Work-in Progress: Aligning an Engineering Hands-On Learning Program to College Strategy: Reducing Implementation Barriers to Support Faculty, Students, and Their Success

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Heidi G. Loshbaugh, Ph.D., is passionate about higher education's role in the public good. She has taught, conducted research, and served as a college administrator with a keen focus on equity. As a community college dean, she was PI for a $3.5M US Dept. of Ed. award to transform STEM education. Her implementation of math corequisite instruction led the B & M Gates Foundation to fund an ROI study that revealed the time and cost savings for students, the cost effectiveness for the college to implement the reform, and the dramatic improvement in completing college-level math for BIPOC, first-generation, and low-in come students. She consults with states and institutions to improve student success in college, particularly with Complete College America (CCA). At University of Colorado Boulder, Heidi is a Senior Research Associate in Ethnography & Evaluation Research, a center focused on STEM education. She recently was the project lead in transforming teaching evaluation practices in the College of Arts & Sciences. A fourth-generation Coloradoan and educator, she lives in Denver with her husband, two college-aged children, and rescue dog.

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Janet serves as the Director of Strategic Community College STEM Initiatives for the College of Engineering and Applied Science at the University of Colorado Boulder. In this capacity, she develops systems-level programming to positively affect two- to four-year transfer pathways in STEM (particularly engineering) for the college. She currently works with 30 community colleges nationwide (including in Colorado) to better prepare developmental math community college students for transfer into STEM bachelor's degree programs or entry into the STEM workforce.

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Abstract

This Work in Progress addresses two of ELOS' requested foci: pedagogy and best practices of laboratory courses and hands-on laboratory instruction. We describe a redesign plan in the Integrated Teaching and Learning Program (ITLP) at University of Colorado Boulder. The ITLP offers hands-on learning experiences, lab space, engineering equipment, technical expertise, and curricular support through lab modules and skill-building workshops for students in the College of Engineering and Applied Sciences (CEAS). Our goals for this redesign are to align ITLP initiatives with college strategic priorities by integrating Universal Design for Learning into hands-on engineering curriculum, to tie ITLP hands-on experiences to learning outcomes for courses using the labs and resources, and to implement program assessment practices that allow for continuous improvement.

Introduction

Over the past half-century, graduation rates among U.S. engineering students have hovered around 50%. University of Colorado Boulder (CU), the focus of this paper, has experienced similar outcomes. A notable uptick in graduation rates at CU occurred between 2009 and 2015, with six-year degree completions reaching 62.2%, yet recent years have witnessed plateaus in retention rates. Persistent disparities befall minoritized students [1], [2]. These stagnant completion rates occur in the face of substantial need for increased engineering talent, both nationally and globally, to support fields including technology, security, transportation, and infrastructure.

The causes of student attrition from engineering are multifaceted and vary across demographics. A range of known issues includes an unwelcoming climate, conceptual difficulties in core courses that hamper progress toward degree, lack of self-efficacy and/or confidence, poor high school preparation, shifting career aspirations, instructional quality, and instances of racism and sexism—both implicit and explicit [2].

Transferring from community college poses another vulnerability. The potential for the transfer pathway has not been fulfilled, despite programming, articulation agreements, and funding over the past 30 years [3]-[20]. Transfers comprise a diverse population that frequently starts in a two-year institution to reduce high tuition costs and maintain proximity to family. Transfer students offer strong potential to increase engineering degree attainment, particularly among students who are first-generation to college, experiencing low income, of racially/ethnically minoritized backgrounds, and/or who need to build academic confidence and skills. However, this group of students often does not complete bachelor's degrees, particularly in STEM. Transfer shock, unfamiliar campus culture, and teaching styles in gateway courses are among the challenges facing transfers [21]. We plan to prioritize partnering with faculty who teach courses that transfer

students often take and/or struggle in during their first year at the university to help those students start their university journey with a positive experience.[1]

Education research has reported multiple teaching avenues to improve engineering completion. One successful practice well known to ELOS is hands-on learning [22]-[27], and, in CU's College of Engineering and Applied Sciences (CEAS), the Integrated Teaching and Learning Program (ITLP) emerged in the 1990's from student demand and with college recognition that attrition was a concern. At the time, CU offered hands-on experiences only in select junior- or senior-design courses. "'From an engineering perspective, lab classes are good because they give you a feeling for what you're learning, and if you're a visual learner, ITLP can help you learn faster and better,' said Eric Peers, an electrical and computer engineering senior," who chaired the student movement to launch more access to hands-on learning [28]. Envisioning an approach that was more targeted for specific populations was not yet on the table.

Improved student retention and satisfaction were early ITLP outcomes [29]. Figure 1 contrasts the six- year graduation rates for students who entered CEAS in the past 17 years and shows that those who participate in a hands-on first year projects course are more likely to persist and complete their degree than students who do not take the projects course. First-year projects is a course in which students work in interdisciplinary teams to design and build an engineering project utilizing the engineering design cycle. The first-year projects course analyzed in Figure 1, GEEN 1400, is offered through the Integrated Design Engineering Program (IDE). This course is supported heavily by the ITLP team through in-class technical skill-building workshops, individual engineering and manufacturing consultations, prototyping and fabrication equipment training and access, and other project resources such as tools, storage, etc.

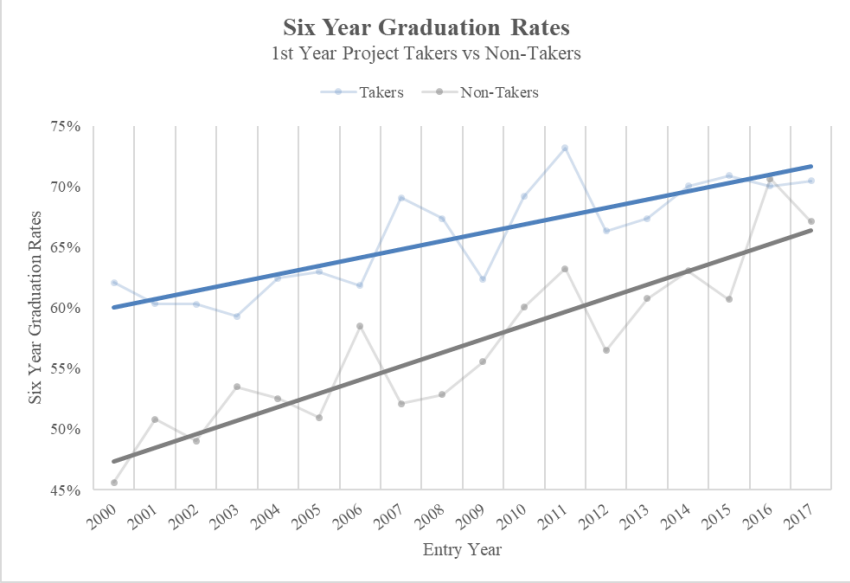

Figure 1. Six-year graduation rates are shown for students who did and did not take first-year projects (GEEN 1400) for students with entry years 2000-2017. Note the substantive improvements early in the program and the more recent plateaus.

[1] This work relates to Department of Defense award (HCQ00342220005) issued by the Office of Naval Research. The United States Government has a royalty-free license throughout the world in all copyrightable material contained herein.

Data show that students who take a project course persist at higher rates. What we cannot determine from available data is **why** ITLP hands-on courses improve student persistence. As a result, it is difficult to know what to change to address the recent plateaus. Nor can we see what skills or specific learning gains students take away. Aligning ITLP work with course learning outcomes can support refining our team's work and also improve the quality of data for faculty to understand the impact of their teaching.

Scaled implementation of hands-on learning often lags in large public universities [30], [31] because large classrooms that seat hundreds of students and departmental pressures to cover content can challenge faculty to adopt hands-on practice. Furthermore, balancing demands of research, service, and teaching can be daunting and limit uptake of research-based practices in the classroom. Moving from lecture-based instruction and high-stakes exams to active modalities, including hands-on learning, has been reliably demonstrated to improve student engagement and learning outcomes [32]-[35]. The ITLP offers space, equipment, engineering expertise, and personnel to deliver hands-on learning and, by mapping to outcomes and addressing conceptual difficulties in associated courses, we project that we can improve student learning. The ITLP's longstanding collaboration with faculty offers our college opportunities to embed evidence-based teaching more effectively, broadly, and deeply [36]-[39].

This Work in Progress describes a multifaceted, data-informed, and research-based redesign of a hands-on program to

- improve the quality of instruction in the college,
- improve student learning outcomes, including retention, persistence and completion, and
- close performance gaps.

"When I Am in the ITLP, I Feel Like an Engineer." (Student)

In our 34,000 square feet of lab space, the ITLP team of full-time engineers, manufacturing specialists, and student staff offers approximately 1,000 skill-building workshops each year to over 8,000 non-unique participants. The workshops span over 20 unique topics related to prototyping, manufacturing, mechanical and electronic CAD, materials testing, and electronics. Every year, the team supports over 3,000 unique students, 50 courses, and 150 sections of those courses across ten departments and programs. Through carefully designed curriculum and curated resources, we offer lab modules and skill-building workshops so students can put theory into practice, improve their confidence and knowledge, and build community.

The ITLP intentionally considers how to make the lab an inclusive and safe space, and its assessments have included non-cognitive aspects of user experiences. At the end of each term, students and faculty respond to approximately 20 closed-ended and four open-ended questions to provide qualitative feedback about access, usage, satisfaction, the physical spaces, and technical staff. One student user noted, "Every year the ITLP strives to make the spaces better." Other students reflected, "Staff is approachable and friendly"; "I was never afraid to ask for help… [it felt] like a safe place to fail"; "Inclusive; a very good place to turn ideas into reality."

Faculty are also surveyed, and one faculty responded that the ITLP engineers are "Some of the best resources I have ever had for academics," and "I love that the university dedicates facilities,

resources, and staff hours to supporting hands-on learning." Faculty also recognize the ITLP as a potential space for their professional growth: "Would love professor skill-building trainings."

After each semester, the ITLP reviews the survey responses to celebrate its successes and to create action plans aligned with areas of improvement. For example, in response to user feedback, the ITLP has recently

- doubled its fleet of 3D printers,
- streamlined tool and resource availability, and
- hired a designer to improve decor and signage when a renovation had left the walls blank and white.

While these semester surveys and informal feedback from users throughout the semester inform incremental changes, the program will benefit from a comprehensive review of its strategies for supporting hands-on learning, with an emphasis on grounding the program in contemporary, evidence-based practices for inclusive teaching and learning.

Why This Change? Why Now?

The hypothesis of our redesign is that with focused alignment of research-based instructional practices, the mapping of hands-on learning activities to individual course learning outcomes, and keen attention and responsiveness to institutional data for identifying performance gaps, we can improve student learning experiences and college performance measures [40]-[42]. We do not believe that stand-alone programming updates are adequate.

For example, as we planned this redesign, we recognized the need to begin measuring both non-cognitive **and** cognitive aspects of ITLP activities to connect learning outcomes in affiliated courses to student experiences in our program.

Recently, our college implemented two priorities documents:

- the 2022 Teaching Quality Framework (TQF), evidence-based teaching-evaluation practices initiated with NSF monies (DRL 1725959) and in partnership with Bay View Alliance, American Association of Universities, and Transforming Higher Education Multidimensional Evaluation of Teaching (TEval). Dimensions for evaluation of teaching include mapping course goals to teaching practices and student learning outcomes, and **improving pedagogical methods**.
- the 2023 CEAS Strategic Plan with the following goals that directly tied to this Work in Progress:
  - improve student retention rates across all student demographics;
  - enhance our co-curricular opportunities....to improve student belonging and career affinity;
  - develop and grow innovative educational offerings through various modalities;
  - implement inclusive learning opportunities and practices for all students, faculty, and staff;
  - incorporate inclusive pedagogy and UDL into faculty development programs.

As the college embraces new methods of evaluating and improving teaching and learning, the ITLP must also critically evaluate its priorities and pedagogies.

Designing a Redesign

We posit that deliberate integration of strategic priorities, college-wide teaching framework, and research-based practices will support our college and colleagues to better outcomes. Our redesigned curriculum and support must strive to further reduce faculty barriers for participation and quality implementation. By considering internal ITLP goals and college-wide teaching goals, we believe this novel approach will be human centered, evidence based, and high impact.

Our long-term goal is to scale hands-on learning to improve retention and completion fulfilling aspects of the TQF and the CEAS strategic plan. Rather than simply "go big" by adding many innovations, we are first collecting data to understand the current impact of our work, contextualizing our future goals and possible techniques with published research, and then developing tools and processes for improvement.

One intersection which we believe to be promising is aligning best practices in hands-on teaching with our newly embraced collegewide pedagogy. CEAS adopted UDL, a framework that offers multiple entry points for learners to engage with new knowledge and demonstrate their gained skills. UDL relies on three pillars:

- the Affective Network engages the "why?" of learning,
- the Recognition Network engages "what?" and
- the Strategic Network engages "how?"

These pillars invite students to interact in modes that meet how they learn and provide clear expectations, so that learners know what they need to do to succeed [43].

As part of a revised strategy, we intend for ITLP to collaborate with faculty to develop lessons and assessments that integrate the UDL framework with hands-on learning. With an emphasis on how principles work, UDL engages students through critical thinking, collaborative discussion, investigative research, and/or problem-solving. We envision partnering with faculty to implement the three UDL pillars into their course content and host active learning and UDL professional development opportunities as the college embraces UDL.

The current success of the ITLP provides an excellent foundation for revamping, refining, and scaling our approach to supporting both faculty and students. Through this intentional redesign that embraces college strategy, we seek to improve the quality of engineering education for our students and quality of work-life balance for our instructional colleagues.

Contribution to Engineering Education

Despite decades of evidence articulating the benefits of hands-on learning, its adoption in engineering has been slow and limited in scope at many institutions. Given the complex

dynamics in institutions, we posit that our redesign plan will support transformation in our own college and offer a model for other institutions to follow. Our intended changes will include

1. Professional staff collaborating with faculty to implement evidence-based pedagogical techniques to improve adoption and scaling of these pedagogies by reducing barriers for faculty,
2. Aligning program strategies with college teaching priorities with the goal of improving student *outcomes*,
3. Embedding cognitive and non-cognitive evaluation in the design, so that we will be able to anticipate the continuous improvement needed to keep the redesigned program strategies current, relevant, and of high impact.

Outcomes to Date

Key deliverables of the design plan to date include

- Literature review of
    - the impact of hands-on learning in engineering on distinct student populations
    - supporting faculty to implement hands-on learning, research-based practices
    - conceptual difficulties as learning barriers
    - increasing implementation of research-based practices that support student success
    - Universal Design for Learning, support for minoritized learners, and integrate with hands-on learning
    - assessment practices to drive improved learning outcomes [40]-[42].
- Design for internal collaboration and data collection processes
    - Qualitative interviews with faculty using semi-structured protocols to learn what they need from our program to improve their students' learning outcomes in courses;
    - Focus-group questions with students to understand the impact of our activities on their learning, sense of identity, and belonging;
    - Iterative data collection, analysis, and refinement to craft Institutional Research reports that allow for identifying problems and point to opportunities to address them (Appendix A illustrates the challenge)
- Collection of relevant prior research and iterative plan for how to implement in ITLP
- Design needs for assessment and continuous improvement, including
    - data collection from and collaboration with faculty
    - understanding how the ITLP already affects student learning outcomes
    - designing/refining activities/assessment to deepen and improve impacts;
    - process/cycle for data reporting, analysis, and planning on the impact of the labs on specific student populations.
- Change Framework: Targeted Universalism offers the equity framework to guide this redesign. A multidisciplinary research, policy, and advocacy approach, Targeted Universalism posits that *transformative* change is best fulfilled by focusing first on areas of greatest need *and* by using data to identify new practices [44]. The framework uses five steps for change:

    - Establish a universal goal based upon a broadly shared recognition of a societal problem and collective aspirations
    - Assess general population performance relative to the universal goal
    - Identify groups and places that are performing differently with respect to the goal and disaggregate them
    - Assess and understand the structures that support or impede each group or community from achieving the universal goal
    - Develop and implement targeted strategies for each group to reach the universal goal
- We have added a sixth step to the Targeted Universalism framework: using data to evaluate for continuous improvement. Through regular review of activities and outcomes, we intend to avoid future plateaus and/or identify vulnerabilities to correct them promptly. This flexible, user-friendly approach will allow us to assess redesigned activities and continuously improve.
    - What are we doing?
    - How well are we doing it?
    - How do we know? (evidence)
    - What do we need to do to improve?

Conclusion

As U.S. engineering colleges strive to meet the demand for a highly trained workforce during rapid changes in higher education, the ITLP is redesigning its suite of teaching and learning opportunities to support CU faculty and students. This program evolution includes evidence-based updates to the curriculum, the incorporation of Universal Design for Learning, the support for busy faculty to connect UDL with hands-on learning, and the adoption of a model for continuous improvement focused on cognitive and non-cognitive student learning outcomes. We propose that this updated ecosystem of hands-on engineering education will serve faculty and students to improve learning, retention in engineering, and completion for our increasingly diverse student population.

Appendix A: Internal Student Data Collection, Appropriate Reporting Protocols, and Analysis Planning

With our Institutional Research team, we have begun processes, timelines, and reports to analyze impact. However, using data at a granular level accurately and appropriately requires careful attention. CU is a Predominantly White Institution and CEAS, like many engineering programs, enrolls a majority white student body. During some academic years and/or in some majors, only a few minoritized students enroll, which can mean that disaggregated data poses the potential to reveal personal identity. To then analyze the impact on our students, we must work closely with IR to implement sensitive, ethical, effective approaches for how to report and how to act on data. Adopting prior education-research findings can help guide some redesign changes. Consulting with our professional network on how their institutions address this challenge can also benefit our practice.

Case Study: The Need for New Reporting and Analysis

In preparing this Work in Progress, we requested data from our IR team. Their follow up taught us areas in which we need to better understand what we track and how we use evidence to support students.

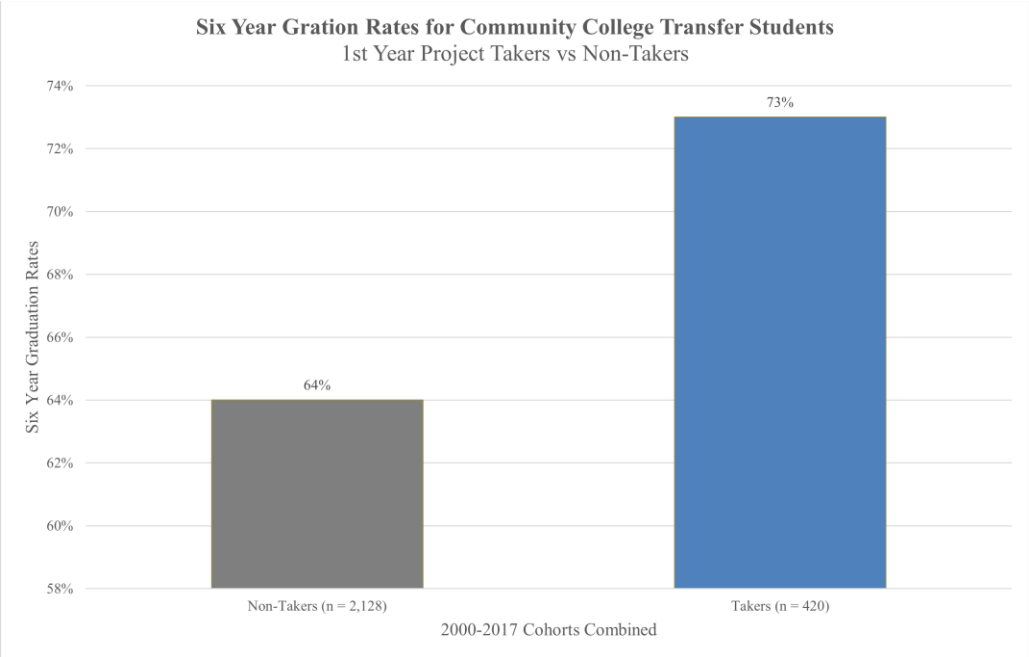

Figure 4. This figure illustrates completion patterns for community college transfers and the differences between students who take a first-year projects course and those who do not.

Figure 4 shows six-year graduation rates for community college transfers into CEAS. At first glance, the outcomes seem clear and positive: taking the first-year projects course supported transfer students to earn their degrees. A closer look indicates why we must develop new processes for monitoring and improving student outcomes [20], [45]. We have completion data on 2,548 transfer students as a report category. What we know: 420 took a projects course and those who did were 10% more likely to graduate than those who did not.

However, to identify these patterns, the report combined student data **over a 17-year** period, which reveals little about individual student experiences. In this format, our ITLP team cannot determine the duration of a student's time at CU, at what point they took the first-year course, or their overall time to degree. Transfer students typically come to CEAS from five regional community colleges; Colorado has 13 across the state. To improve transfer as a pathway to a CU engineering degree, we need more granular data and must clarify reporting processes and terms with our IR team so we can understand what has or has not worked historically. Clarity on reporting and analysis will better support transfer students to earn their bachelor's degrees in engineering.

Appendix B: Qualitative Data Sources and Methods

Qualitative interviews and focus groups will follow semi-structured ethnographic protocols with questions similar to those below. Interviews and focus groups will be digitally audio recorded.

Faculty Interviews

To best understand how to support faculty to align learning outcomes with ITLP initiatives, we will conduct qualitative interviews. Sample questions for faculty include

- Have you used hands-on labs in the past, either at CU or elsewhere?
- What historically has worked/has not worked for your classes in hands-on labs?
- Do your classes have common content "sticking points" (conceptual difficulties) for students which make them vulnerable to falling behind or failing?
- What changes, if any, have you experienced in student learning when they participate in hands-on laboratories?
- How can the ITLP support how you implement UDL in your courses and labs?
- Have you mapped course learning outcomes to student experiences in the hands-on labs? If so, what has been your experience?
- How can the ITLP support your evidence for student learning for evaluation of instruction?

Student Focus Groups

In support of CEAS goals to improve retention, data collection from students will investigate what does work as well as what **does** not work in ITLP activities. Because it is very difficult to collect data from students who have left, we seek to know what helps retain students through graduation and what those students know about peers who have left.

Student focus groups will allow data collection on the role of ITLP in areas such as interest, capacity, belonging, retention to completion, and ITLP resources/experiences that positively impact students.

Sample questions for student focus groups include

- What has been your experience in using the ITLP?
- What is your discipline, and have your courses included ITLP activities?

- Did your experience in the ITLP affect your understanding of your course content? Of engineering? If so, how? If not, why not?
- What changes in ITLP could help students learn more about becoming an engineer or their sense of belonging in engineering?

Qualitative Data Collection Methods, Analysis, and Design Implementation

After collecting data from faculty and students, we will

- transcribe the digital recordings
- analyze and code them for themes
- map them against the literature review, needs for UDL and evidence for evaluation of teaching quality,
- triangulate these findings with those of prior education research, and
- create tools for evaluating effectiveness and impact of the planned redesign elements.

Appendix C

Redesign Timeline

The redesign will occur in five phases as shown in Figure 5. Phase I is outlined in this work in progress, phase II is in progress, and phases III—IV will occur in Summer 2024—Spring 2025. The ITLP will iteratively refine the redesign until college strategic priorities are met.

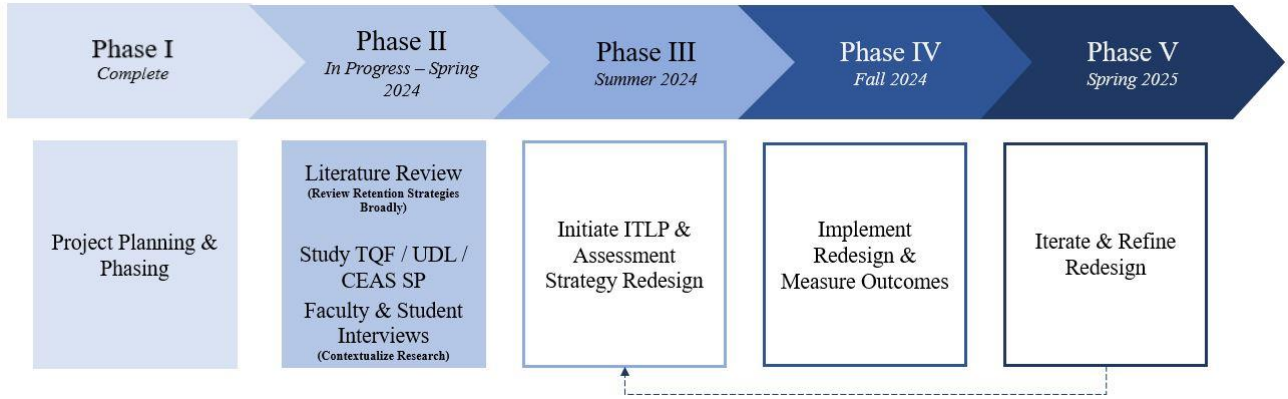

Figure 5. This figure illustrates a project roadmap for the ITLP redesign.

Appendix D
Redesigning Program Assessment

We have long been responsive to student and faculty *experiences* with the ITLP. Now, we seek evidence of ITLP's impact on student outcomes *in specific courses*, including learning outcomes, retention, persistence, and completion. We plan to learn *how* to broaden our impact on student learning.

Our literature search of known barriers and successful practices in engineering education will guide subsequent work. Data from faculty interviews and student focus groups will help us develop tools for collecting and analyzing *student outcomes data*. In collaboration with faculty, we will map ITLP experiences to specific courses. With these tools, we can

- reinforce what we know about user *experience;*
- expand our knowledge about non-cognitive aspects such as belonging and engineering identity;
- understand the ITLP's cognitive impact on student learning;
- plan for continuous improvement; and
- measure and report our impact on TQF and the Strategic Plan to connect our work more directly with CEAS priorities.

Degree completion is unequally attained across our student population, leading to a CEAS strategic priority is to close equity gaps. A "one size fits all" redesign will not serve change. We need relevant, current data on why those gaps exist AND must develop compliant, sensitive, and relevant processes and structures to do so. Because some minoritized student populations enroll at CU in such small numbers to report them in discrete groups could allow them to be personally identified. Clustering similar groups together can preserve individual student's privacy yet offer insight into institutionalized, systemic inequities. To meaningfully report, analyze, and change, we must develop protocols and processes to access and act on disaggregated data that reveals impact for distinct student populations. College leadership and IR personnel will guide this process. We will prioritize doing so in ways that recognize staff time and capacity and rely on research-based practices.

Acknowledgement

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