2, Sophomore

Despite the low-stakes nature of these inquiry labs, our quantitative results that student motivation was high, especially for women, emphasize that lab motivation is not dependent on assignment weight. In contrast, the de-emphasis of grades in these labs helped students focus on learning instead and view the struggle as a necessary step in the learning process:

> Yeah, actually, it is valuable to, like, be confused and then figure it out yourself, because then you tend to remember that more. Yeah, maybe [more information is] not needed. It just would make things easier for like, yeah, but sometimes it's good to struggle. – Student 3, Sophomore

> When you're, like, initially uncertain, you really come out of there feeling like you've learned something, or you've like, developed, if there's like, a difference in what you knew coming in and what you know coming out. So, I think it is helpful. And that's like, what sticks with you. – Student 4, Junior

Every faculty instructor had different priorities for what grade percentage to allocate to inquiry labs in their course. As such, we cannot recommend a specific value to balance student motivation and the impact on growth mindset. However, we observe that providing clear inquiry lab learning objectives and lowering the stakes of these assignments can help students avoid stressing about their grade and focus more on the value the lab can provide for their learning.

***Interacting with Peers Helps Overcome Challenges***

Many students also expressed that interacting with their peers during inquiry labs helped them overcome an initial lack of confidence during labs:

> Yeah, and for the, I mean, for, for that lab, I was, like, pretty confused at the start…so I think just the process of asking questions, talking with people, figuring out, like, what is the best way to fully approach like or understand it. So, I think that was pretty nice, and overall, that was a pretty fun lab. – Student 5, Junior

> I can talk a little bit more about, like, the vibes. I think for the lab, I think for me, is a good chance to get to know people that I didn't really know in my major. And also I think it's fun doing hands on things. Like, it's kind of boring just sitting and doing problems all day. – Student 6, Sophomore

This quote also aligns with learning theory, specifically social constructivism, emphasizing that discussing lab content with peers was one of the best ways to overcome confusion, generating knowledge and having fun in the process. As such, we intentionally designed both the in-lab experiments and deliverables to be team-based, hoping to promote student engagement, community-building, and learning. Students also highlighted that knowing other students shared in their confusion was beneficial in gaining the confidence to ask questions and make mistakes while completing a lab:

> But it was like, it was really just, like, knowing when to, like, ask questions. Because that can very, that can be very scary here, asking question- questions, because, like, everybody thinks that you know everything, right? You don't know everything. So, it's, like, just knowing that, like, it's okay to ask questions when you need them, like, nobody will laugh or make fun of you, because we're all probably thinking, like, the same stuff. So, it was really just, like, knowing that, like, we should be comfortable to, like, make a mistake or, like, vocalize that we didn't understand something. – Student 1, Sophomore

This student expressed a commonly held sentiment among the participants: working with peers in these labs helped deconstruct the perception of being alone in confusion (normalized struggle as a typical and surmountable experience). As a result, help-seeking norms such as asking questions to faculty, TAs, and peers are more readily established, which could help students view challenges as opportunities to grow their knowledge rather than assessments of their current states. In the process, students also grow their bonds with each other, further deconstructing the perception of isolation and improving learning:

> Because of this lab and stuff, it really was, like, a more humanizing thing, like, it's like, people aren't as, like, stuck up as they appear to be, like, because it's not like you're stuck up, but you just feel very closed off, like, everybody was very reserved, right? So it's nice to know that, like, they're not reserved. It's just everybody's too, like, I think everybody's thinking the same…So like, during the lab, it's like, we're forced to interact and, like, be human with each other, so it's nice. It's nice, I made, like, actual, like, real, like, connections and friends in ChemE from the lab. – Student 2, Sophomore

> I think that's really important for, like, also, like, the ChemE, like, culture, for us to be better at. Like, I don't know, like, talking with each other and, like, understanding that, like, it's not about perfection, it's about learning more and, like, being comfortable asking questions. – Student 7, Junior

The above quotes from some of our women participants, despite expressing lower confidence in their abilities on the lab feedback survey, exemplify that growth in their connection with their peers supports their comfort in making mistakes on the path to learning. The UO lab environment, itself an intimidating space with large, expensive equipment, safety requirements, and limited time, seems to be a positive force for growth by forcing students to work together to solve a problem too big to tackle alone.

***Connection to Future Self***

Students also expressed an appreciation for the ability to see what chemical engineering looks like in practice, which in turn gave them an idea of what their future careers could look like:

> And especially because, like, engineering is all about applications. Like, how do you create solutions to, like, problems, whatever. So, like, actually going in there, and, like, working with the machines, and, like, distillation columns and things like that, I think it's pretty helpful to, like, visualize it and see what you could be doing in the future, I guess. – Student 8, Junior

> Like, not only does it help reinforce our knowledge a little bit in class, but it also does help us, like, it does give us a little peek into, like, what it is actually working with these instruments, instead of just seeing it on [paper] so like, I think, like, I do think a lot of us value not just getting through school, but like, also knowing what we're gonna have to do later on. – Student 9, Sophomore

Furthermore, students also highlighted that even if they were not planning on working in the chemical engineering industry or with the specific equipment they used in the lab, the experience itself was still applicable to their future:

> Yeah, I think any kind of exposure is, like, useful, because you never know when you might pull out this, like, little tidbit of knowledge. But even just, like, having seen, like, a distillation column, for example, before is helpful maybe in the future, like, if you go to an internship or something and you have to work with something similar. – Student 10, Sophomore

The students' descriptions of their instrumentality in these labs, or the view that their experiences in lab are useful for their future selves, point to a possible connection with improving growth mindset over time [45]. The ability to learn more about potential future careers in chemical engineering and see themselves working on those types of problems in these labs could help them view their abilities as dynamic and able to grow towards their desired future. By intentionally mimicking different chemical engineering career environments through these labs, we could enable students to compare who they are now to who they wish to be, and that contrast could help them focus more on the steps needed to close the gap rather than the size of the gap itself.

Overall, our qualitative results uncover the dimensions of inquiry labs that could be driving our observed quantitative increase in growth mindset. The low-stakes nature of labs reduced our students' typical focus on grades and performance, enabling them to focus more on learning and growth. The intentionality of these labs in building and fostering connections and community among the students helped deconstruct social barriers between them, promoting asking questions, seeking help, and making mistakes as essential for learning rather than signs of incompetence. The modeling of chemical engineering industries in the problem statements and structures of these labs also afforded students glimpses into their potential future careers, improving their motivation to learn and grow towards those careers. Altogether, students viewed labs as valuable for their learning, motivation, and growth, evidenced by both our quantitative and qualitative data.

## Limitations and Future Directions

Although we are confident that our mixed-methods approach provided rich insights into some of the impacts of inquiry labs on our students, our study still had several limitations. Since we began data collection in the same semester as inquiry lab implementation, we have not been able to directly assess the baseline growth- and fixed-mindset values of our student population. Despite this limitation, we still observed an increase in growth mindset among our students. Furthermore, we lacked the statistical power to conduct other demographic group analyses, such as assessing the effects of inquiry labs on underrepresented minority students or first-generation college students. Similarly, not all students completed all three semesters of attitudes and beliefs surveys, which would have enabled detailed analysis of the growth mindsets of individual students. As we continue to collect data on students as they progress through our revised curriculum, we anticipate being able to expand our sample size and conduct more detailed analysis on all students. Additionally, since our attitudes and beliefs survey measured more constructs than we focus on in this study, we would like to conduct moderated and mediated regression analysis to provide a richer understanding and further corroborate our qualitative findings that peer community and instrumentality facilitated growth mindset increases in our students.

## Conclusions

Our concurrent mixed-methods study identified the positive impacts of active learning in the form of inquiry-based laboratories on undergraduate chemical engineering students. Our quantitative results identified an overall increase in growth mindset among our students. This increase was driven primarily by our women students, who historically have lower growth mindset beliefs. We also found that women felt lower levels of confidence in labs than men, but showed higher motivation to try their hardest in lab despite their lower confidence. Our qualitative results highlighted lab structure, peer interaction, and instrumentality as the lab aspects with the largest impact on students' growth mindset. Intentionally designing labs to have minimal impact on students' grades transformed them from intense, pressure-filled assessments into low-stakes growth opportunities. Working with peers allowed students to feel connected instead of confused, overcoming their lack of confidence with support from others and learning more in the process. Mimicking real engineering career scenarios in labs gave students glimpses of their future careers, helping them see education as a learning journey towards their future selves rather than as assessments of their current states. Together, these findings support further implementation and investigation of inquiry-based labs in chemical engineering and provide a foundation for other, similar efforts and our ongoing work.

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