Exploring and Advancing Inclusivity in Engineering Education Across Academic Communities

by

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The overarching theme of this research was to explore different aspects of the science, technology, engineering, and math (STEM) education experience across cultures and contexts in two engineering education communities, higher education and K-12. This dissertation offers new perspectives and resources to the engineering education community and provides a point of view to improve inclusivity and accessibility in engineering for all students.

The research performed in the higher education community focused on the development and pilot of an inclusive classroom practices menu for engineering faculty across three contextually different institutions including predominantly white, Hispanic-serving, and STEM-focused. Inclusive learning communities (ILCs) were also convened to support participating faculty. To assess the impact of the menu and ILCs, faculty and student assessment plans included end of semester surveys and semi-structured interviews. Though literature has highlighted the positive impact of improving inclusivity in STEM classrooms, this research shares both the development of the inclusive classroom tools and the impact of these tools from student, faculty, facilitator, and researcher perspectives. This research also shares a novel conceptual framework of the STEM education environment which centers students' identities in relation to those who impact their development as STEM students.

The second part of this research, performed in the K-12 education community, focused on the development and pilot of an international, engineering virtual learning experience for middle and high school students (7^{th}-12^{th} grade) in rural Kenya in response to a local air pollution problem. This research offers a citizen science, problem-based curriculum that utilizes air quality monitoring to guide the learning. This curriculum employed a combination of educational and teaching frameworks which emphasized student-led and hands-on learning. In addition to the curriculum, this part of the research shares the air quality data and analyses, the student learning assessment and results, and recommendations. Compared with previous environmental-focused learning experiences, this research offers a unique perspective as it was conducted with an international partner amidst the COVID-19 pandemic.

Results of this dissertation present a larger case for improving inclusivity and accessibility to engineering throughout the education pipeline, particularly in the face of new social, political, and environmental challenges.

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Nomenclature

ABET	Accreditation Board for Engineering and Technology
AQ	Air Quality
ASU	Arizona State University
CEE	Civil and Environmental Engineering
CIRTL-INCLUDES	Center for Inclusive Research, Teaching, and Learning – Inclusion Across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science
CO	Carbon Monoxide
COVID-19	Coronavirus-19
CRT	Critical Race Theory
CV	Curriculum Vitae
DEI	Diversity, Equity, and Inclusion
DHHS	Department of Health and Human Services
EDIL	Engineering Department Inclusion Level
EPA	Environmental Protection Agency
FGM	Female Genital Mutilation
FLC	Faculty Learning Community
IAQ	Indoor Air Quality
ILC	Inclusive Learning Community
IUSE	Improving Undergraduate STEM Education

K-12	Kindergarten through Twelfth Grade
KCE	Kakenya Center for Excellence
KD	Kakenya's Dream
LC	Learning Community
LO	Learning Objective
Mines	Colorado School of Mines
NAAQS	National Ambient Air Quality Standard
NO_x	Nitrous Oxides
NSF	National Science Foundation
NSSE	National Survey of Student Engagement
PBL	Project-based Learning
PI	Principal Investigator
PIPE	Proven Inclusivity Practices for Engineering
Pitt	University of Pittsburgh
PM	Particulate Matter
PWI	Predominantly White Institution
SDG	Sustainable Development Goals
SDOH	Social Determinants of Health
SRUI	Social Reality Under Investigation
STEM	Science, Technology, Engineering, and Math
TOC	Theory of Change
UN	United Nations
US	United States

VLE — Virtual Learning Experience

VLE — Virtual Learning Experience

VOCs — Volatile Organic Compounds

WHO — World Health Organization

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Thank you and until next time, Dr. Jessica Moriah Vaden.

1.0 Introduction

1.1 Motivation and Rationale

Now more than ever, diversity, equity, and inclusion (DEI) initiatives are facing threats from politics, state educational regulations, and campus culture. The Chronicle of Higher Education has been tracking legislation that would prohibit colleges from participating in DEI-related activities such as prohibiting them from having DEI offices or staff and barring colleges from considering race, sex, ethnicity, or national origin in admissions or employment [1], [2], [3], [4], [5]. Since 2023, 85 bills in 28 states have been introduced, 14 have final legislative approval, 13 have become law, and 41 have been tabled, failed to pass, or vetoed which further necessitates the need to make systemic changes that encourage efforts and engage conversations around DEI [1]. A number of these bills define DEI to include Critical Race Theory (CRT), the body of scholarship focused on studying and transforming the relationship among race, racism, and power, anti-racism, implicit bias, health equity, social determinants of health, and other topics related to race, sex, and gender identity [2], [3], [5], [6]. Public attacks on CRT and other DEI topics have helped to lay the groundwork for policies and laws prohibiting teaching and research on them [7]. However, literature has highlighted the importance of DEI in both higher education and K-12 education and has provided possible responses and recommendations for combatting these policies. Some of these recommendations range from systemic changes that impact educational policy while others are efforts led using a bottom-up approach that is discipline-specific.

Over the past two decades, science, technology, engineering and math (STEM) faculty in higher education have been working to provide a more inclusive experience for collegiate students, particularly those who are historically marginalized and minoritized [8]. This has been a salient focus in STEM and more specifically engineering disciplines due to the longstanding and systemic inequalities between the success of underrepresented students in comparison with their White peers. For example, in 20 years of concerted effort to broaden participation in engineering, bachelor's degrees earned by women have increased marginally from 18.4% (1997) to 20.9% (2019) and degrees earned by Black or African Americans declined from 4.93% to 3.68% [9]. Though the decrease in earned bachelor's degrees may be described by other factors such as decreased enrollment overall in higher education, these gaps point to a wide-scale systemic problem that includes engineering [9].

One of the ways faculty have begun to address this is by focusing efforts on improving the classroom environment considering the pervasive, exclusive culture that has historically characterized the STEM classroom. Previous education research has highlighted the need to improve inclusivity in the classroom to encourage student belonging and persistence, however, these efforts also necessitate sustained institutional commitment and support from key stakeholders at collegiate institutions [10], [11], [12], [13], [14]. Since higher education is experiencing declining enrollment, and persistence and completion rates are linked to enrollment, it behooves higher education to retain as many students as possible by creating environments and climates that foster belonging and inclusivity. Inclusivity, in the context of this dissertation, is defined as the practice or policy of providing equal access, opportunities, and resources for historically excluded and marginalized groups of people [15]. This definition is particularly applicable to this work as it highlights both actions in practice and policy of which implications are described in this work, and it also mentions access, opportunities, and resources for historically marginalized and minoritized groups which are also salient in this work [15]. Not only do these issues of DEI in STEM persist at the higher education level, but they also impact the STEM pipeline and K-12 education nationally and globally, particularly in the face of new global challenges.

The COVID-19 pandemic exacerbated many public health challenges, particularly for historically marginalized and minoritized groups of people as well as for lower-income and developing countries. One of the biggest impacts from the COVID-19 pandemic was on the educational system when schools and institutions switched to largely virtual instruction and years later from the onset, some low-income and developing countries still struggle to keep up [16]. STEM online education in African contexts was largely unexplored before the pandemic and the switch to primarily online education affected students in rural settings the most due to connection issues and the costly price of data [16], [17]. STEM education around the world, with its importance emphasized throughout the literature, has been successful in more developed and wealthy countries seeing as "the element of quality is intertwined with access" [17]. Inclusivity, as it was defined earlier for this work, includes providing access, opportunities, and resources to marginalized and minoritized groups of people who traditionally may not have access to those opportunities [15]. Increasing accessibility to engineering, and more broadly STEM, is necessary to increase the accessibility to engineering, and more broadly STEM, through educational experiences has been shown to improve student learning and interest in related fields [17]. Additionally, the need for quality and wholistic STEM education in more rural settings and poorer countries is critical as it is both central to personal and societal betterment and diversifies the fields of STEM and education through new perspectives and contexts [18].

This research explores different aspects of the STEM education, and more specifically the engineering education experience across cultures and contexts at both the higher education and K-

12 levels. Solving these problems requires solutions spanning education and engineering, and this research aims to develop actionable solutions.

1.2 Theme and Communities

DEI issues in education are complex problems to solve because they are simultaneously affected by social, cultural, and political impacts at local, national, and international scales. The community of impact for this research is the broader engineering education community; however, this work specifically addresses engineering education communities in higher education and K-12 contexts. Prior research has shown that within the United States, educational attainment and access, followed by occupation, social class, and race/ethnicity, are the primary indicators of adolescent health and overwhelmingly link greater social disadvantage with poorer health outcomes [19], [20], [21]. However, the role of educational quality is directly connected to economic stability as well as social and community context [20], [22]. Research has shown that some of the most effective interventions to improve the STEM education experience for all students includes building a classroom environment that prioritizes inclusion and values and celebrates students' cultural and social wealth [10], [11], [12], [13], [14]. **The overarching theme of this work was to explore different aspects of the STEM education experience across cultures and contexts in two engineering education communities, higher education and K-12.**

The first community is the higher education engineering community. For historically marginalized and minoritized students, the higher education engineering community has historically been characterized by a harmful and unwelcoming culture which can undermine student success and belonging [8], [10], [11], [12], [13], [23], [24]. For example, Hartman et al. cite that one of the key reasons for students leaving STEM, especially underrepresented students, is the perception of a chilly climate where students feel the cultural climate excludes their attitudes, behaviors, beliefs, and values [12]. A lack of diverse populations within engineering departments, and more broadly at the institutional level, have also been cited to negatively impact marginalized students through tokenism, which enhances their visibility and can produce negative social stigma, and feelings of social pain, such as rejection and a lacked sense of belonging, which both adversely affect student achievement and persistence [10], [23]. Underrepresented students in engineering and STEM disciplines have and continue to experience situations and classroom climates that negatively impact and undermine their performance and success.

To aid students, particularly historically minoritized and marginalized students, in succeeding both academically and socially, previous research has indicated that instructors should create classroom environments that foster inclusivity and belonging [10], [11]. However, there is a lack of specific guidance on how to create these environments, especially in *engineering classrooms* where much of the focus is on *technical content*. Some previous interventions and resources for engineering faculty to improve the classroom environment have been discussed in the context of learning styles or lend themselves to classrooms which cover subjective material where elevating contributions from diverse populations may be easier [25], [26].. However, in more technically rigorous engineering courses, such as Design of Structures or Water Treatment and Distribution Design, this type of change may be more challenging as the learning material may not present as many opportunities as the course progresses. However, the classroom climate can be considered. Research has also highlighted the need for professional development opportunities, such as workshops and learning communities, which were developed and convened for this work, for

STEM faculty considering the diverse experiences and unique backgrounds students bring to the college classroom and the need to become more culturally responsive in their teaching, particularly as the face of the collegiate classroom changes over time [27].

As shown in the literature, there are known issues related to DEI in engineering disciplines, and engineering faculty have expressed desire to improve inclusivity and belonging in their classrooms; however, the technical content and historical context of the engineering classroom can make these efforts more challenging. This part of the work aimed to address this gap by developing a menu of inclusive classroom practices from a synthesis of existing inclusive classroom literature and resources based on categorizations from the Aspire Alliance which focus on improving classroom climate, not changing the content of the course [28]. This menu was piloted with engineering faculty and their implementation was supported through inclusive-focused learning communities which provided safe, trusted learning spaces with their peers and encouraged practice implementation. Other tools, such as a decision matrix for the menu and public website, were also developed and shared in order to further support engineering faculty in weaving inclusivity into their engineering courses. This work shares the results on if this menu implementation was successful from the students' perspective in order to provide faculty with evidence of the positive impact of improving inclusivity in their engineering classrooms.

The second community of impact for this research was the K-12 engineering education community. Traditionally in K-12 education, engineering is presented through curricular additions or changes and can effectively support students' awareness of the role of STEM in society and secondary teachers feel that engineering-based learning activities are useful for student learning and mastery of math and science concepts [29]. Other times, engineering concepts are introduced to K-12 students through partnerships with local organizations to incorporate engineering concepts and thinking into the classroom environment for students or out of school extracurricular programs, which are not always accessible to all students [29], [30]. However, secondary teachers have expressed concerns in how to incorporate STEM concepts and pedagogy into traditional science and math curriculum and need more effective methods for integrating those concepts into instruction [29].

Incorporating place-based and context specific educational experiences into curriculum has been shown to improve student learning and interest in new topics as well as promoting a more inclusive classroom environment [31], [32], [33], [34]. Using varying classroom techniques and connecting student experiences to their in-classroom science education has also been cited to encourage student belonging and accessibility to engineering and more broadly, STEM [17], [30], [35]. Morris's experiential learning cycle, which was one of the guiding educational frameworks for this work, denotes four phases of learning based on experiences. The cycle begins with a 'concrete experience' which is contextually rich for the learner and provides a base problem for learning from [29], [36]. The cycle continues with 'reflective observation' and 'abstract conceptualization' where the learner comprehends the problem and generates ideas for engineering design through connecting the experience to their learning [29], [36]. The cycle ends with 'active experimentation' where the learner applies their engineering design ideas using their previous knowledge, tools, and technology and they have a new learning experience which commences the learning cycle once again [29], [36]. This work also utilized Britain and Liber's Conversational Teaching Framework to build the curriculum for the experience which emphasizes the importance of two-way dialogue between instructors and their students to encourage learning for both groups [37]. This framework was particularly useful, especially considering it was a virtual learning experience, because it allowed for dialogue and learning to mutually influence each other throughout the experience and encouraged student participation [37]. These educational approaches allowed for the development of an engineering learning curriculum which prioritized student participation and was reflective of their context-specific experiences which have been shown to improve inclusivity in the classroom.

This work was conducted in collaboration with Kakenya's Dream (KD), a non-profit organization based in rural Kenya, that leverages education, health, and leadership programs to empower girls and end harmful traditional practices including female genital mutilation (FGM) and child marriage to transform communities in rural Kenya. More specifically, through the development and pilot of a virtual, place- and problem-based learning curriculum with their upper all-girls school Kakenya Center for Excellence (KCE) II, this research sought to provide an engineering educational experience to the students and teachers by employing a combination of teaching and educational frameworks and citizen science activities, including ambient and indoor air quality monitoring. In addition to the curriculum, we also collected and analyzed the indoor and ambient AQ results and shared them with the KD staff. We worked to co-develop low-cost solutions at KCE II to improve the AQ impacts they have experienced from the local air pollution. Students in more rural and lower socioeconomic communities do not often have the opportunity nor access to STEM education experiences, particularly when they are out of school experiences that accompany their learning [30]. As an engineer myself, I served as their access point in providing them with an educational experience which utilized context-specific and citizen science engineering tools to guide the VLE.

1.3 Aims, Goals, and Objectives

This research aims, overall, to offer new perspectives and resources to the engineering education community across institutional contexts and cultures. In addition to the outcomes from each portion of the research, this work also aims to provide a holistic point of view that improves the accessibility to engineering education for all students and people.

The first goal was to develop an inclusive practices menu for engineering faculty looking to improve inclusivity and belonging in their classrooms. The practices on the menu were sourced from peer-reviewed literature and teaching and learning center websites covering a number of aspects of inclusivity including race, gender identity, and mental and physical accessibility. The menu was unique to other existing inclusive practices resources as it provided not only the practices and their descriptions, but also organized them by suggested implementation timeframe in a collegiate semester and by three domains related to inclusive climates.

The second goal of this research was to develop and pilot tools to support faculty in implementing these practices including learning communities (LCs) and a decision matrix for prioritization. Learning communities have been used to provide instructors with supportive learning environments with their peers to improve their teaching and more recently, LCs have emerged across higher education with a particular focus on diversity, equity, and inclusion [38], [39], [40], [41]. However, many of these LCs have not articulated their development and fewer have provided best practices and advice for inclusive-focused LCs within engineering and other STEM disciplines. This research fills a gap in the literature by investigating the impacts of inclusive practices implementation on engineering students and the impact of support mechanisms for faculty across three institutions with different contextual needs (i.e. predominantly white institutions, Hispanic serving institution, STEM-focused institution).

The third goal of this research was to develop and pilot an international, engineering virtual learning experience (VLE) for middle and high school age students (7th through 12th grade) in rural Kenya in response to a local air pollution problem. This experience utilized a combination of educational and teaching frameworks as well as the engineering design process and citizen science to provide students with a place-based, context-specific learning experience. Previous literature has shown the success of both virtual and nonvirtual learning experiences focused on environmental problems, however, most of them were conducted prior to the COVID-19 pandemic and in wealthier countries where traditional opinions about girls' education may not be as pervasive culturally. Additionally, literature has illustrated that engagement in engineering at an early age, especially prior to and in high school, is a significant predictor of STEM interest later in their education and life [30]. Particularly for girls and students from low-income families, this is especially important as they are less likely to pursue engineering due to a lack of accessibility to effective programming that allows them to develop an interest in STEM that has personal meaning and offers potential career goals [30], [42]. This research fills a gap in the literature by developing and conducting a place-based environmental engineering VLE internationally at an all-girls school in a rural area in the midst of global and cultural challenges affecting students learning including COVID-19 and harmful traditional practices such as female genital mutilation and child marriage.

The following research questions were explored to address these research goals:

Higher Education Engineering Education Community

1. What are the most effective practices to promote an inclusive engineering classroom?
2. How do different learning communities foster and support inclusive engineering classrooms?

K-12 Engineering Education Community

1. Environmental issues such as poor air quality and harmful cultural traditions such as female genital mutilation continue to impact communities in the midst of global challenges including the COVID-19 pandemic. As engineering educators, how can we continue to provide support and deliver effective international engineering educational experiences that lead to understanding and empowerment?

To achieve the research goals and address the aforementioned research questions, the following objectives are:

1. Collect and provide instructors with proven, pragmatic inclusive practices for improving inclusivity in engineering classrooms.
2. Create and pilot an international, virtual engineering educational program for the students and teachers to simultaneously monitor the ambient and indoor air quality at a school in rural Kenya, as well as educate and empower both the students and instructors with knowledge on air quality and its impacts to collaboratively develop a sustainable solution.
3. Synthesize the aforementioned objectives and develop a conceptual framework of the STEM education environment at both the higher education and K-12 levels which centers students' identities and experiences and reflects the interplay of the people and groups who impact their development as a STEM student.

1.4 Broader Impacts

The nature of an engineer's work requires them to approach their work in a collaborative and holistic way considering it can directly impact communities both socially and structurally across many different cultures and contexts [43]. More specifically, the field of and research within engineering education, as stated by the American Society of Engineering Education, seeks to advance innovation and increase the accessibility to the engineering profession at all levels of education [44]. One of the key outcomes of this work was to develop a menu of evidence-based and tested teaching practices to help engineering faculty foster inclusive classrooms at the undergraduate level. These practices aim to improve the classroom experience for engineering students of all identities and provides a new and unique resource of practice to the engineering teaching community. Importantly, in engineering classrooms, we tested the practices to demonstrate if the practices improved aspects of classroom inclusivity through a student survey. Further, we aimed to support engineering faculty through learning communities. Specifically, this portion of the work also shares the development and pilot of support tools for engineering faculty implementing inclusive practices across three different institutional contexts and provides the engineering education community with lessons learned for other faculty endeavoring to do similar work.

The second portion of this work, which was conducted in the international K-12 engineering education community, similarly focused on improving engineering education efforts but through the lens of increasing access to engineering experiences for historically underrepresented students in rural and lower socioeconomic communities. This portion was conducted virtually in collaboration with Kakenya's Dream, an organization and all-girls school in rural Kenya, with their upper school students (7^{th}-12^{th} grades). This work aimed to demonstrate the impact and strength of a cross-cultural engineering education collaboration which provided students with hands-on experience with new engineering concepts, technology, and materials. The project with Kakenya's Dream was guided by the engineering design process, problem-based learning, and utilized citizen science tools such as air quality monitoring as a learning mechanism which are unique in comparison with their traditional curriculum. This work, overall, aimed to increase the inclusivity within and accessibility to engineering through efforts within and outside of classroom throughout the education pipeline from K-12 through higher education.

1.5 Intellectual Merit

This research addresses needs within the engineering education, and more broadly, the STEM education community by providing inclusive-focused educational resources that have been piloted across cultures and contexts for both the K-12 and higher education engineering communities.

Higher education engineering community: Though inclusive classroom resources exist in the literature, the practices menu uniquely categorizes the practices using suggested implementation time and an inclusive professional framework [28]. Further, this study also shares all parts of the research process with the broader engineering education community including the development and pilot of the inclusive classroom tools, student and faculty participant results, and lessons learned from the study participants and the researchers. Previous inclusive-focused intervention studies have shared outcomes from in-classroom interventions as well as inclusive practice resources that have been piloted over time through peer-reviewed literature and public websites. For example, Hartman et al. and Mills et al. shared strategies to improve inclusion in engineering classrooms by implementing changes in faculty training and curriculum [12], [13]. A number of existing inclusive classroom literature and resources are either broadly applicable to many disciplines, such as those referenced to develop the inclusive practices menu in this work, or the results of their implementation are not widely shared in the literature, particularly within engineering contexts. Previous studies have also not fully shared their results from resource development through researcher perspectives across multiple institutional contexts. Literature has illustrated the need for actionable inclusive classroom resources which focus on aiding faculty in improving the classroom climate, particularly within the engineering classroom context.

K-12 engineering education community: The study approach expands the traditional norms of place-based, environmental education experiences through utilizing a combination of teaching and learning frameworks, collaborating internationally with students and teachers, and incorporating citizen science educational tools. This study offers a fully virtual, problem-based environmental learning curriculum for middle and high school grades (7^{th}-12^{th}) that is characterized by citizen science to the K-12 engineering education community. Compared with previous environmental education experiences and projects, studies conducted in the midst of environmental and global challenges, such as air pollution and COVID-19, and in rural communities where harmful traditional cultural practices impact student education (i.e. child marriage) are less represented in the literature and this research aims to fill that gap.

1.6 Dissertation Organization

This thesis begins with an overview of inclusion in the STEM classroom, and more specifically the engineering classroom at the K-12 and collegiate levels, as well as a conceptual framework for STEM education. Chapters 3, 4, and 5 address Objective 1 which was to provide faculty with proven, pragmatic inclusive practices for improving inclusivity in engineering classrooms and develop and pilot support tools for faculty implementing the practices. Chapter 6 addresses Objective 2, which is to create an international, virtual educational program for the students and teachers to simultaneously monitor the ambient and indoor air quality at school in Kenya, as well as educate and empower both the students and instructors with knowledge on air quality and its impacts to collaboratively develop a sustainable solution. Conclusions of the overall results and considerations for future work, which includes Objective 3, the synthesis of Objectives 1 and 2 through a conceptual framework of the educational environment, are discussed in Chapter 7.

2.0 Background and Literature Review

2.1 Inclusion in the STEM Classroom

The STEM classroom environment, particularly within engineering disciplines at the higher education level, has historically been exclusive and harmful to minoritized and marginalized students [8], [10], [11], [12], [13], [24], [45]. Literature has shown that the academic and personal development of students can be deeply linked with their interactions in their learning environments, which highlights the need to prioritize the inclusive nature of those environments for all students [46], [47], [48], [49]. Previous research has also cited that students' academic and social success can be positively impacted when instructors cultivate inclusive classroom environments that facilitate a sense of belonging [10], [11]. This is especially prevalent for historically marginalized and minoritized students as they are more likely to experience prejudice and discrimination within and outside of the classroom that can undermine their success in comparison to their White peers [10], [11], [12], [49], [50], [51], [52].

Various pedagogical tools such as embedding a social justice framework into engineering curriculum and developing a sense of community in the classroom have also been reported to improve student belonging [26], [53]. Another teaching tool, which has been utilized at both the higher education and K-12 levels, is incorporating context-specific and place-based learning material or projects into engineering, and more broadly STEM, curriculum. Research has shown that using a learner-centered approach and contextualizing material to student experiences or local environments can provide multiple benefits to students including exercising autonomy and creativity in problem solving and providing for better understanding and retention of material [31], [32], [33], [34].

Though the impact of improving inclusivity in the engineering classroom, and more broadly the STEM classroom is well illustrated in the literature at the higher education and K-12 levels, there has been a lack of actionable guidance for instructors who teach more technical courses, such as engineering [9], [10], [11], [54], [55]. From an instructor perspective, the lack of practical guidance in the literature makes implementation challenging because of the overlap in practices, uncertainty of timing, and the lack of information on which strategies have the highest impact. Dewsbury et al., in their creation of an inclusive teaching tool for science faculty, found that focusing on classroom climate and pedagogy in the classroom with support from external resources sustains effective inclusive teaching [8]. However, they also mention that these elements of the classroom are highly dependent on university and professional contexts and they must be considered for inclusive teaching efforts [8]. Other studies, such as Hartman et al. and Mills et al., have shared strategies to improve diversity and inclusion in engineering classrooms by implementing change at the department- or school-level by implementing policy changes for faculty training and curriculum [12], [13]. Existing inclusive classroom literature and resources are either broadly applicable to many disciplines, such as those referenced to develop the inclusive practices menu in this work, or results of their implementation are not widely shared in the literature, particularly within engineering contexts. The engineering education field, and more broadly the STEM education field, will benefit from the development of tools, learning materials, and educational and teaching frameworks which incorporate a learner-centered mindset that prioritizes and reflects the identities, contexts, and cultures of all students into their learning experiences and environments.

2.2 Humanizing STEM Education

Historically, the curriculum of STEM disciplines has been marked largely by technical prowess and career readiness [18]. However, literature has emphasized the need to move beyond just the technical part of engineering education and provide students' with broader perspectives where they understand the impact of technical solutions and contribute to the betterment of society across cultures and contexts [18], [56], [57], [58]. In order to consider and offer a solution for engineering and STEM education, Yao et al. [47] developed a framework to guide efforts in the argument of humanizing STEM education (Figure 1). A fully humanized STEM education, according to Yao et al., centers and focuses on teaching students, not disciplines, in ways that recognize the humanity of students and create learning environments that support the mental, emotional, physical, and academic wellbeing of all students [47]. Their framework is guided by the ecological model of human development developed by Bronfenbrenner et al. that is grounded in psychological and educational research [47]. The Yao et al. framework, as shown in Figure 1, centers the student and their identity, showing that it is formed and impacted by relationships and interactions they have with family, peers, and within their working environment (Figure 1) [47]. The framework also centers the student's interactions, from micro to macro level, with the systems and people that support their development in their undergraduate STEM teaching and learning experience [47]. The framework also includes exosystems, such as industry and local politics, which also shape and influence the environments and interactions students experience throughout their undergraduate STEM education (Figure 1) [47].

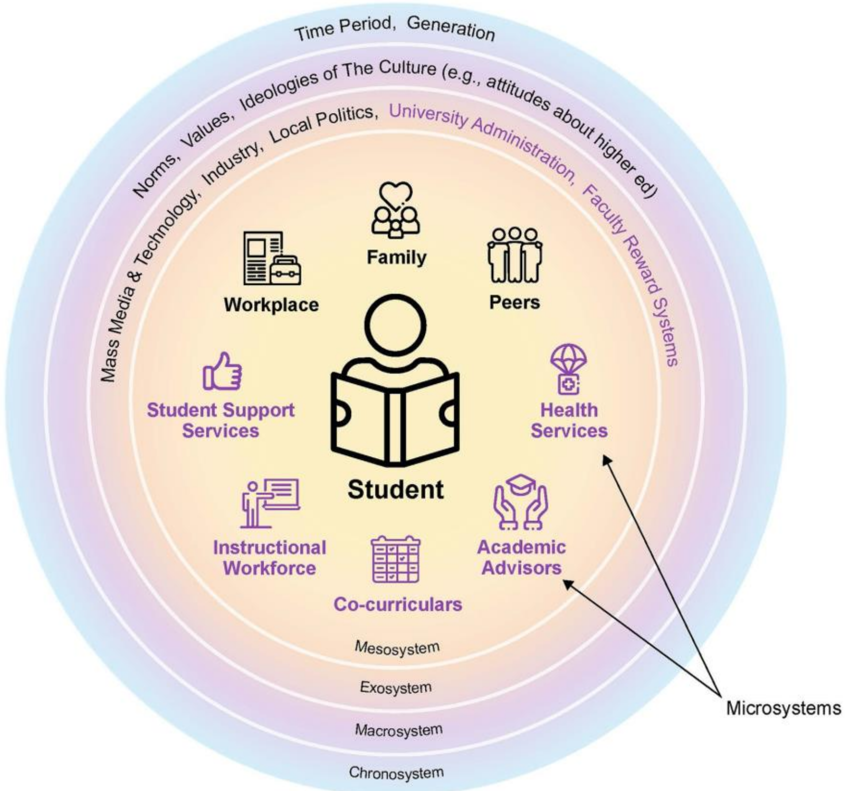

Figure 1. Humanizing STEM Education Framework (Yao et al. 2023).

Yao et al. argues that all members of the academic community, as well as external stakeholders who interact with the educational community, have the responsibility to create equitable and empathy-based learning environments that value the cultural wealth and wellbeing of all students [47]. As a part of this framework, Yao et al. provides some recommendations to every member of the academic community including students, faculty, staff, and administration. One of their recommendations to faculty, specifically, is to increase their awareness of and make connections with students as well as to adopt teaching practices that center care, empathy, and inclusion for all students [47]. In their recommendations, they also urge higher administration to consider what institutional conditions encourage, support, and elevate student voices and honor their humanity, though top-down strategies are often insufficient [47], [59]. The Yao et al.

framework not only prioritizes teaching students with an increased awareness and care to their wellbeing, but also highlights the need to enact change strategies from all parts of higher education, from the classroom through upper administration, simultaneously, to institute sustainable and meaningful change. Humanizing STEM education is one of the ways to educate and develop students to approach solving the world's problems from both a technical and social perspective as it values and celebrates the identities and cultures of all students. However, since this is not currently the norm within STEM education, at both the higher education and K-12 levels, there is a need for further investigation into actionable ways to pursue and sustain this change and this dissertation aims to offer solutions within the engineering classroom to help address this gap.

3.0 Developing and Implementing an Inclusive Practices Menu in Undergraduate Engineering Classrooms

This chapter addresses research question 1, *what are the most effective evidence-based teaching practices to promote an inclusive engineering classroom environment?* The research presented is a reproduction of an article under review in the *Journal of Civil Engineering Education.*

Vaden, J. M., Dukes, A. A., Parrish, K., Nave, A. H., Landis, A., & Bilec, M. M. (2024 Under Review). "Developing and Implementing an Inclusive Practices Menu in Undergraduate Engineering Classrooms". Under Review, Journal of Civil Engineering Education.

3.1 Introduction and Background

Historically minoritized and underrepresented students have experienced prejudice and discrimination within and outside of their classrooms which negatively impact their educational outcomes [10], [11]. Minoritized students have reported feeling recruited and tolerated rather than appreciated; their institution's structure and history and interactions with people on campus, both parts of the campus climate, have induced feelings of alienation and isolation which can negatively impact their success as engineering students [10], [23], [49]. Campus climate is a key factor for minoritized students dropping out of college. Unfortunately, Black students have the lowest completion rate (43%) and are more likely to discontinue enrollment, rather than complete a college degree in comparison with their White peers [10], [12], [49], [50], [51], [60]. The recognition and transformation of pedagogical decisions and classroom interactions that cultivate inclusive excellence have been shown to yield a positive climate and promote more equitable education outcomes [10], [11]. To aid students, particularly historically underrepresented students, in succeeding both academically and socially, previous research has indicated that instructors should create classroom environments that foster inclusivity and belonging [10], [11], [12], [13].

The impact of creating more inclusive classrooms is well-studied; however, guidance on creating inclusive environments in disciplines where technical content is prioritized, such as engineering, seem to lack specificity for the needs of the curriculum [10], [11], [54], [55]. The Center for the Integration of Research, Teaching, and Learning (CIRTL) - Inclusion Across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (INCLUDES) validates this notion that there are "no central set of skills/ideals agreed upon as 'inclusive' even though there are many models around inclusive pedagogy…[indeed, there]...is not a complete list of how an instructor can engender inclusivity within an undergraduate classroom setting" [61]. Some of the current inclusive classroom resources tend to lend themselves to subjective course material where it may be more straightforward to elevate and emphasize contributions to the field by historically minoritized and underrepresented people [25], [62], [63]. Resources and research on inclusive teaching in engineering have also been available and explored but have been largely focused on interventions in the context of learning styles or developing a sense of community in the classroom, not on actionable guidance or resources for instructors to utilize in accompaniment to their course instruction [26], [53], [64], [65]. However, in more technically rigorous engineering and STEM courses, such as Statics or Mechanics, this type of change may be more challenging as the curriculum may not present as many opportunities as the course progresses further into more technical aspects. Research has also highlighted the need for professional development opportunities for STEM faculty considering the diverse experiences and unique backgrounds students bring to the college classroom and the need to become more culturally responsive in their teaching [27].

In response to this lack of actionable guidance in the engineering classroom, we conducted the IUSE-PIPE (Improving Undergraduate STEM Education – Proven Inclusivity Practices for Engineering) Project. This project was an NSF-funded study focused on providing actionable practices for engineering faculty to improve inclusivity in their classrooms and to support faculty in the implementation of those practices. This chapter, specifically, reports on the development of the inclusive engineering practices menu and the assessment of the successful implementation of those practices from the students' perspective, aiming to provide STEM faculty with evidence.

This work was conducted across three universities engineering programs, as they represent different institutional norms, cultures, and demographics. The institutions were the University of Pittsburgh (Pitt), Arizona State University (ASU), and the Colorado School of Mines (Mines). Pitt is a mid-size, Predominantly White Institution (PWI) with a semi-public engineering school, the Swanson School of Engineering. Swanson has a school-level Office of Diversity in addition to a university-wide office for equity, diversity, and inclusion [66]. ASU is a large, public university and the Ira A. Fulton Schools of Engineering have six engineering areas of focus. ASU's Office of Diversity, Equity and Inclusion is a university-wide office that serves the entire institution and ASU is also designated as a Hispanic-Serving institution [67]. Mines is a small, public PWI that offers majors of study within the fields of science, engineering, and mathematics. Diversity, Inclusion and Access at Mines is an initiative collectively led by faculty, graduate students, and institutional partners for the university as a whole [68].

We will first describe the theory of change developed by Henderson, Beach, and Finkelstein as the guiding framework for the IUSE-PIPE project in the theoretical framework section. We then describe the development of the inclusive engineering practices menu and participant feedback surveys as well as our data collection and analysis methods. We then detail and discuss the results and statistical analyses of the student survey. Finally, we culminate with a discussion on further investigation for this work.

3.2 Theoretical Framework

The development of the inclusive engineering practices menu, as detailed in the Methods section of this chapter, was in part informed by and aligned with the Theory of Change (TOC) model developed by Henderson, Beach, and Finkelstein [59]. The TOC model includes four quadrants of change strategies for higher education: disseminating curriculum and pedagogy, developing reflective teachers, enacting policy, and developing a shared vision among instructors and stakeholders (Figure 2). The first quadrant of disseminating curriculum and pedagogy focuses on teaching educators about new strategies they can use in the classroom and advocating for their use. Developing reflective teachers centers on encouraging and supporting educators as they develop new teaching concepts, action research, and develop curriculum as seen in the second quadrant. The third quadrant focuses on enacting policy changes and strategic planning which usually occurs at an administrative level rather than at the educator level. The final quadrant is focused on developing a shared vision among stakeholders and empowering them to create an environment that fosters new teaching concepts and practices [59]. This chapter focuses on the development and deployment of the practices menu, quadrant I, and students' feedback to being in classrooms where instructors employed the menu, a part of quadrant II. Additional findings for this research, which are referred to in the other quadrants in Figure 2, will be further detailed in Chapters 4 and 5.

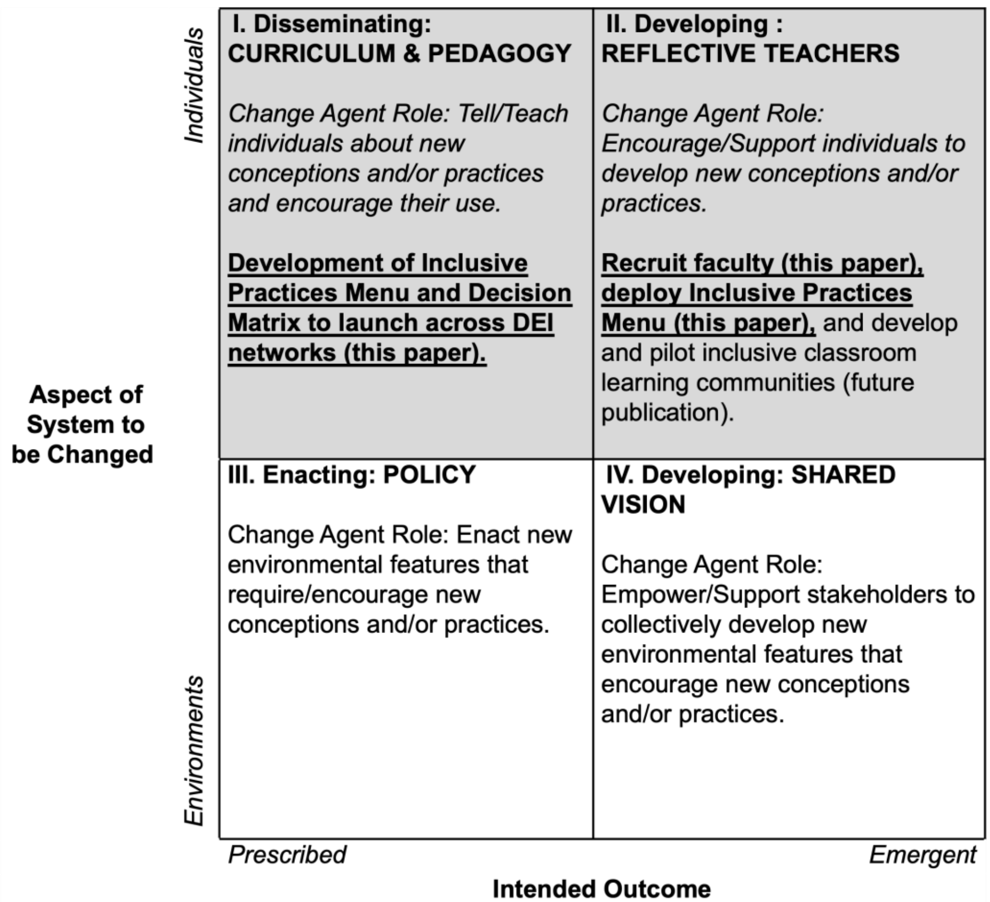

Figure 2. Guiding Theoretical Framework (Henderson et al. 2011). Quadrants highlighted in grey are the focus of this chapter.

3.3 Methods

In this section, an overview of the development of the inclusive engineering practices menu is presented. The recruitment strategy for faculty and student participation is also discussed followed by a detailed description of the assessment plan and survey development for participants, which precedes a detailed discussion of the survey assessment and data analysis methods.

3.3.1 Inclusive Classroom Engineering Practices Menu Development

We developed and deployed an inclusive engineering practices menu through an extensive review of practices from both peer-reviewed literature and university teaching and learning center websites [54], [55], [69], [70], [71], [72], [73], [74], [75], [76]. Teaching and learning center websites were included in the review for the menu because they offered both inclusive classroom strategies and pedagogical advice. We curated the descriptions and instructions, examples of implementation, and references and impact reported for the listed strategies. The literature sources used to develop the inclusive engineering practices menu spanned the past ten years of research on inclusive strategies that have demonstrated efficacy in classroom settings [54], [55], [69], [70], [71], [72], [73], [74], [75], [76].

The inclusive engineering practices menu can be seen in full in Section 1.01(a)(i)Appendix A.1 or on the IUSE-PIPE project website. Two strategies found in the literature during the review process included examining current and previous assumptions about students and committing to increasing awareness of your worldview as well as integrating relevant and culturally diverse examples into course material [54], [55], [76], [77]. Some of the strategies, specifically from teaching and learning center resources, included activating student voices throughout the entirety of the class, modeling inclusive language, behavior, and attitudes, and interrupting blatantly racist and discriminatory behaviors in class [74], [78], [79]. A large proportion of these inclusive classroom resources referenced for the menu were developed and apply to all classroom contexts, but only a few of them were specifically focused for the engineering classroom, showing a lack of availability for engineering-specific inclusive classroom resources. Through our assessment plan, we aimed to show if these approaches could also be used in the engineering classroom. The inclusive engineering practices menu from this project synthesized these existing resources into one menu using additional organization and frameworks applicable to the engineering classroom as well as focused on addressing the classroom climate and not curricular content in order to encourage engineering faculties use of inclusive practices.

During the literature review process, it was rare to find an inclusive teaching resource that included both the strategies and descriptions as well as suggestions on the timeframes for implementing those strategies into courses. Due to this finding, we organized our inclusive engineering practices menu by sorting the strategies into timeframes reflecting the progression of the traditional collegiate semester to suggest when instructors should employ them. They are titled: Pre-Semester, Syllabus, In-Classroom Engagement, and Discussion Tools.

In addition to organizing the strategies by semester timeframe, we categorized them by the Aspire Alliance's Inclusive Professional Framework's core domains: identity, intercultural, and relational [28]. Within the faculty role of teaching, the identity domain focuses on mitigating bias in class design, content, grading, and group work through developing an awareness of self and others' social and cultural identities. The intercultural domain applied to teaching focuses on supporting students' connections to content and encouraging them to be their authentic selves through developing an understanding of cultural differences and how those impact peer-to-peer interactions. The last domain, relational, focuses on building trusting relationships among peers and instructors, encouraging student belonging, and inclusive communication which all support interpersonal interactions in the classroom [28], [80].

3.3.2 Faculty and Student Recruitment

The faculty recruitment strategy at all three institutions was centered around the development of inclusive learning communities (ILCs) to support the efforts of implementing the practices menu as well as providing a forum for learning and feedback. The recruitment email to faculty, staff, and other instructors encouraged those who were interested in creating more inclusive classrooms and receiving support while doing so, to join the ILCs for a minimum of three semesters. Though this was the shared recruitment strategy across the three institutions, they varied slightly as the learning communities were formed from either an existing learning community or one created exclusively for this study. Further details on the ILCs at each partner institution will be discussed in Chapter 4.

The faculty participants, which included both research- and teaching-focused faculty, sent the student survey to their students who were in classes where the practices menu was employed for each semester they were a part of the ILCs. Most of the faculty participants from the three institutions were engineering instructors and the students surveyed were mostly students in engineering programs of study. 52% of the courses surveyed in this study were designated Civil Engineering courses including ‘Fate and Transport in Environmental Engineering’ and ‘Life Cycle Assessment’ (n=14). 37% of the courses (n=10) represented other engineering courses that are often included in the curriculum for CEE students through required or elective courses (n=10). These included ‘Senior Design’, ‘Advanced Engineering Thermodynamics’, and ‘Introduction to Probability’. The remaining 11% surveyed were other STEM courses not within engineering (n=3). Table 16 in Appendix A lists an example of classes that were distributed the student survey.

3.3.3 Inclusive Menu Student Experience Survey

3.3.3.1 Survey Design

The intended outcome of the student survey was to capture student experiences with a sense of belonging and inclusion in their classrooms where faculty intentionally implemented strategies from the inclusive engineering practices menu. The student survey was approved by the partner institutions Institutional Review Boards (Pitt and Mines #STUDY20050402 and ASU #14693).

The student survey was developed by combining existing survey instruments that were used to assess feelings about the classroom and university environment as well as peer and instructor interactions [81], [82], [83]. The survey was comprised largely of questions from three existing survey instruments: the Engineering Department Inclusion Level (EDIL) survey by Lee et al. [81], the National Survey of Student Engagement (NSSE) by the Center for Postsecondary Research at Indiana University's School of Education [82], and the Classroom Community Scale by Rovai [83]. The EDIL survey instrument was developed to provide engineering educators with a tool to investigate how underrepresented students in engineering rate the level of inclusion, with a particular focus on racial and gender differences among students [81]. The NSSE instrument is aimed at assessing the extent to which students engage in educational practices associated with high levels of learning and development across five categories [82]. The last survey instrument, the Classroom Community Scale, measured community within a learning environment to help educational researchers learn how to best design and deliver instruction that promotes community and persistence among students [83].

We referenced all the survey questions from the EDIL and Classroom Community Scale instruments when developing the student survey and selected questions from the NSSE instrument. From NSSE, we used the survey questions asking students how often their instructors employed specific teaching techniques as well as the background and demographic information questions. From the long list of survey questions from the three sources, the authors went through a series of selections with the research team, comprised of three engineering faculty, a faculty developer, and a faculty development program director, to determine which questions would best capture student's feelings about their classroom and university communities as well as their interactions with peers and instructors.

The final student survey was comprised of 23 Likert-style questions for inclusion and classroom-related feedback; 13 fill-in-the-blank and multiple-choice questions were also included for the course and demographic information. The survey has three sections: Instructor Course Questions, Peer Questions, and Department/University Questions with the course and demographic information questions at the beginning and end of the survey, respectively. The Instructor Course section aimed to elucidate student experiences in the classroom related to their instructor's course management. For example, one of the survey questions in this section was "Indicate the frequency in which your instructor clearly explained course goals and assignment requirements" to which students had the option to respond with "Very Often", "Often", "Sometimes", or "Never". The Peer Questions section asked student respondents about their experiences with their peers in the classroom with a focus on their connection and trust level with their classmates. The final question section, the Department/University Questions, was a series of questions asking students about how they felt in terms of who has the largest impact on different aspects of their collegiate experience.

Due to the nature of the student survey questions as well as there being four and five-response questions, survey reliability and possible biases may have been introduced. Rovai tested their survey instrument for reliability and found the Chronbach's coefficient alpha for the survey was 0.93 and the equal length split half coefficient was 0.91 [83]. Both of these values indicate excellent reliability for the survey instrument and for our student survey, Question 1 in the 'Instructor Course Questions' and Question 2 in the 'Peer Questions' were referenced from Rovai and had five response choices [83]. The National Survey of Student Engagement from Indiana University reported their benchmark testing produced highly reliable group means ($E_q \geq 0.7$) with as few as 50 students and generalizability coefficients greater than 0.6 for samples of 25 students [84]. They do caution against overinterpreting small differences and encourage institutions to utilize their survey over time and focus on major trends produced from the results [84], [85]. In our student survey, Question 2 in the 'Instructor Course Questions' and Question 1 in the 'Peer Questions' were referenced from the National Survey of Student Engagement from Indiana University and had four response choices. Both of these surveys, in their original formats, produced very reliable results and we elected to keep the survey questions written 'as is' to maintain the integrity of the questions we utilized. However, we do acknowledge we combined questions from these survey instruments to develop our student survey. We did not evaluate the impact the different answer choices may have had on the student respondents.

In terms of bias, two potential biases were social desirability and neutral response bias. Social desirability bias refers to the tendency to present oneself and their social context in a way that's perceived to be socially acceptable instead of reflective of their reality. This can stem from the sensitive nature of an answer and can lead to an overestimation of the positive and diminish heterogeneity [86], [87]. Since the questions were all asking students to reflect on their classroom experience and on their instructor's classroom behavior, they may have elected to answer the questions more positively. The survey may have also introduced neutral response bias, when respondents tend to choose more neutral answers as opposed to the strongly worded choices, in part due to social desirability [88]. In the same way student respondents could have been more positive about their experiences, they also may have chosen more neutral answers unless they encountered specific situations that would have them choose otherwise. Though the authors acknowledge the biases that may have been present in the student survey, the results from the student survey, which will be discussed in the results and discussion section, did not appear to be biased towards the majority groups present in the survey population and the student demographics reflected similarly to demographic groups that have typically been underrepresented in engineering and STEM disciplines in higher education. Additionally, these survey instruments have been used across higher education across many institutional contexts and have produced reliable results cited across the literature. The student survey questions, less the course information and demographic questions, can be seen in Table 1. The student survey in its entirety can be seen in Table 17 in Appendix A.

Table 1. Example of Student Survey Questions (Lee et al. 2014; Rovai 2002; The Trustees of Indiana University 2013).

Question	Possible Response
Instructor Course Questions	
1. For this course, indicate the extent to which you agree with the following statements: a. I feel encouraged to ask questions. b. I feel uneasy exposing gaps in my understanding. c. I feel reluctant to speak openly in this class. d. I do feel a spirit of community in this class.	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
2. For this course, indicate the frequency in which your instructor has done the following: a. … asked students to discuss a solution or answer with others during class b. … clearly explained course goals and assignment requirements c. … provided feedback on an assignment, draft, or work in progress d. … connected your learning to societal problems or issues (unemployment, climate change, public health, etc.) to explain or provide context to class materials e. … tried to better understand someone else's views by imagining how an issue looks from their perspective f. … included diverse perspectives (political, religious, cultural, gender, etc.) in this course's discussions or assignments	Very Often, Often, Sometimes, Never
3. To what extent did the instructor provide flexibility given the effects of the COVID-19 pandemic on students?	Very Much, Quite a Bit, Some, Very Little
4. Indicate the quality of your interaction with the faculty member who invited you to complete this survey.	1 (Poor), 2, 3, 4, 5, 6, 7 (Excellent), NA
Peer Questions	
1. For this course indicate the frequency in which YOU have done the following: a. … felt judged based on a question, answer or comment you made in class	Very Often, Often, Sometimes, Never
2. For this course, indicate the extent to which you agree with the following statements: a. I feel connected to others in this course. b. I feel wary trusting other students in this course	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
3. Indicate the quality of your interactions with other students in this course.	1 (Poor), 2, 3, 4, 5, 6, 7 (Excellent), NA
Department/University Questions	
1. Select the two options which have the largest impact on the statements below: a. I feel most respected by… b. Women are treated most fairly by… c. I feel the most belonging due to my interactions with… d. I feel the most valued by… e. Minoritized people are treated the most fairly by… f. In regard to my success in college, I can depend the most on g. I am the most comfortable voicing my concerns to…	My Peers, This Instructor, My Department, This University

In order to receive feedback on student experiences in classrooms where the menu was employed, we developed and launched a student survey through email in November 2021 using *Qualtrics Research Software* [89]. The student survey was administered to students in participating classrooms for the duration of the IUSE-PIPE project. From the duration of the project, there were 228 students who responded to the survey, however due to all of the questions being optional, the number of completed student surveys, which were used in analysis, was two hundred and nineteen (n=219). Our analysis also included analyzing the student responses by self-identified racial and gender identity groups to explore if there were differences among student experiences. For this analysis, the student survey population was two hundred and two (n=202) due to incomplete surveys. Across the study period, there may have been common student responses, however this was not likely due to participating instructors largely teaching the same courses for each semester they were involved in the study. For information on the student respondents per university, see Table 18 in Appendix A.

3.3.3.2 Statistical Methods

To evaluate the impact of the inclusive engineering practices menu on students' experiences and feelings of inclusion in their classrooms, two data analysis methods were employed: descriptive statistics with visual analysis and a 2-sample t-test on the difference in means comparing across student-identified demographic groups. For these tests, they were conducted at a 95% confidence interval (alpha=0.05) and the null hypothesis was there would be no significant difference found between the demographic groups of students being compared. The null hypothesis would be rejected with a p-value of less than 0.05. The combination of these statistical methods provided insight on the relationship and differences between how students of different identities experience their classroom environments.

3.3.3.2.1 Organization of Student Survey Responses

The student survey responses were first analyzed in aggregate to observe the experiences the students had across all three institutions and all three semesters in classrooms where the menu was employed. Following this, the student survey responses were sorted according to the self-identified categories of *race* and *gender identity*. For the *race* category, students were able to choose from a list of races including American Indian or Alaska Native, Black or African, Hispanic or Latinx, Middle Eastern or North African, Hawaiian or Other Pacific Islander, White, Another race or identity, or they could choose “I prefer not to respond.” Students were also able to choose more than one race. The *gender identity* category was similar in structure where students could choose from a list of options including Female, Male, Non-binary or gender-fluid, another gender identity, which then asked them to specify, or they could choose “I prefer not to respond”. The remaining demographic questions can be seen in the full student survey in Table 17 in Appendix A.

3.3.3.2.2 Transformation of Data

The 2-sample t-tests, utilizing StataSE16, required the transformation of the categorical survey responses into binomial or numeric data, depending on the question. The binomial transformation needed to occur for the student survey responses to *race* and *gender identity*. For *race*, the student self-identified choices were assigned binomial values according to whether they identified as the Majority race. The Majority race included any student who self-identified their race as White or White with another race and was given a value of one. Students who did not identify as White and chose different races or a combination of the other options were given a value of zero. This categorization allowed us to compare how students of the Majority race at each institution felt about their classroom, peer, and instructor experiences to the Non-Majority group of students’ experiences. For *gender identity*, the student self-identified choices were also assigned binomial values according to whether they identified as Male. Any student who self-identified as Male was assigned a value of one, and students who did not identify as Male, which in our study included Female and Non-binary/Gender fluid gender identities, were assigned a value of zero. Similar to the race category, this categorization allowed us to compare how students who identified as Male felt about their classroom, peer, and instructor experiences to those who did not identify as Male.

The transformation of categorical data to numeric data needed to occur for the Likert-scale student survey responses to conduct two-sample hypothesis tests. This transformation was conducted for all the survey questions except for the course and demographic information. All the Likert-scale survey responses had answer choice sets of either "strongly agree, agree, neither agree nor disagree, disagree, strongly disagree" or "very often, often, sometimes, never". For these responses, each answer choice was assigned a value in sequential order from the most positive response to the most negative response: "strongly agree (5), agree (4), neither agree nor disagree (3), disagree (2), strongly disagree (1)" or "very often (4), often (3), sometimes (2), never (1)". The transformation of these responses allowed us to utilize them in the two-sample hypothesis tests to determine if different student groups had different perspectives on their classroom, peer, and instructor experiences.

3.3.3.2.3 2-Sample T-Test on the Difference in Means

A 2-sample t-test on the difference in means was selected to analyze the relationships between: (1) students who did or did not self-identify their race as the Majority race or students who did or did not self-identify their gender identity as Male and (2) student responses to the survey questions asking about their feelings on their classroom, peer, and instructor experiences. In these comparisons, two-tailed hypothesis tests were constructed under a 95% confidence level and null hypothesized difference, in means equal to zero. The alternative hypothesis for the two-tailed test was set with the difference in means not equal to zero. The results of a p-value greater than 0.05 suggests that there was not a significant difference in how the two student groups felt about their classroom, peer, and instructor experiences, whether that was race or gender identity. The combination of the results of the tests provides insight into the interaction between groups of students and their experiences in the classroom.

3.4 Results and Discussion

This section details key findings from the student survey which are accompanied by supporting statistical evidence. First, the demographics of the student respondents are shown to illustrate the survey population thus far. This is followed by visual representations and discussion of the student survey results in aggregate, then by the racial breakdown of Majority and Non-Majority, and finally by the gender identity breakdown of Male and Non-Male.

3.4.1 Student Demographics

Student Respondents were primarily early in their undergraduate collegiate careers, reported their grade point averages above 3.0, and were mostly White and Male. From the duration of the IUSE-PIPE project (every Fall and Spring semester from Fall 2021-Fall 2023) across all three institutions, 228 students responded to the student survey. However, since all of the questions were optional, the total student survey population used for analyzing the student data in aggregate was two hundred and nineteen (n=219). The student respondents were largely first-, second-, or third-year undergraduate students (86.4%), and self-reported their grade point average greater than 3.0 (89.7%) (**Error! Reference source not found.**). Compared with the student d emographics from one year of study, the students in this dataset were more racially diverse with 37.6% of them identifying as White, 17.4% Middle Eastern, 14.1% Latinx or Hispanic and 17.8% Another unidentified race (**Error! Reference source not found.**). Most of the student respondents i dentified as Male (70.6%) and most reported their sexual orientation as heterosexual (87.8%) (**Error! Reference source not found.**).

Table 2. Participating student demographics from duration of the IUSE-PIPE project (Fall 2021-Fall 2023) (n=219).

(Note: Bold indicates majority in each category.)

Characteristic	No. (%)	Characteristic	No. (%)	Characteristic	No. (%)
Class Year		Race		Sexual Orientation	
1st year	**94 (44.1)**	Black or African American	6 (2.8)	**Straight**	**187 (87.8)**
2nd year	62 (29.1)	**White**	**80 (37.6)**	Bisexual	10 (4.7)
3rd year	28 (13.2)	Latinx or Hispanic	30 (14.1)	Gay	1 (0.5)
4th year	18 (8.5)	Middle Eastern	37 (17.4)	Lesbian	1 (0.5)
5th or more year	5 (2.4)	Another Race	38 (17.8)	Queer	1 (0.5)
1st year graduate student	6 (2.8)	Multiple Races	9 (4.2)	Asexual	0 (0.0)
GPA Entering Semester		Prefer not to respond	12 (5.6)	Questioning	3 (1.4)
3.50+	**128 (60.1)**	Gender Identity		Other	3 (1.4)
3.00-3.49	63 (29.6)	Female	57 (26.6)	Prefer not to respond	7 (3.3)
2.50-2.99	16 (7.5)	**Male**	**151 (70.6)**	International Student	
2.00-2.49	3 (1.4)	Non-binary	4 (1.9)	Yes	81 (38.2)
1.99 or below	3 (1.4)	Another identity	0 (0.0)	**No**	**131 (61.8)**
		Prefer not to respond	2 (0.9)	First Gen. Student	
				Yes	64 (30.3)
				No	**147 (69.7)**

The NSF's Science and Engineering indicators tracks the demographic attributes of science and engineering bachelor's degree recipients among U.S. citizens and permanent residents [90]. For 2019, most of the engineering bachelor's degree recipients were White (50.1%) followed by Hispanic or Latinx (19.8%), then Asian (9.1%), then Black or African American students (7.1%), and all other races made up the remaining 14% [90]. Compared with the participating student survey demographics for this project, they are similar with White students as the majority race, however further breakdowns by other races were not. For example, this project's largest student demographic groups after White were Another Race, Middle Eastern, and Hispanic or Latinx students, respectively, whereas the second largest according to the NSF reports were Hispanic or Latinx. The NSF also tracks engineering bachelor's degrees by sex and in 2019, 83.4% of engineering degrees were awarded to men and 16.5% were awarded to women, which was similar to the gender identity split between participants in this project [90].

3.4.2 Menu Strategies Employed

When examining all the data, the majority of students in participating classrooms indicated their instructors utilized inclusive classroom strategies from the Inclusive Engineering Practices Menu. Students' responses to the survey questions on how often their instructors employed specified classroom strategies from the inclusive engineering classroom menu are presented in Figure 3 for the duration of the project. This set of questions asked student respondents to indicate the frequency in which their instructor has done the following on a scale of "very often" to "never". Overall, the student respondents indicated that their instructors often encouraged students to discuss solutions together (84%), clearly explained course goals (93%), provided feedback on assignments (87%), connected their learning to society (90%), tried to better understand someone else's perspective (81%), and included culturally diverse perspectives in the course material (78%). This is a positive result given that there are strategies on the inclusive engineering practices menu encouraging instructors to utilize these tools in their classrooms and course design. Most students indicated they have never felt judged based on a question, answer, or comment; however, about 20% of students did experience this in the classroom.

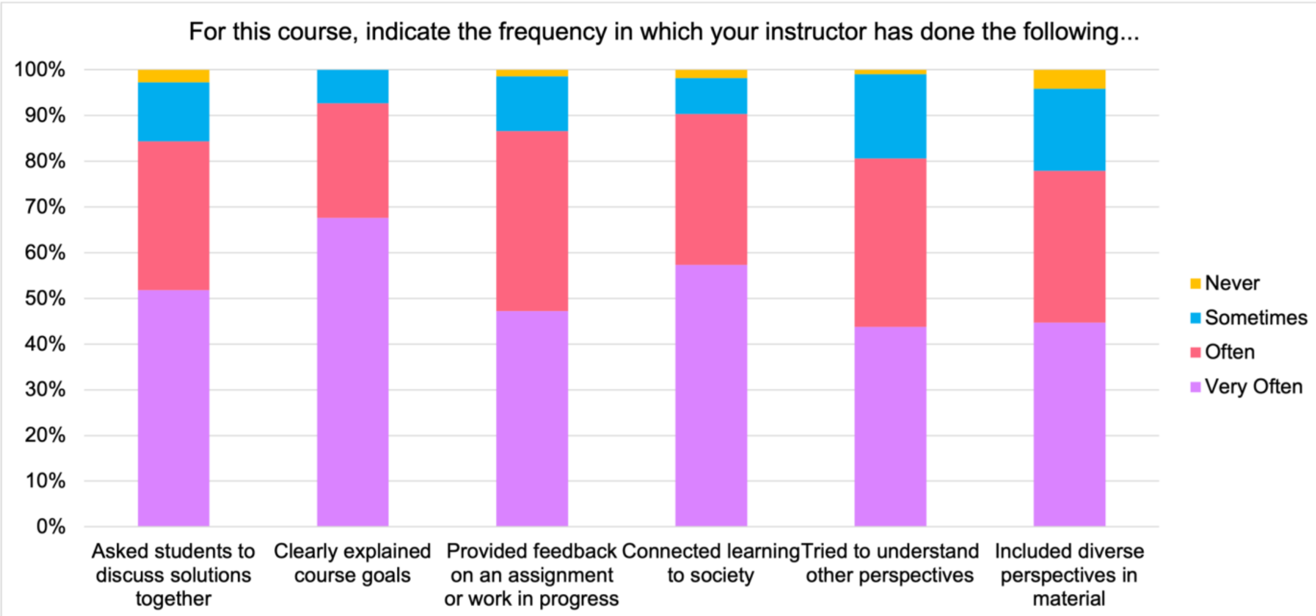

Figure 3. Student survey responses on how often their instructors employed specified classroom strategies for the duration of the IUSE-PIPE project (n=219).

3.4.3 Interactions and Experiences

The majority of students felt positive about their interactions and experiences with their instructors but were not very trusting of their peers in their classes. Students' responses to questions asking about their experiences with their instructors and peers in their class are presented in Figure 4. For example, one of the questions asked students, "For this course, indicate the extent to which you agree with the statement: I do feel a spirit of community in this class" to which they could choose from answer choices on a scale from "strongly agree" to "strongly disagree". The majority of students agreed that they felt encouraged to ask questions (85%), felt a spirit of community (73%), and felt connected to others in their classrooms (70%). More than half of the student respondents also felt they could discuss gaps in their learning (53%) and a large proportion did not feel reluctant to speak openly in class (44%). However, when it came to trusting their peers in the classroom, about one quarter of the respondents felt wary of trusting their peers (28%).

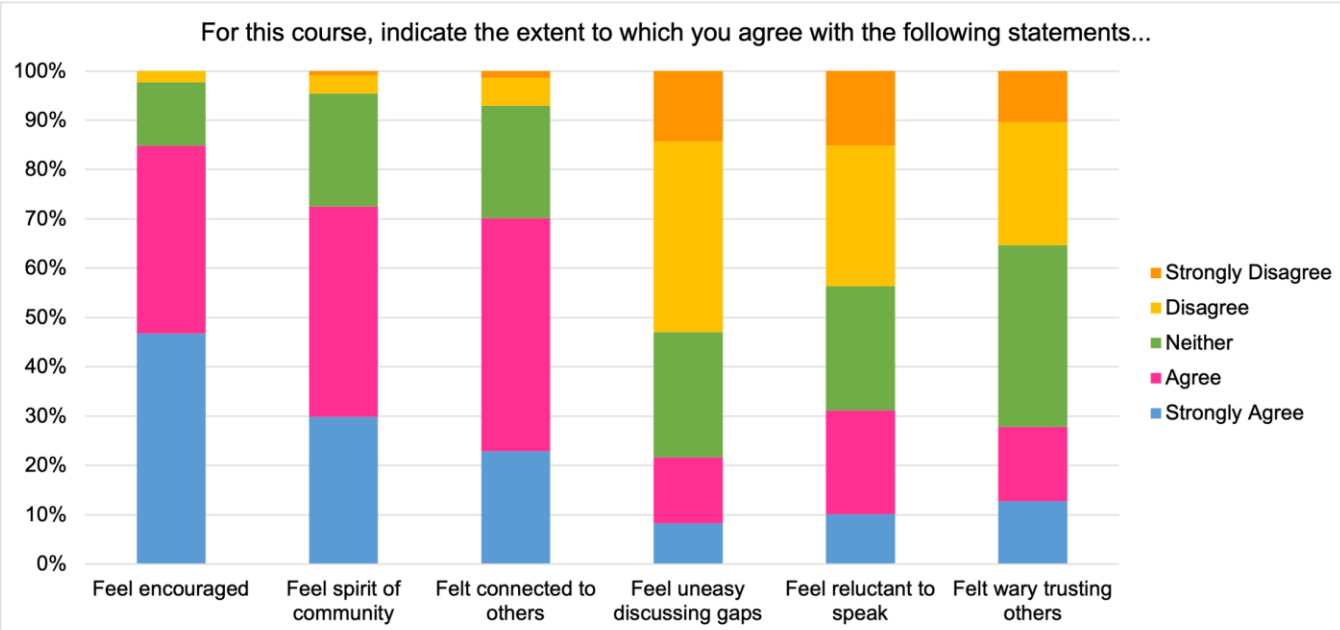

Figure 4. Student survey responses on their classroom experiences with instructors and peers for the duration of the IUSE-PIPE project (n=219).

In summary, the student responses indicated that most students had a positive experience with their peers and instructors in classrooms that utilized the inclusive engineering practices menu. The complete student survey results can be seen in the Appendix A Figure 16-Figure 19. However, considering the demographics of the student respondents, it was imperative to also analyze the data across key categories.

3.4.4 Comparisons between Majority and Non-Majority Identifying Students

Majority and Non-Majority students report having dissimilar experiences with trusting their peers, discussing gaps in knowledge, speaking openly, and feeling judged during classroom participation, which are confirmed through statistical analyses. For analyzing the student respondent data by race, we categorized the racial identities into two categories: Majority (M) and Non-Majority (NM). All students who identified their race as White or White in combination with another race were considered to be in the Majority group and the remaining respondents were categorized as Non-Majority. First, the overall results are discussed, and then the statistically significant results are presented.

Compared to their Majority peers, Non-Majority students indicated feeling judged by their instructor based on a question or comment they gave during class (24%) when asked about the frequency in which their instructors utilized specific classroom techniques (see Figure 5). However, when asked about how often their instructor encouraged discussing solutions together and how often the instructor tried understanding other perspectives, the Non-Majority students reported experiencing this more often as compared to their Majority peers (99% for both questions).

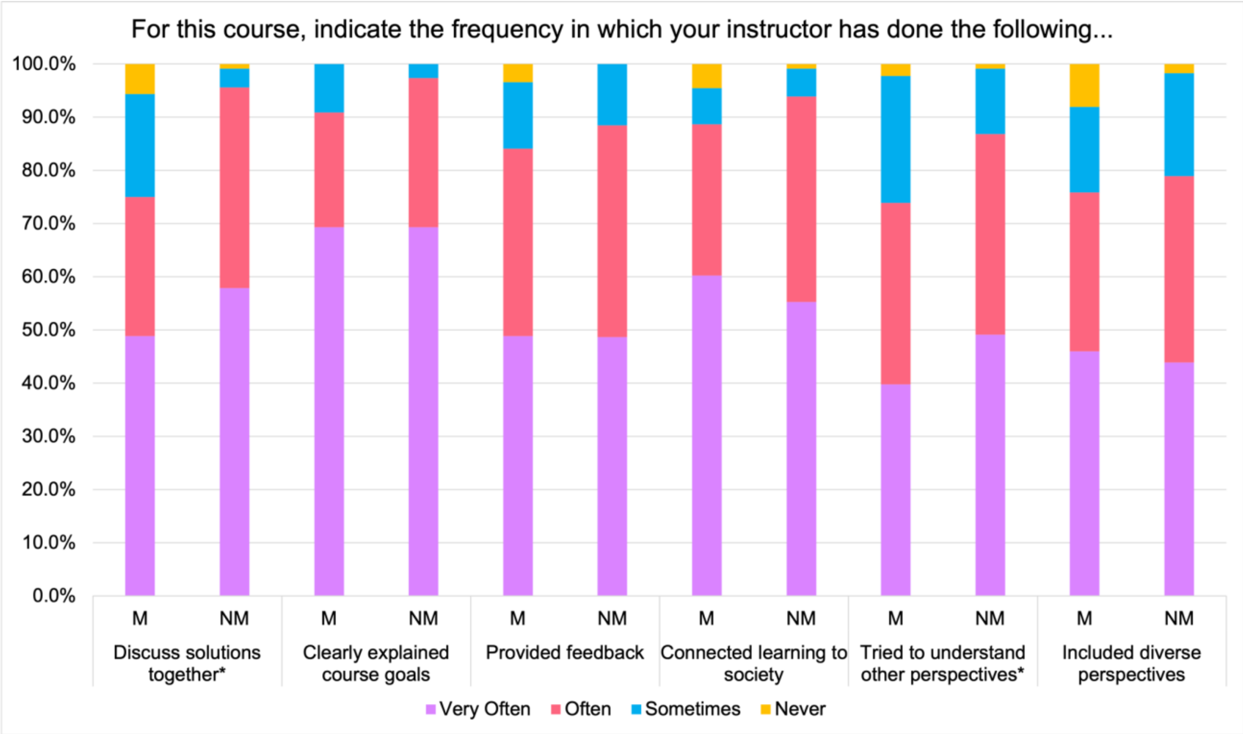

Figure 5. Selected Majority (M) and Non-Majority (NM) student results indicating instructor use of specified classroom techniques for the duration of the IUSE-PIPE project (n=202).

(note: M- Majority: Students who self-identified their race as White or White with another race; NM – Non-Majority: Students who self-identified their race as a different option or a combination of options excluding White; *Asterisk denotes significant differences found between groups in 2-sample t-tests which are shown in Table 3).

Compared to Majority students, the Non-Majority students reported feeling more uneasy discussing gaps in their learning (10% vs. 28%), feeling more reluctant to speak openly in class (17% vs. 40%), and feeling more wary of trusting others in their class (20% vs. 35%) (see Figure 5). The complete student survey results comparing Majority and Non-Majority student results can be seen in Appendix A Figure 16 and Figure 17.

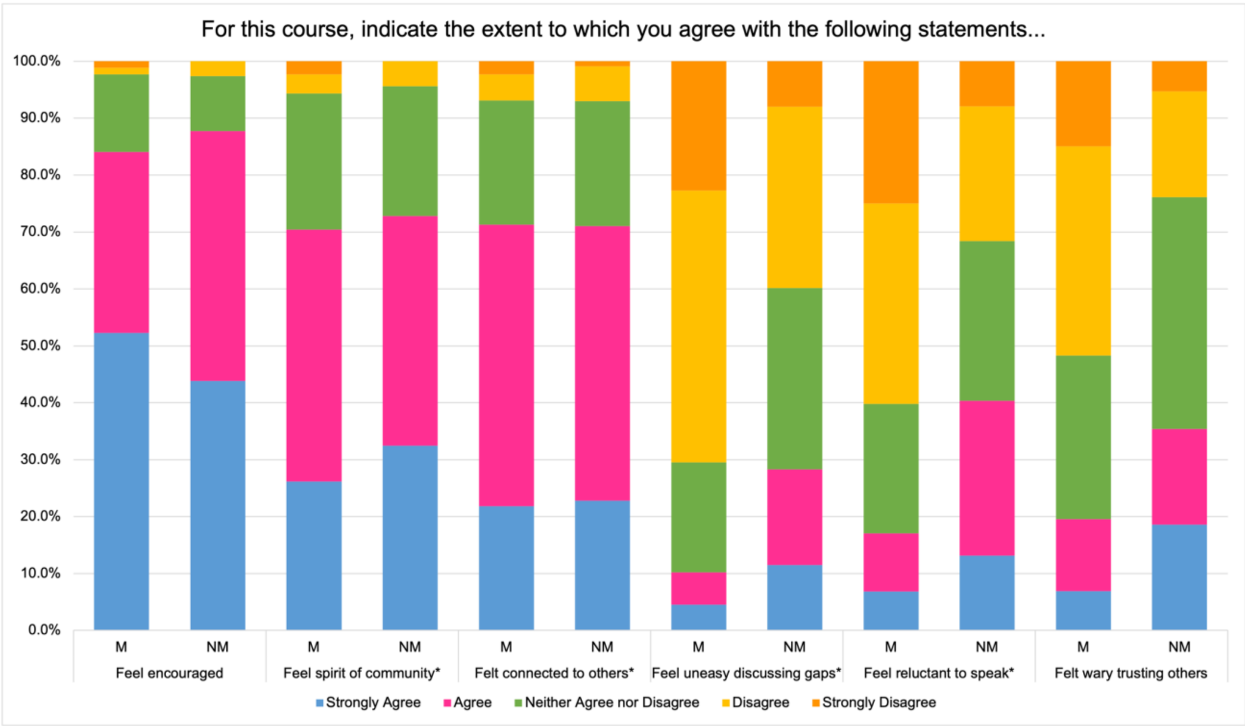

Figure 6. Selected Majority (M) and Non-Majority (NM) student results on their classroom, instructor, and peer experiences for the duration of the IUSE-PIPE project (n=202).

(note: M- Majority: Students who self-identified their race as White or White with another race; NM – Non-Majority: Students who self-identified their race as a different option or a combination of options excluding White; *Asterisk denotes significant differences found between groups in 2-sample t-tests which can be seen in Table 3).

We utilized StataSE16 to conduct 2-sample t-tests for the student survey questions comparing the Majority and Non-Majority groups of students, detailed in Table 3. For the 2-sample t-tests, the p-value (less than 0.05) was analyzed to determine statistical significance for the difference in the means at a 95% confidence level. For this analysis, we did not control for institution type in order to provide a view of all students who were in participating classrooms and to increase the number of samples in the test. However, we did provide each partner institution with their student's results using summary statistics. When comparing Majority and Non-Majority students, there was a statistically significant difference (at an alpha level of 0.05) between the means for seven questions including between how students felt about discussing gaps in their knowledge, speaking openly in class, and their connection to their classmates (Table 3). The results also showed statistically significant differences in the means of how Majority and Non-Majority students felt about other classroom experiences including feeling judged based on their contributions in class, whether their instructor asked students to discuss solutions together, and if their instructor tried to understand things from others' perspectives (Table 3).

Table 3. Results for 2-sample t-test on the difference in means at 95% confidence level, Comparing Majority to Non-Majority students about their feelings on their classroom, peer, and instructor experiences for the duration of the IUSE-PIPE Project (Majority n=88; Non-Majority n=114).

	Majority		Non-Majority		
	Mean	SD	Mean	SD	*p-value*
5-Response Choice Questions					
Feel uneasy discussing gaps in knowledge (gaps)**	2.216	1.011	2.920	1.127	0.000
Feel reluctant to speak openly in class (reluctant)**	2.386	1.169	3.140	1.159	0.000
Felt connected to others in class (connection)**	3.689	0.847	4.062	0.727	0.017
Feel wary trusting other students in class (trust)	2.598	1.105	3.248	1.122	0.000
4-Response Choice Questions					
Asked students to discuss solutions during class (discuss)*	3.182	0.941	3.526	0.613	0.001
Tried to understand things from others' perspectives (perspectiv)*	3.113	0.850	3.351	0.682	0.034
Felt judged based on a question, comment, answer (judge)**	1.170	0.551	1.456	0.913	0.010

Note: Alpha = 0.05; Majority – Students identifying as White or White with another race Non-Majority – Students who do not identify as White nor in combination with another race; *specified teaching techniques questions **student feelings questions

3.4.5 Comparisons Between Male-Identifying and Non-Male Identifying Students

Male-identifying students reported less positive experiences when asked about their trust in their peers, discussing gaps in their knowledge, and speaking openly in class as compared to their Female- and Non-binary/Gender-fluid-identifying peers, which were

confirmed through statistical analyses. We also analyzed the student survey data by self-identified gender identity. As shown in the demographic table (**Error! Reference source not found.**), participating students self-identified their genders as Male, Female, or Non-binary/Gender fluid. Due to only four students identifying as Non-binary/Gender-fluid, those students were grouped with Female students into the Non Male group for analysis. When asked about their classroom, peer, and instructor experiences, Male-identifying students felt more wary of trusting their peers (57%), felt more uneasy discussing gaps in their knowledge in class (43%), and felt more reluctant to speak openly in class (34%) as compared to their Female and Non-binary/Gender-fluid peers (Figure 7). One of the questions that stood out in comparison to other survey questions was that about 9% more Male students, in comparison to Female-identifying students, reported feeling judged on questions or comments they made during class. The remaining survey questions, though there was variability among how Male-identifying students answered questions, showed that Male-identifying students answered similarly to their Female-identifying peers. The complete student survey results comparing Male and Non Male students can be seen in Appendix A Figure 18 and Figure 19.

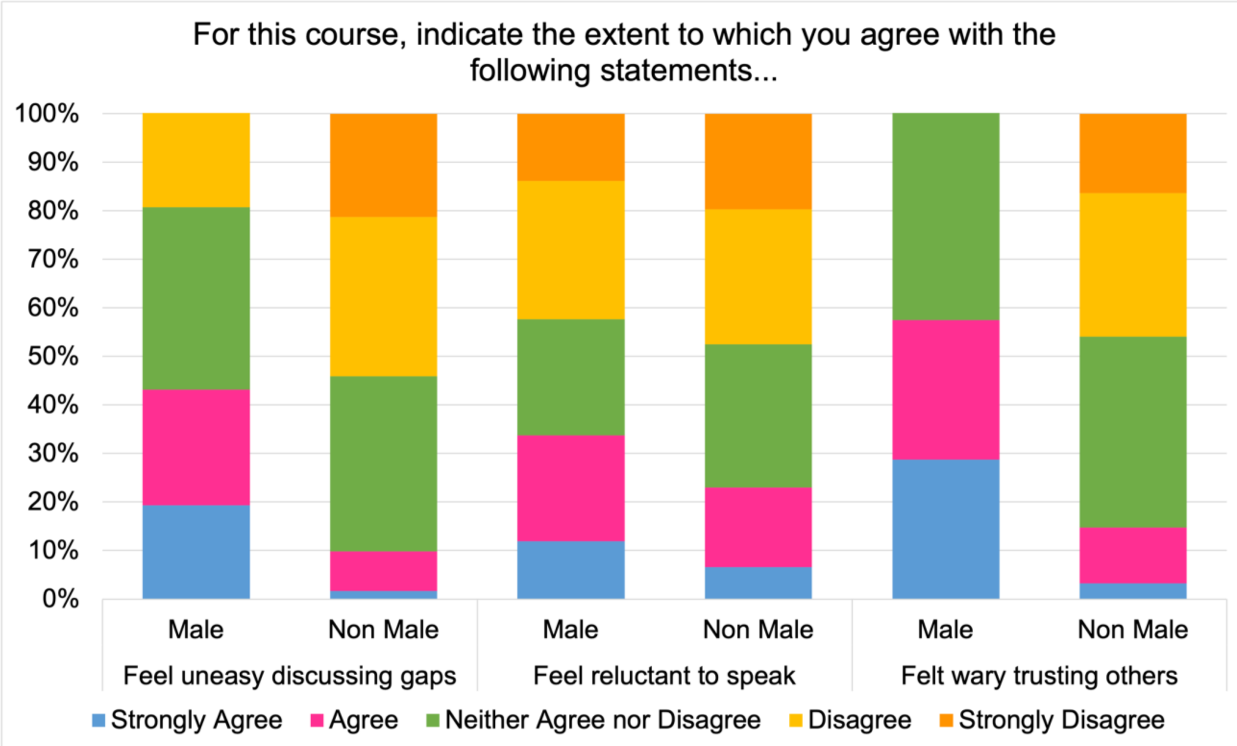

Figure 7. Selected Student Results by self-identified gender identity on their classroom, instructor, and peer experiences for the duration of the IUSE-PIPE project (n=202).

(note: Non Male group includes students who self-identified their gender identity as Female or Non-binary/Gender-fluid.)

We also conducted 2-sample t-tests on the student survey responses for the gender identity categorization as well. Similarly to the t-tests conducted comparing racial groups, the p-value (less than 0.05) was analyzed to determine the statistical significance for the difference in the means at the 95% confidence level. The results comparing these two groups revealed statistically significant differences in the means of how Male and Non Male students felt about their trust level of their peers, the extent to which their instructor provided flexibility during the COVID-19 pandemic, and feeling judged based on a question, answer or comment made in class at an alpha level of 0.05. From all of the student survey questions, these were the only three that showed a statistically significant difference in the means when comparing the Male and Non-Male categories of students (Table 4).

Table 4. Results from 2-sample t-tests on the difference in means at 95% confidence level, Comparing Male to Non-Male students about their feelings on their classroom, peer, and instructor experiences for the duration of the IUSE-PIPE project (Male n=151; Non-Male n=61).

	Male		Non-Male		
	M	SD	M	SD	*p-value*
<u>Five Response Questions</u>					
Feel wary trusting other students in class (trust)**	3.142	1.023	2.542	1.023	0.000
<u>Four-Response Questions</u>					
Extent to which instructor provided flexibility during COVID-19 pandemic**	3.035	0.967	3.339	0.779	0.033
Felt judged based on a question, answer, or comment made in class (judge)*	1.406	0.882	1.153	0.448	0.037

Note: Alpha = 0.05; Male – Students who self-identified their gender identity as male Non-Male – Students who self-identified their gender identity as female or non-binary/gender fluid; *specified teaching techniques questions **student feelings questions

Overall, as supported by the student results from the duration of the project, the inclusive engineering practices menu may have had a positive impact on student experiences in the classroom with their peers and instructors. Jahan et al. (2022) conducted a similar study in which they trained and encouraged civil engineering faculty to implement inclusive teaching practices in their classrooms [12], [45]. Their results showed students in participating classrooms indicated the positive impact the inclusive practices had on their learning experiences and in courses where more practices were implemented, reflected even more favorably when asked about their classroom experience [45]. Cress et al., in their study on analyzing campus climate longitudinally across the U.S., found that students can be the primary culprits of creating hostile classroom climate [91]. However, faculty can help combat this by interacting with students in a way that makes them feel valued and affirmed to moderate a negative learning environment and facilitate a positive learning environment for all students [91].

However, our student results, when analyzed by racial and gender identity groups, emphasized that even when instructors intentionally implement inclusive teaching practices, there may be other factors influencing student experiences that impact their classroom interactions with their peers and instructors, which is the first key finding from this study. The student results, as well as other previous studies, have shown that there is still a continued need to incorporate inclusive teaching practices into engineering classrooms with the intention to create a more inclusive environment for all students, particularly for historically minoritized and marginalized groups of students who may have tangential experiences which could impact their classroom success [12], [45], [59], [64], [92]. These results also indicate a need for further investigation utilizing student interviews where the researchers can employ coding to further tease out the reasoning behind student survey responses.

3.5 Limitations

This chapter has a few limitations that could have impacted the conclusions drawn from the data collection. One of the major limitations is we did not collect data from a "control group" of students. We discussed utilizing a pre-semester survey for students or surveying students in classrooms where the inclusive engineering practices menu was not employed in order to compare with the data collected from students who were in those participating classrooms. However, we, as well as members of the ILCs at the partner institutions, believe that inclusive teaching practices are valuable for all students so no one wanted to 'disadvantage' their students by not implementing the practices. Incorporating inclusion-focused questions into existing universities end-of-semester and other institutional surveys could also be leveraged to improve student survey response rates.

Another possible limitation to this study is the demographical layout of the universities that are being compared and combined in the data collection process. Though all three universities are public and research-focused, Mines is an engineering, science, and mathematics-focused institution while ASU and Pitt offer degree programs in the sciences and engineering as well as in the liberal and performing arts. The racial demographics of Mines, ASU, and Pitt all differ, with ASU being a designated a Hispanic-Serving Institution while Mines and Pitt are primarily white institutions when considering their student populations. However, we see this limitation as a strength as well considering they are enacting very similar interventions across different schools and are able to compare results and successes. One last limitation of this chapter we wanted to highlight was the uneven distribution of student survey responses from the three participating institutions. To date, ASU has the largest student representation in the student survey responses as compared to the other institutions and should be considered as the survey data is analyzed in total. Though the limitations to this study have been highlighted, we believe the study and the inclusive engineering practices menu has shown important and unique contributions to the field of engineering education.

3.6 Assessing the Student Impact of the Practices Menu and Concluding Remarks

The inclusive engineering practices menu was developed and deployed in engineering classrooms across three institutions for every Fall and Spring semester from Fall 2021-Fall 2023. The menu was accompanied by a survey that measured how students in classrooms where the menu was employed felt about their classroom, instructor, and peer experiences and interactions as they relate to inclusivity and belonging. Furthermore, the survey also helped to elucidate how different student demographic groups, based on race and gender identity, reported on their classroom, instructor, and peer experiences. Two hundred and nineteen students from all three institutions have responded to the student survey in full across five semesters of distribution, though the number used for demographic comparisons was lower due to optional questions.

The survey utilized in this study was developed through existing survey tools focused on elucidating feelings on inclusivity and belonging in the classroom, as well as with instructor, peer, department, and university experiences. Results of the two-sample hypothesis tests comparing racial groups revealed that in comparison to their Majority peers, Non-Majority students reported feeling more positive about some experiences in the classroom such as feeling a spirit of community and feeling connected to others in their class. However, Non-Majority students also reported feeling less trusting of their peers as well as feeling more reluctant to speak openly in class as compared to their Majority peers. Results of the two-sample hypothesis tests comparing gender identity groups revealed that compared to their Non-male peers, Male students felt less trusting of their peers, felt their instructors were not as flexible during the COVID-19 pandemic, and felt more judged in their classroom participation. This suggests a key finding that students of different identity groups, specifically racial and gender identity, are still reporting differently about their classroom experiences even when practices from the inclusive engineering practices menu are employed. This finding also suggests the need for further exploration to learn more about why students are continuing to have different experiences even with the use of the practices menu through individual or group interviews.

This chapter on student feedback of their feelings of inclusivity and belonging in engineering classrooms is a part of a larger research project, the IUSE-PIPE project, that will continue to assess the impact of the inclusive engineering practices menu within engineering classrooms. During the duration of the IUSE-PIPE project, we also collected feedback from instructors and faculty on practices they employed from the menu through the inclusive learning communities (ILCs) convened at each partner institution through a faculty survey and interviews. Further details on the ILCs and results from the faculty survey will be detailed in Chapters 4 and 5. The inclusive engineering practices menu presented in this chapter is the first part of creating an instructor toolkit for engineering disciplines to encourage instructors to make inclusivity integral to their class design and teaching at the collegiate level.

4.0 Inclusive Engineering Classroom Learning Communities: Reflections and Lessons Learned from Three Partner Institutions

This chapter addresses research question 2, *how do different learning communities foster and support inclusive engineering classrooms?* The research presented is a reproduction of an article under review in the *Journal for STEM Education Research.*

Vaden, J. M., Brooks, A., Dukes, A. A., Parrish, K., Nave, A. H., Landis, A., & Bilec, M. M. (2024 Under Review). "Inclusive Engineering Classroom Learning Communities: Reflections and Lessons Learned from Three Partner Institutions". Submitted, Journal for STEM Education Research.

4.1 Introduction

Numerous education entities have called for reform in science, technology, engineering, and math (STEM) education at all levels due in part to enrollment concerns, retention levels, and instructional practices [2]–[5]. Teaching and learning training are not often highlighted in research intensive STEM graduate training as an essential part of preparing for a postsecondary faculty position [97], [98], [99]. Due to this, many faculty in STEM fields are unfamiliar with the ways theory informs decisions about educational methods and how they can transform their teaching to have the contextual awareness and critical sensibilities to teach diverse groups of students [100], [101]. Professional development has traditionally served as the "on-the-job training" for faculty and instructors to help improve their teaching skills and faculty learning communities (FLC) have emerged as a promising professional development tool. FLCs sit at the integration of research and teaching and provide a long-term collaborative structure of safety and support for instructors to learn and improve their teaching skills [102], [103].

In addition, education research has also highlighted the necessity to improve inclusivity in the classroom to enhance student belonging and persistence [10], [11], [12], [13]. The transformation of pedagogical decisions and classroom interactions that cultivate inclusive excellence have yielded a positive classroom climate and promoted more equitable education outcomes among students [10], [11]. Improving inclusivity and belonging is especially important in STEM disciplines, because historically, the culture of the dominant class has framed the terms of interaction within the STEM classroom, leaving out diverse and historically marginalized perspectives and students [12]. The impact of improving inclusivity in the classroom has been illustrated in the literature; however, instructors in technical disciplines, such as engineering, have found difficulty finding actionable guidance on how they can weave inclusivity into the fabric of their classes [9], [10], [11], [54], [55].

FLCs, by design, are a promising approach, especially when considering improving inclusivity and belonging in the classroom. However, implementing FLCs targeting these goals in diverse and technical academic settings can be challenging. Thus, to provide actionable guidance to the broader community, we documented the process of developing the inclusive learning communities (ILC) across three universities that represent three ILC archetypes: A department-wide ILC based at a mid-size, semi-public, predominantly White institution (PWI) with an engineering school that has both school-level and university-wide offices for diversity, equity, and inclusion (DEI); a school-wide ILC based at a large, public, Hispanic-serving institution with a university-wide DEI office; and an institution-wide ILC based at a small, public PWI that is a STEM-focused institution with an institution-wide DEI office. In addition to discussing the ILC development process in this chapter, we also present the results of the faculty survey and interviews from each institutional ILC archetype which focused on elucidating the faculty participant experience in their ILCs.

4.2 Background

This chapter focused on the development of ILCs convened to support participating faculty and instructors in improving inclusivity in their classrooms. To contextualize, first topics are individually explored, beginning with an overview of LCs in the higher education context. The authors then explored broadly how inclusivity in the STEM classroom has been discussed in the literature with a focus on how teaching impacts the classroom experience. The background section in this chapter concludes with a discussion of existing literature on both topics, using LCs to support instructors improving inclusivity and belonging in their classrooms, and on this chapter's contribution to the body of literature on the topics.

4.2.1 Learning Communities

An FLC is a type of community of practice comprised of a relatively small group of instructors who gather for the purpose of learning and have a clear sense of membership, common goals, and the opportunity for extensive interaction [103], [104]. FLCs aim to provide a safe space where faculty can share, explore new ideas, build community, and learn about pedagogical innovations for teaching students with increasingly diverse needs [98]. Hord et al. defined five components that are present in FLCs: shared beliefs, values and vision, shared and supportive leadership, supportive structural and relational conditions, collective intentional learning and its application, and shared personal practice [104]. Participation in FLCs has also promoted productive outcomes and sustained faculty commitment [100], [103]. In other studies that feature FLCs, participants have expressed an appreciation for increased collaboration and accountability with their peers, feeling safe enough to break down personal barriers to share authentically, and gained confidence in employing new knowledge they learned as a part of the FLC [105], [106], [107]. Some authors have argued that colleges and universities as a whole entity should be considered LCs, however FLCs tend to emerge from faculty themselves for the benefit of student instruction rather than from the institution [103].

There are two major types of FLCs: *cohort-based* and *topic-based*. Cohort-based FLCs focus on addressing the teaching, learning, and developmental needs of a group of instructors and the participants shape the LC curriculum [103]. On the other hand, curricula for topic-based FLCs are designed to address a specified campus teaching and learning need, issue, or opportunity and offer membership across departments and experience [103]. Both topic-based and cohort-based FLCs can span focuses such as success with online teaching or designing the classroom environment for equitable student success, even though they differ in their membership structure. Typically, the tenure of cohort-based FLCs is longer because the curriculum and learning goals of the community are guided by the participants as opposed to topic-based FLCs which are guided by the community's topic of focus [103]. Research has also identified some of the key elements of successful FLCs include continuous administrative or institutional support, specific and clear goals that are consistent with the values and concerns of the members, trust and accountability among members, and activities that enhance competency and autonomy to help members grow and develop as instructors [14], [105], [108], [109], [110].

FLCs are a powerful convening approach to improve teaching and community among instructors and most communities pass through similar stages of development. The beginning stages are characterized by setting expectations and specific tasks to guide the group as well as sharing personal practices and experiences [111]. The middle stages involve members collaboratively working together to plan and develop common assessments for students as well as analyze student learning to determine where improvements can be made and where instructors need the most support [111]. In the final stages, the facilitators and members act more like collaborative partners since the focus of the FLC is now largely determined by the participants. In these final stages, the participants also spend increased time reflecting on their instruction as well as connecting the most effective teaching practices with their in-classroom instruction [111]. The switch from instructor to learner-centered pedagogy requires a paradigm shift due to instructors' need for training and learning in different areas [103], [112].

FLCs have disparate purposes that include many teaching and learning-related topics. FLCs can be formed for any discipline and sometimes focus on supporting new approaches for designing a course or new topics. FLCs also sometimes offer membership to other types of instructors such as graduate teaching assistants, which may add additional perspectives to the conversation around teaching, however due to their focus on teaching do not often involve student members. However, the FLCs that were a part of the IUSE-PIPE project had a sole focus on sharing and supporting the implementation of inclusive practices in engineering for teaching and research faculty, although our findings may be relevant to other disciplines.

4.2.2 Inclusivity in the STEM Classroom

Literature has emphasized the need for instructors to create classrooms that foster inclusivity and belonging and celebrate diversity for all students, particularly given the racial climate in the United States [10], [11], [12], [13], [52], [112]. One of the factors in the achievement disparities between historically marginalized and minoritized students and their privileged peers is that classrooms are often characterized by curriculum and pedagogy that enforce the "absent standard" [12], [113]. This occurs when the cultural norms of the dominant group are accepted as the "correct" norms, which further alienates students from underrepresented groups [113]. Faculty who authentically incorporate diversity and equity in their courses can intentionally create inclusive spaces as both instructors and members of the university community [52].

One of the key findings from Walton et al. study on LCs designed to build capacity for inclusive teaching was that *context matters* [95]. Context directly impacts and guides the functioning and focus of an LC and can help provide an understanding of the factors that work against the use of innovative instructional practices [57], [95]. Walton et al. stated the ethical demand of inclusive teaching is to transform social norms to include everyone in the learning environment [23], [95]. Considine et al. study, which focused on their workshop-based intervention that encourages instructors to create culturally responsive classrooms, described the importance of having recognition from higher levels within the institution which helps increase instructor buy-in and motivation [14], [96], [110], [112]. This also helped to normalize the implementation of culturally responsive strategies and curricula which could shift cultural norms at an institution [52], [112]. A systems approach to STEM change acknowledges the role played by individuals in change efforts while also considering the complex contexts in which they find themselves and how those work together to promote and inhibit change [96]. Because of their utility for improving inclusion in the classroom, FLCs may provide the setting for faculty development and promotion of effective and sustainable change.

4.2.3 Inclusivity-focused Learning Communities

FLCs can be considered one of the best places for faculty and instructors to improve their teaching skills and they also serve as a community for implementing and sharing evidence-based pedagogies and their experiences [102]. FLCs, particularly over the last five years, have emerged across the higher education landscape focused on a myriad of topics that broadly address improving the scholarship of teaching and learning among faculty, instructors, and staff. Virginia Commonwealth University and Clemson University both have semester-long FLCs focused on different topics that impact faculty success including improving teaching online and course design in STEM [38], [114]. Among these emerging FLCs, a large proportion of them focus on diversity, equity, and inclusion in the classroom, particularly on inclusive teaching. Georgia Institute of Technology, Princeton University, University of Mississippi, and Pennsylvania State University are among those who have developed and continue to host FLCs focused on equitable and inclusive teaching in STEM and broader areas [39], [115], [116], [117]. A number of these inclusion-focused FLCs have emerged over the last few years, however, their development and lessons learned are not often shared with the broader engineering community who are looking to develop their own FLCs based around improving inclusion in teaching.

Literature has shown the effectiveness of FLCs and best practices but is sparse on the topic of communities focused on culturally inclusive content and pedagogies that aid faculty in effectively teaching all students [105], [109], [110], [112], [113], [118]. Though FLCs focused on inclusive teaching in both STEM and broader areas currently exist, the tools or information being used in these communities are not always widely shared with the broader higher education community.

This chapter expands on the results shared in Chapter 3 as a part of a larger project investigating and providing faculty and instructors with the most effective practices to promote an inclusive engineering classroom, known IUSE-PIPE Project. Chapter 3 focused on the student participant perspective on their classroom experiences with their peers and instructors as well as the development of the inclusive engineering practices menu faculty participants used in their classrooms [119]. Given the trend of emerging FLCs focused on topics such as inclusive teaching and the challenges associated with implementing FLCs, in this chapter, we share the documentation and synthesize the process of developing and implementing FLCs across three universities that represent three ILC archetypes (department-wide, school-wide, and institution-wide) to explore context-based operational and developmental differences. This chapter also shares the process and analysis of participating faculty perspectives through structured interviews and surveys who have implemented inclusive practices in their engineering classrooms and their experiences in the FLCs convened for the IUSE-PIPE project.

4.3 Theoretical Framework

The IUSE-PIPE project, and hence this chapter, was guided by the Theory of Change (TOC) model developed by Henderson, Beach, and Finkelstein [59]. The model denotes four quadrants of change strategies for higher education: (I) disseminating curriculum and pedagogy, (II) developing reflective teachers, (III) enacting policy, and (IV) developing a shared vision [59]. Most of the literature on improving STEM undergraduate education highlights strategies that fit in the first quadrant, disseminating curriculum and pedagogy [59], [92]. The second quadrant, developing reflective teachers, is an approach often used by teaching and learning centers to provide services to motivated faculty [92]. The development and distribution of the inclusive engineering practices menu to faculty participants, the focus of Chapter 3, can be categorized under quadrants one and two [119]. FLCs are a quadrant two strategy that supports the learning and development of engineering and STEM instructors [92]. The development of the ILCs for faculty participants, the focus of this chapter, aligns with quadrants two and four, developing reflective teachers and shared vision. The ILCs developed for the IUSE-PIPE project apply to the fourth quadrant because they exist at an organizational level that involves leaders at the top as well as those in the classroom to develop ideas that can lead to changes in the way departments or institutions operate [92]. A visualization of the IUSE-PIPE Project tasks aligned with the TOC model is presented in Figure 8.

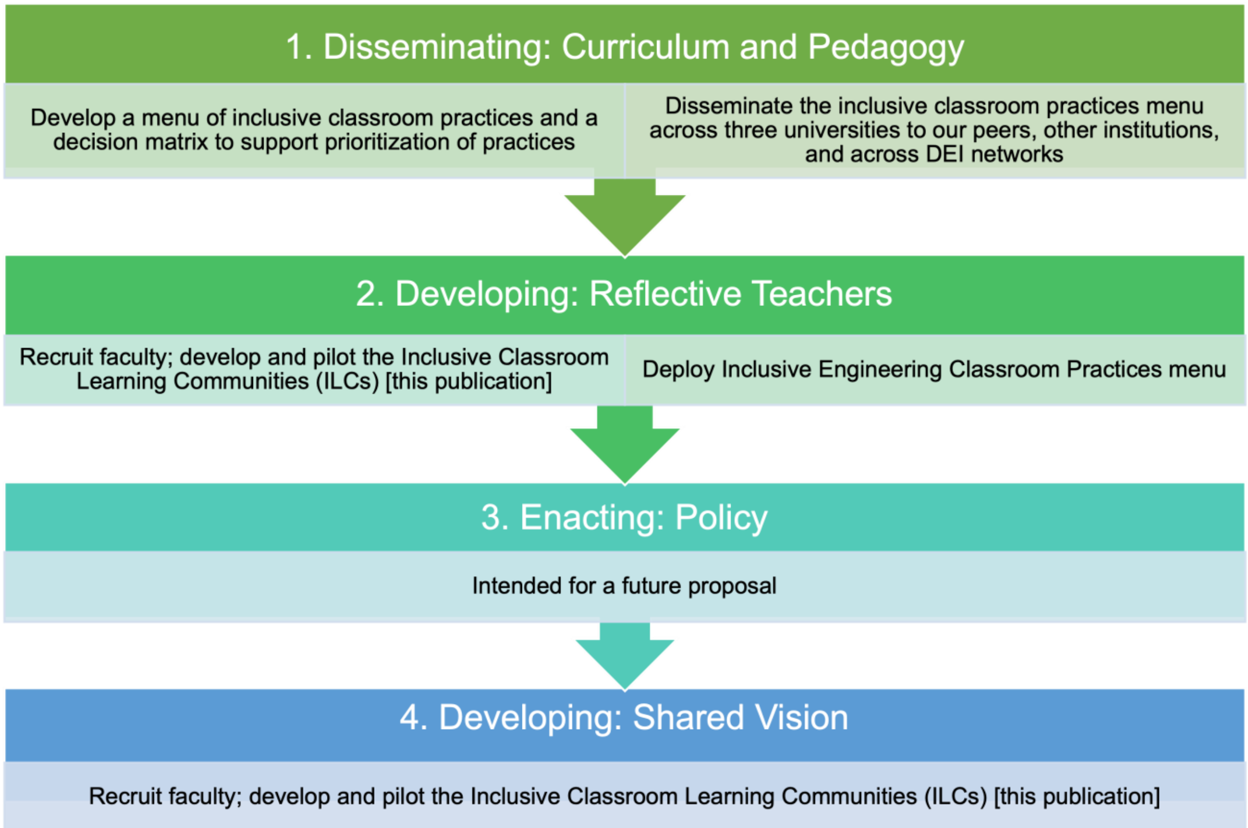

Figure 8. Study alignment with Henderson et al. 2011 Theory of Change [2], [76].

4.4 Methods

For our methodology, this section first describes the partner institutions who participated in the IUSE-PIPE project by their ILC archetypes which frame the quantitative and qualitative data analysis methods used. Then, we used the swim lane method from industrial engineering research to document and evaluate each ILC archetype, along with detailing the faculty and instructor recruitment strategy, ultimately aiming to provide guidance for LCs. We also developed and deployed faculty surveys and conducted structured faculty interviews through a protocol designed to assess the ILCs and provide guidance on best practices.

4.4.1 Three ILC Archetypes

This study investigated three archetypes of ILCs based at three different engineering programs: 1) Department-wide, 2) School-wide, and 3) Institution-wide. These archetypes provided a point of comparison between different academic environments and institutional contexts. The first ILC archetype, department-wide, describes an ILC led by someone or a group from a singular engineering department and whose members are also part of that department (e.g., Civil Engineering). The second archetype, school-wide, describes an ILC that is led at the school-level (e.g., School of Engineering) and whose members are from any engineering or STEM discipline within that school. The third archetype, institution-wide, describes an ILC that is led by a group or person who interacts with the institution such as a teaching and learning center or the President's office. The membership of an institution-wide ILC consists of instructors or faculty from any discipline the institution offers. A visual representation of the three ILC archetypes can be seen below in Figure 9.

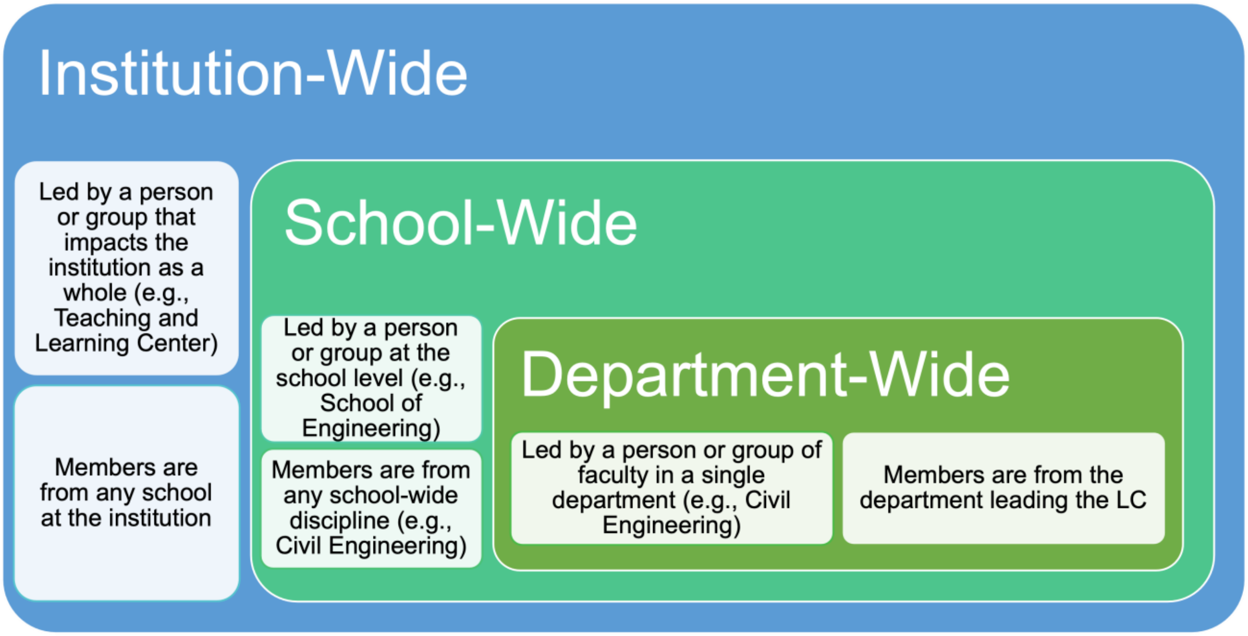

Figure 9. Visual Representation of Three ILC Archetypes

4.4.1.1 Department-wide ILC (University of Pittsburgh)

The first partner institution, the University of Pittsburgh (Pitt), is a mid-size, semi-public PWI with seven engineering disciplines represented within a School of Engineering. At Pitt, this study's ILC was housed within a faculty-led DEI committee that dedicated its efforts to improving departmental culture and was a department-wide ILC. This ILC will be referred to as the department-wide ILC archetype for the remainder of the paper. Further demographic information about the department-wide ILC can be seen in Table 5.

4.4.1.2 School-wide ILC (Arizona State University)

The second partner institution was Arizona State University (ASU) which is a large, public, Hispanic-serving institution. The ILC for this study was affiliated with their Research for Inclusive STEM Education (RISE) Center, a research center focused on inclusion in engineering and STEM disciplines. This ILC is referred to as the school-wide ILC archetype for the remainder of the paper. Further demographic information about the school-wide ILC can be seen in Table 5.

4.4.1.3 Institution-wide ILC (Colorado School of Mines)

The last partner institution is the Colorado School of Mines (Mines) which is a small, public STEM-focused PWI. This ILC was led by the Trefny Center, the institution's university-wide teaching and learning institute, and worked in tandem with the president's office. This ILC will be referred to as the institution-wide ILC archetype for the remainder of the paper. Further demographic information about the institution-wide ILC can be seen below in Table 5. More detailed information on the development of each of the individual ILCs is provided in Appendix B Figure 20-Figure 22.

Table 5. Summary of ILC Attributes by Institution

ILC Archetype	Department-wide	School-wide	Institution-wide
Institutional Archetypes			
Type	Public research university	Public research university	Public, STEM-focused research university
Geographic Region	Northeast	Southwest	Rocky Mountain/West
Minority Serving Institution?	No	Yes (Hispanic-serving institution)	No
Student Enrollment (Fall 2022)	19,928	65,492	5,733
% women student enrollment	56.7% (Fall 2023)[2]	49% (Fall 2022)[1]	31.7% (Fall 2021)[3]
% underrepresented student enrollment	33.5% (Fall 2023)[2]	45% (Fall 2022)[1]	24.4% (Fall 2021)[3]
Learning Community Attributes			
Established (Semester/Year)	Fall 2021	Fall 2022	Fall 2021
Independent?	Formed as part of a department-wide DEI&A committee	Formed as part of interdisciplinary education research center	Yes, initially; then partnered with other DEI initiatives/programs
Average number of participants	14	10	10
Type of participants	Students, staff, and faculty	Teaching and research faculty	Teaching and research faculty
General participant disciplines	Engineering	STEM	STEM
Leadership description	Consistent leader with a facilitator	Two co-leads	One facilitator
General LC meeting location and frequency	Bi-weekly, then monthly virtually	Monthly, in person with virtual option	In-person, on-demand meetings
General meeting format	Portion of meetings (~30 minutes)	Portion of meetings (~15 minutes)	Full focus of meetings
Resources or tools used?	Book club		
Funded?	Yes, by Department chair	Yes, Established Research Center	Participants individually funded
Dedicated administrative support?	No	Yes	Yes

[1]U.S. News and World Report [2]University of Pittsburgh Student Dashboard [3]Diversity at Mines
Note: Underrepresented groups includes American Indian/Alaskan Native, Asian, Black/African American, Hispanic/Latinx, multiple races, and Native Hawaiian/Pacific Islander

4.4.1.4 Inclusive Learning Community (ILC) Development

To help support participating faculty and to provide a space for feedback, inclusive learning communities (ILCs) were convened at each partner institution in alignment with the goals of the IUSE-PIPE project. The members of the ILCs consisted of faculty, staff, and/or students (e.g., graduate student researchers and/or teaching assistants) who expressed interest in creating more inclusive classrooms and were committed to engaging with the ILCs for at least one semester. The ILCs were framed as research- and topic-based LCs and employed the core ideas of an LC from the Center for the Integration of Research, Teaching, and Learning (CIRTL) [61] and were frames as research- and topic-based LCs. Some of the core ideas of the ILCs were creating and fostering functional connections among learners as well as connections with other related learning and life experiences. Another strength of the ILCs was that they focused on both creating inclusive learning environments in the classroom and fostering an inclusive learning environment within the LC itself [61]. The ILCs at each partner institution were aligned by these same shared goals, however, were developed separately at each institution with different origins, institutional partners, and resources that best suited the institution's context and student populations. The facilitators for the ILCs were initially each institution's respective research team member(s), but this changed in some instances as the ILCs developed further.

4.4.1.5 Swim Lane Diagram Documentation

Since the development of each institution's ILC differed given their institutional archetype, context, and opportunities, we utilized the swim lane method, also known as Rummler-Brache diagrams, to document the development of the ILCs and then synthesize the findings. Swim lane diagrams are used to map out a process as tasks horizontally on the page, similar to other process diagramming techniques, however, these diagrams are unique by utilizing swim lanes, or horizontal rows across the page, for each group responsible for tasks that move the process along [120], [121], [122]. The swim lanes allow for the addition of arrows to be drawn across the lanes to show how the tasks in each lane impact or connect to the larger process. Swim lane diagrams are often used in industrial engineering and manufacturing applications, but we chose instead to utilize them as a documentation method and visualization tool for the development of the ILCs from the duration of the project and to glean key findings [121], [122], [123]. We chose this method, as opposed to a process diagram, to visualize and analyze actions from the research team, ILC facilitators, and faculty and instructor participants in relation to institutional archetypes. More detailed swim lane diagrams for each ILC archetype can be seen in Appendix B Figure 20-Figure 22 and key similarities and differences will be discussed in the Results section.

4.4.2 Assessment

In this chapter, various methods to assess the ILCs and their impact on the faculty participants were used including surveys, structured interviews, and classroom observations. The recruitment process for ILC participants is described below followed by the development of the faculty survey and analysis methods used for the survey data. The faculty and instructor interview protocol and the associated qualitative analysis methods are also described.

4.4.2.1 Recruitment for Learning Communities

The faculty recruitment strategy at each of the partner institutions centered around the development of the ILCs to support the instructors' efforts in implementing inclusive practices in their engineering classrooms (see [119] for more detail). The recruitment email detailed the full project as well as the participant parameters, most importantly that they would be a participant for at least three semesters. Across the three partner institutions, the email recruitment strategy and all research activities were approved by Institutional Review Boards (Pitt and Mines #STUDY20050402 and ASU #14693). Some institutions were able to leverage pre-semester or early semester events focused on faculty and instructors to recruit participants as well.

4.4.2.2 Faculty Survey

4.4.2.2.1 Survey Development

The faculty survey was developed in the first year of the project, and participating faculty were also given the opportunity to engage in structured interviews. The faculty surveys collected feedback on strategy implementation and the ILCs. The final two questions on the survey asked participants to reflect on their experiences in their ILC and to list suggestions or changes to make the ILC more impactful for them. All of the faculty survey questions can be seen in full in Appendix B Table 19, however the survey results discussed in this paper focus on the last two questions that ask participants for feedback about their ILC experience. The faculty survey was developed and launched through email in November 2021 using *Qualtrics Research Software* [89] and was administered to participating faculty and instructors in the Fall 2021, Spring 2022, Fall 2022, Spring 2023, and Fall 2023 semesters. As the project continued, we found that sending the faculty survey to participating faculty through each of the ILC facilitators in early November worked well and incorporated at least two reminder emails in December and early January to glean as many faculty responses as possible for each surveyed semester.

4.4.2.2.2 Overview of Survey Participants

The data period for this chapter included, Fall 2021, Spring 2022, Fall 2022, and Spring 2023 semesters. The faculty survey was distributed to about 35 faculty across all three institutions each semester. In total, there were 28 faculty survey responses from the duration of the project from all three institutions, which resulted in a 69% response rate. However, most of these faculty responded to the survey every semester so each survey response did not necessarily correspond to an individual faculty participant. However, for our analysis, we treated each of the responses as an individual respondent. Due to incomplete surveys, the total number of faculty survey respondents used in the analysis was twenty-four (n=24). Further details on the response rate by ILC archetype for each semester can be seen in full in Appendix B Table 20. The number of faculty respondents varied across semesters with the Fall 2022 semester having the most participants across the institutions (n=10). To date, both the department and institution-wide ILCs have had the most faculty participation in the survey. Majority of the faculty and instructor participants from the three archetypes were engineering instructors and 52% of the courses they taught during the duration of this study were designated Civil Engineering courses (n=14). 37% of their courses were classes often included in the broader engineering curriculum such as 'Senior Design' and 'Engineering Design and Society' and the remaining 11% of courses were other STEM-focused courses not within engineering (n=3).

4.4.2.2.3 Organization of Faculty Survey Responses

To analyze the survey results asking participants about their experience in the ILCs at each partner institution, they were first organized by semester and then in the aggregate to get an overview of faculty participants' experiences. The survey responses were also organized by ILC archetype for analysis to highlight similarities or differences between the archetypes.

4.4.2.2.4 Survey Analysis Methods

Following the organization of the faculty survey responses, the open-ended faculty survey results were analyzed by ILC archetype to see if there were distinct patterns in the faculty's experiences across the different ILC archetypes. The first and second authors, individually and collaboratively, utilized descriptive and *in vivo* coding to develop themes from the participants' responses [124]. Following this, the authors grouped the responses by theme and ILC archetype to explore any trends among the archetypes.

4.4.2.3 Faculty and Instructor Interviews

4.4.2.3.1 Faculty Interviews

In addition to the faculty survey, some faculty volunteered to participate in structured interviews with the research team aiming to provide feedback on their ILC experience and to identify areas where the ILCs, and LCs in general, can improve to further support faculty in implementing inclusive evidence-based practices in their classrooms. Interview participants were recruited by the research team members at each respective institution through email. Interviews were held during the Fall 2022, Spring 2022, and Fall 2023 semesters in person when possible or virtually via Zoom. The interview protocol was designed to elucidate faculty experiences with participating in their local ILCs and gather feedback on the ILC implementation. Specifically, some interview questions prompted participants to describe the main goal of their ILC, the gains or benefits the ILC has provided them, and what they have learned about LCs that they want to share with others interested in running their LCs. Table 6 details the questions in the faculty interview protocol.

Table 6. Faculty Interview Questions

Question
1. Since we started the IUSE project, how were the members of your LC identified and recruited?
2. Describe the main goal or focus of your LC.
3. How often has your LC met? Has this changed over the course of the study?
4. What format (what kind of activities, in-person or online) has your LC used? Has this changed over the course of the study?
5. What gains or benefits has your LC provided to the participants, if at all? What evidence supports your answer?
6. What barriers have you noticed regarding attendance or engagement in your LC? What evidence supports your answer?
7. What have you learned about LCs that you'd like to share with anyone who is interested in running their own LC?

We interviewed nine total faculty members, with two participants from the department-wide ILC, three from the school-wide ILC, and four from the institution-wide ILC (n=9). One interview from the institution-wide ILC was held with two participants at the same time. We recorded each interview with the consent of the participants, and the time ranged from 10.5 to 24 minutes long with an average length of 15 minutes. Interviews were machine transcribed by Zoom, the web meeting platform we utilized to conduct the interviews and reviewed for accuracy. Participants were assigned pseudonyms, and we reported demographic information in the aggregate to protect their confidentiality. For ease of comprehension, we assigned pseudonyms starting with 'D' for department-wide ILC participants, 'S' for school-wide ILC participants, and 'I' for institution-wide ILC participants. For the institution-wide ILC, our participants were Ian, Isla, and Isabella and Isaac. The school-wide participants were Sabrina, Sara and Simon and the department-wide participants were Denise and Dani.

Participants also represented a range of LC roles and discipline-based backgrounds. Three of the faculty participants were also facilitators for their ILC, which included responsibilities such as planning and administering their LC activities, allocating or providing funding for the LC, and communicating information to the members of the LC. Two of the ILC facilitators were also co-authors of this study due to the nature of this study's institutional partnerships. However, those co-authors were not involved in administering the surveys and interviews nor their subsequent analysis. Further, most participants were from an engineering background, but three participants represented other STEM disciplines or relevant education disciplines. Lastly, participants represented a range of academic titles with representation from instructor/lecturers, assistant, associate, and full professors, as well as administrative roles such as librarians and leaders of university centers. Participants also represented a range of identity demographics, however, because we disclosed the school names, we did not report this information to protect the identity of the participants.

4.4.2.3.2 Faculty Interview Coding Scheme

Given the three different ILC archetypes in this study, department-, school-, and institution-wide, the interview transcripts were qualitatively analyzed by treating each archetype as an individual case study. Following transcription, we completed an iterative process of coding interviews individually and collaboratively to develop convergent codes using Microsoft Excel. The first cycle coding consisted of descriptive and in vivo coding to develop familiarization with common attributes and language used to describe participants' experiences in the ILCs [124]. All of the interview transcripts were coded using these methods and following this initial review, we developed preliminary codes which illuminated themes across the interviews such as ILC modality, trust among members, and leadership. However, considering we wanted to utilize the interviews to identify similarities and differences in the ILCs across the three archetypes, a more efficient way of coding the interviews for the second cycle of coding was determined.

The second cycle of coding began with deciding on which questions they wanted to compare the faculty's experiences across the archetypes and determined those would be: the goal of the ILC, meeting structure and modality, gains and benefits from participation, barriers to participation, and lessons learned. This decision allowed for a more granular view during the second cycle while looking for similarities, as well as differences, within each archetype. For example, when exploring the meeting structure and modality for each archetype, they noted when the interviewee’s responses aligned, but also indicated where they did not respond similarly. From this second cycle of coding, we developed a table that comparatively showed each archetype and the associated responses for each of the five questions. However, this second cycle did not create a codebook so we employed a third cycle of coding to do so.

In this third coding cycle, we created an Excel worksheet with the headers: Question number, Question description, Archetype, Respondent, Member type, Discipline, Theme, Coder, Interrater Reliability (IRR), Descriptive code, and Text/quote. This third cycle was characterized individually by each coder by pulling the keywords and phrases from the first cycle of coding into the sheet and developing a descriptive code that summarizes the interviewees response using actions and gerunds (i.e., action words ending in ‘–ing’) to describe an observable action. After coding the interviews, in order to show IRR, we reviewed one another’s coding as well. During this cycle, we filled out each column according to their headers except the ‘Theme’ category. We developed the interview themes together as a final step in the coding analysis process.

4.5 Results and Discussion

This section details key findings from using the swim lane method to visualize each ILC archetype's development, the faculty survey, and the structured faculty interviews. The key similarities and differences in ILC development across the three archetypes are discussed first. This is followed by the faculty survey results including the faculty participants' demographics up to the Spring 2023 semester and a discussion of the open-ended survey results in aggregate and by ILC archetype. Finally, the results from the analysis of the structured faculty interviews are visualized and discussed.

4.5.1 Archetypal ILC Development Key Similarities and Differences from Swim Lane Method

The ILCs convened for the IUSE-PIPE project, as mentioned previously, were safe, supportive learning environments for the participating faculty to share about their practice implementation, lessons learned, and recommendations for one another. Though the ILCs at each institution leveraged different existing structures and existed at various levels of the institution (department-, school-, and institution-wide), they largely focused on the same content, implementing the inclusive engineering practices menu in their classrooms. Some of the ILCs leveraged different learning tools such as inclusive-focused workshops or using a book to accompany practice implementation and provide further support and resources to their faculty participants (department-wide). In order to elucidate further similarities and differences among the three ILC archetypes, we utilized the swim lane method to visually map the development of each ILC archetype. A general swim lane diagram, which depicts similarities among all of the archetypes, can be seen in Figure 10 below. The swim lane diagrams for all three archetypes can be seen in Appendix B Figure 20-Figure 22 due to their large size. In addition to the swim lane method providing a visual map of how the research team, ILC facilitators, and faculty participants actions affected each other throughout the project, they also clearly showed key developmental similarities and differences between the three archetypes.

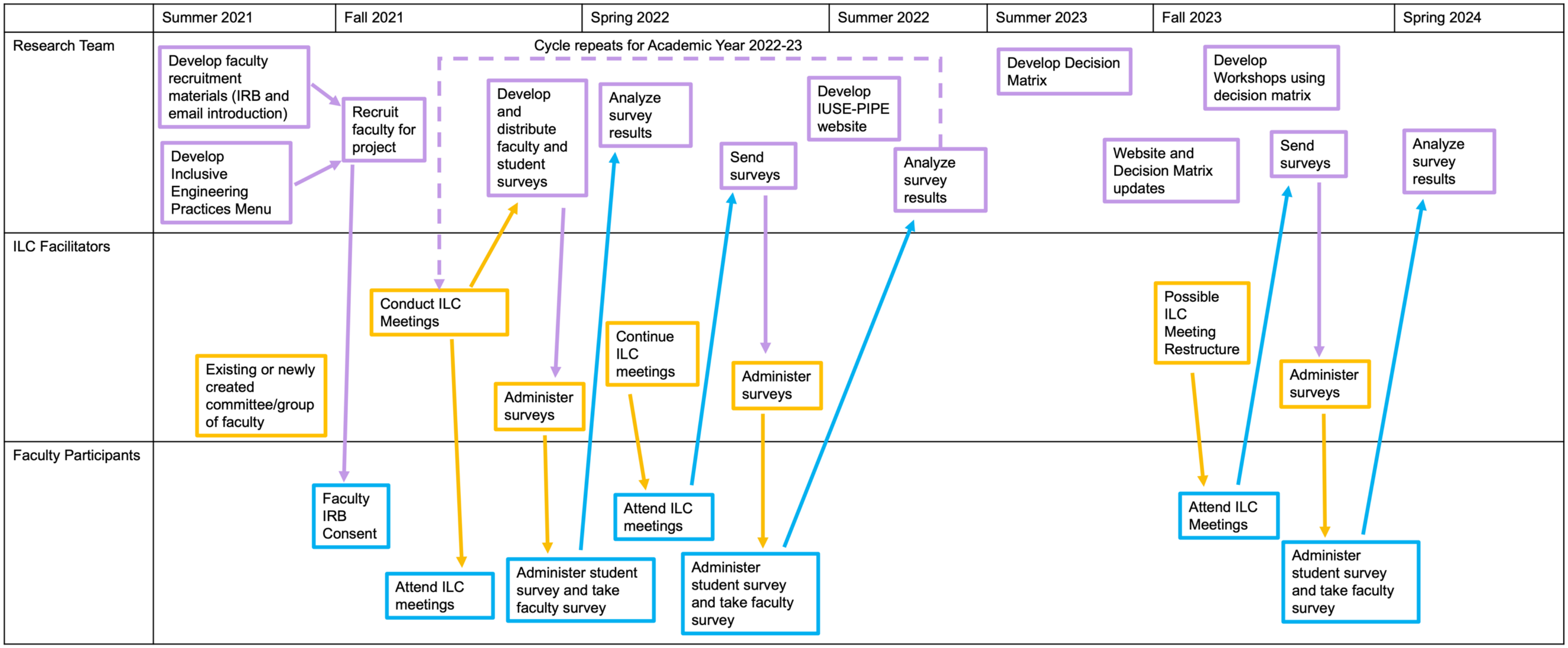

Figure 10. General swim lane diagram showing similarities between the development of all three ILC archetypes

The key similarities highlighted by the swim lane method across the three archetypes included how often the ILC meeting structures changed over the course of the project as well as how the general flow of ILC activities at each archetype remained similar throughout the project. Each ILC archetype experienced at least two different meeting structures over the course of the study. In the IUSE-PIPE project, we define meeting structure as the format and flow of each ILC meeting (e.g. meeting agenda, tools used during ILC meetings). Though the cause of the meeting re-structures over the course of the study ranged from incorporating faculty participant feedback at the department-level or partnering with institutional opportunities at the institution-level, the ILCs all experienced a change in meeting structure which may have impacted the faculty experience overall.

In addition, the general flow of ILC activities remained similar throughout the study period for all three archetypes. This general flow included hosting and attending ILC meetings, administering and taking faculty and student surveys, and analyzing the survey results. There were also similarities in the general flow among some of the archetypes rather than all of them. For example, both the department- and school-wide ILC meetings existed mostly as an agenda item of a larger inclusive-focused meeting, but the institution-level ILC meetings were developed for this study. However, this changed for both the department- and institution-wide archetypes in the Summer 2023 and Summer 2022 semesters, respectively. The department-wide ILC shifted to having workshops both pre- and during the semester in lieu of formal ILC meetings for the 2023-24 school year. Similarly, in the Summer 2022 semester, the institution-wide archetype also hosted workshops in lieu of formal meetings but was due to a new partnership with an institution-wide fellowship program. The institution-wide archetype restructured again for the 2023-24 school year where they partnered with an institution-wide LC for new faculty and continued leveraging institutional opportunities that had similar focuses as compared to the initial meetings.

In addition to the swim lane diagrams highlighting key similarities among the development of the ILC archetypes, they also explicitly showed some key differences between the archetypes including that the school-wide ILC operated for one semester shorter than the other ILCs and how frequently the department-wide ILC changed its meeting structure over the course of the study. The leaders of the center that the school-wide ILC archetype was associated with were both on sabbatical for the 2021-22 academic year, so the school-wide ILC did not officially begin until the Fall 2022 semester. This observation highlights that there may be other opportunities or conflicts that can arise that impact the development of an LC. However, since the school-wide ILC in this study was partnered with an existing center on the campus, their recruitment process was fairly quick and were able to adapt to the general flow of the ILCs rapidly. However, it is still important to highlight this because the delay still impacted their ILC development and results for this project compared to the department and institution-wide ILC archetypes.

The swim lane diagrams also highlighted that the department-wide ILC experienced a meeting restructure every semester between the Fall 2022 and Fall 2023 semesters (three total restructures). These changes were largely due to incorporating participant faculty into how the meetings were constructed throughout the study in addition to the ILC being a part of a larger inclusive-focused committee that had other goals they wanted to accomplish. Though the members may have benefitted from seeing their feedback in action through the ILC changing, these changes may have also negatively impacted the members by promoting confusion and disorganization because of the constant change over the course of three semesters. Compared to the school- and institution-wide ILC archetypes, who also experienced restructures during the study but on a yearly basis, these quick changes at the department level also shows the fluidity of leading a LC from a bottom-up approach led by faculty instead of from a higher-level like at the school or institution level.

4.5.2 Faculty Survey Results

4.5.2.1 Positive ILC Experiences with Recommendation on Additional Discussion and Reflection

4.5.2.1.1 (Q1) Overall Positive Faculty Experience in LCs

Seventeen ILC participants responded to open-ended question one, which prompted respondents to describe their overall experience. Responses were largely from participants from the institution- and department-wide ILCs, with only one response received from the school-wide ILC. Seven of the responses specified faculty experiences specifically about the ILC, while the remaining eight respondents attended to their experiences with transferring strategies learned in the ILC to their classroom. Almost all descriptions from the faculty were positive, with faculty pointing to feeling happy about their participation, gratitude toward what they learned within a supportive community, and feelings of encouragement for trying new things in their classrooms.

Classroom-focused responses described experiences with trying strategies learned within the ILC in their courses. While participants reported positive and often rewarding experiences in their classrooms, some respondents discussed how certain strategies required more forethought and planning to incorporate. Participants from the department-wide ILC especially noted challenges with adapting inclusion strategies within their technical courses: *"Some classes are easier than others to make connections to diversity of culture, voices, and perspectives"*.

Respondents from the institution-wide ILC described a process of developing alongside their students through reflection on inclusive teaching strategies. Highlighting the nuances of incorporating such strategies, one participant described how they and their students *"are still trying to understand and embrace what the idea of 'inclusiveness' really means, particularly in a classroom environment".* Several of these participants signified the impact of building connections with others, including students, by sharing *"strategies and struggles",* with participation leading to confidence in not just trying strategies in class but also negotiating and justifying their use with students. While participants were generally happy with their respective ILC experiences, they also offered feedback for improving them via open-ended question two.

4.5.2.1.2 (Q2) Suggestions or Changes to Improve ILCs

The second open-ended question on the faculty survey asked participants to provide suggestions or changes to make the ILCs more impactful. Across the three ILC archetypes, the responses could be grouped under three major focuses: class applications, students, and LC changes (n=15). Four of the faculty responses focused on specific strategies or changes they wanted to apply to their course in future semesters. One participant noted they wanted '*to incorporate more one-on-one or small group interactions with their students early during the course [to] establish a personal, humanistic aspect of ourselves and each other so we can be sensitive to topics discussed [during] the semester'.* Most of these responses also referenced using inclusive practices from this study's inclusive engineering practices menu showing faculty's willingness to continue implementing inclusive strategies in their courses [119].

The four student-focused faculty responses, all from the department-wide ILC archetype, expressed interest in gaining feedback from their students on their experiences in the classroom and '*wonder if more direct and proactive student engagement would be useful [by] asking students* *"out of this menu of options, which would be most impactful to you?"'.* These results showed us that while faculty are employing inclusive practices in their classrooms, they also want to know whether they are making a positive impact on the student experience and how they could continue to improve for their students. The practices on the inclusive engineering practices menu were sourced from both peer-reviewed literature and inclusive-focused resources that were broadly applicable to all classroom types and have been shown to successfully improve student belonging. For example, some of these practices were from the Universal Design for Learning guidelines, as developed by CAST, which are a widely referenced and used educational framework which aims to intentionally design learning experiences to eliminate barriers and make learning more inclusive [78]. On the other hand, some of the literature sources for the menu, such as from Cooper et al. and Bohannon et al. sources, shared inclusive practices as a part of their conclusions or recommendations from their study of different aspects of inclusivity in the classroom including gender identity and race [125], [126]. Though these sources were previously assessed in the classroom environment, the results from the student and faculty participants provided evidence for the implementation of inclusive practices in engineering classrooms and encouraged further exploration of this positive impact.

The seven remaining faculty responses to this question focused solely on improvements that could make the ILC experience more impactful for them. The archetypal split of these responses was two from the department-, one from the school-, and four from the institution-wide archetypes. A similarity among all three archetypes included incorporating more activities into the ILC meetings while some of the department- and institution-wide ILC members mentioned increasing the number of members as well as wanting more diversity in the membership of their ILCs. An institution-wide participant mentioned '*they would love if there were a few more* *participants so we could get a larger pool of experiences [and want to] see more male instructors [participating]'*. Other responses, though not shared across the archetypes, included changing the format of the ILC meetings, having time conflicts that limited participation, and spending more time '*reflecting on lessons learned'* and sharing during the meetings. One of the participants specifically wrote about trying a different format for the ILCs: *'I wonder if this may have been more effective as two full-day workshops [because] it often felt like just as the discussion was getting really good, the time was up… there just wasn't enough time in our brief meetings'*.

4.5.3 Faculty Interview Results

From the faculty interviews, we found three thematic categories related to ILC development that converged across the archetypes: 1) Establishing and defining ILCs, 2) ILC logistics and operations, 3) Building a foundation of trust. Within each category, we found affordances and barriers that were typical across the three archetypes as well as some emergent differences that we discuss in the following sections (Table 7).

Table 7. Affordances and barriers among the interview thematic categories.

Theme	Affordances	Barriers
ILC Formation	• Leveraging existing structures and member networks • ILCs can target multiple objectives	• Bounding the ILC • Need for clear value proposition
Meeting logistics and ILC operation	• Hybrid and online modalities support attendance • Flexibility leading to welcoming environment	• Balancing 'Zoom fatigue' with physical meeting challenges (e.g., transportation on large campus (School archetype) • Flexibility leading to diminished commitment
Trusting community	• LC supports learning from different perspectives • LC fosters trusting space for difficult conversations	• Preexisting biases about others diminishes connections • Small group size limits diverse voices and experiences

4.5.3.1 Convergent Affordances and Barriers for ILCs

4.5.3.1.1 Establishing and Defining ILCs

All three ILCs leveraged existing structures, including existing DEI committees, research initiatives, and a STEM equity faculty fellowship program (Table 7). These structures provided access to cohorts of faculty interested in inclusive STEM teaching as well as social networks to identify efficient pathways to establishing their community and recruiting potential members. Doing so also meant that the ILCs could ‘piggyback’ from existing meetings, leveraging time and scheduling issues: *“The other thing that I learned is because everyone has so many meetings, it seems like a good idea to pair it up with it another initiative or another committee, and I still think that's the way to do it…”*. While participants did not perceive this approach for ILC formation negatively, some noted that it was difficult to discern where their ILC existed relative to other initiatives, leading to some confusion among members. For example, in describing ILC activities and modality over time, Simon explained, *“…again, it's like, when, where [the research initiative] ends and this learning community starts is a little vague for me.”*

The lack of clarity in the structure of the ILCs may have also driven some confusion among members regarding their respective ILC objectives. Many participants perceived their ILCs to have multiple objectives and goals, which may have been a result of aligning ILCs with the existing programs and networks. Many participants plainly noted that their ILCs aimed to support faculty endeavors to teach more inclusively. Other common goals reported across participants included sharing teaching strategies, learning from other members, and building community around common interests. While the overarching goals of integrating inclusive teaching strategies in the classroom were similar across archetypes, how the ILCs approached meeting that goal diverged. Although interviews with participants from the institution-wide ILC did not elicit information about formation and recruitment specifically, the establishment of the institution-wide ILC similarly aligned with an existing industry-funded faculty program housed at the institution. In the department-wide ILC, both participants noted the obligations to meet research grant activities through the formation and operation of the ILC. As a research-oriented group, the school-wide ILC centered its approach around sharing and disseminating research related to inclusive teaching practices.

This uncertainty was observed in other non-facilitating members, who felt that describing the objectives of the ILC was *'fuzzy'*. Thus, despite participants having awareness of ILC goals, several noted that there was a lack of clarity around what the ILCs were really offering members. For example, one noted feeling frustrated around progress in the ILC: *"...my main takeaway is that it's difficult, but it's worth doing in the sense that there has been a frustration of like, are we doing what we want to do? Are we getting things accomplished? And, and there have been periods of, you know, more and less activity."* Similarly, two described that *"a product is helpful like, even if you're doing sort of like a, a community of practice, or whatever, like having a, a thing people are working towards can help keep them engaged."* An ILC facilitator, described how intentional crafting of a *'value proposition'* mid-way through the evolution of the school-wide ILC helped clarify expectations and growth beyond *"putting [the ILC] on your CV."*

4.5.3.1.2 ILC Logistics and Operations

Logistics and modality were common attributes of ILC operations that influenced member participation as well as the activities chosen (Table 7). The department-wide ILC met exclusively online, the school-wide ILC held hybrid meetings (providing both virtual and in person attendance options), and the institution-wide ILC held in person meetings. Additional communications occurred via email for all three archetypes. For the department- and school-wide ILCs, the online modality lent flexibility to members. Concurrently, some participants noted that online modalities reduced engagement, with some members feeling *"tired of zoom meetings and participating in a zoom environment" (Denise).* Additionally, Dani described how the online modality may have encouraged honest discussions by reducing 'pressure' on individuals during discussions of sensitive issues in the ILC: *"If it was more of an in-person activity…I think that that would have made it more difficult in some ways, because there's more pressure when you see a person in front of you. So I think there would have been maybe more reluctance to be as honest…"*

Although modality provided flexibility, the ILCs all struggled from lacking accountability structures resulting in varied levels of participation among members. One of the most commonly cited barriers to ILC engagement was grappling with competing priorities among members, relying on intrinsic incentives for participating, and difficulty maintaining momentum. "*I think it makes it a little funny, of maybe people aren't quite sure how much it matters if they do go, or they don't go. Um, so. But at the same time I think the flexibility has been really great. Because I think if it was super regimented: Here's your like assignment. Here's this thing. Here's what that thing. I don't think I'd feel comfortable committing to doing it as much, right. So I think it's that tricky balance".*

Along with logistical challenges related to scheduling ILC meetings, facilitators and members had to navigate other priorities related to their work in academia. One faculty member described the tension between wanting to dedicate time to the ILC and having to make progress toward tenure: "*I want to do this. I want to have the community. I want to have the people. I want to improve my teaching. I want to think about teaching. I want to do all of those things. But at the same time I'm pre-tenure (laughs). So like I'm trying to like balance things that I care about that don't get recognized, or things that I care about, that do get recognized."* Their latter point was a salient barrier related to lacking recognition or awards for participating in the ILCs. Similarly, many participants described challenges with navigating varied levels of participation among faculty.

4.5.3.1.3 Building Trust Among ILC Members

Several participants found that their ILCs provided a supportive and welcoming space for discussing difficult topics related to diversity, equity, and inclusion, with a few interviewees suggesting that creating such a community is a key foundation to developing a successful ILC (Table 7). As LCs dedicated to encouraging the integration of inclusive teaching practices, learning from others was a critical feature of the ILC development. But unlike broader educational practices, many inclusive teaching strategies require a thoughtful approach and often deep reflection on the part of instructors as well as students. Several participants described how ILC tools and activities such as icebreakers, book clubs, research dissemination, and structured discussions catalyzed difficult conversations and empowered members to be open with one another. Beyond providing members with strategies, these tools helped to create a focal point for supporting conversations. For example, one person described a rotating discussion approach that gave voice to more introverted members: "*And then you just start writing your reactions to it, without talking. And then you rotate. And then at the end, you have a discussion. So I mean it's, when you go through it, you realize it's really not that daunting. And it gets a lot of the introverts who otherwise would not participate" (Ian).*

The flexibility offered by the structure and operation of ILCs also played a role in strengthening the groups' communities. Several participants, particularly facilitators, described how ILCs need to *"evolve over time like, and you need to be able to evolve with them" (Denise)* to meet member and group needs. Similarly, Sabrina described how *"these sorts of learning communities… tend to* *ebb and flow as purposes and needs change".* These changes were evident in adaptations negotiated between ILC facilitators and members such as using new tools (e.g., starting a book club) or setting ground rules in response to a contentious interaction: *"Well, set ground rules immediately for your community like what are the expectations? And I think for us it was really successful. Once we started having people present and get feedback, and I think now that we set those ground rules for feedback"* (Sabrina). In the institutional context, Ian's offer of support and coaching on an as-needed basis meant that members of the ILC could reach out to him with specific questions, feedback, and needs as they arose. Through creating an agile ILC atmosphere, facilitators were able to foster comfortable and democratic environments for growth and development rather than prescriptive or rigid expectations.

4.5.3.2 Archetypal Affordances and Barriers (Table 7)

4.5.3.2.1 Department-wide ILC

The department-wide ILC was weaved into a department-wide DEI committee formed in response to national events involving police violence against Black people in the United States. However, over time, Denise noted that the ILC group momentum waned: *"It kind of the you know, the height [of] what happened with the murder of George Floyd, and I think as a society we were so, and we should still be, but I mean we were so focused on, what can we do?...Um, but I think part of that intensity has waned that intensity has kind of drawn off."* This ILC also incorporated students and staff in the department, and both interview participants noted that involving other members of the wider departmental community helped to bridge gaps: *"...it's really nice to have some engagement, where you remove the hierarchical structure of academia, where students and faculty are given the same position to talk, and the same thing with staff and faculty and students—*

because I think that gets in the way of a lot of clear communication sometimes, especially when students are intimidated by that power structure. So I think that's one of the more helpful aspects of the community" (Dani). Removing the hierarchy described by Dani may have contributed to a cohesive group identity that strengthened their community bonds. Specifically, Denise described a sense of empowerment and pride among members: *"But I think that, like in [the College], some departments have made more progress than others in diversity, equity, and inclusion. And I, I think, I think people in [our department] feel good that we're, that we're a little bit ahead of the curve and—in having this committee. And that it's an avenue where people that are really concerned about this subject can have a voice."*

4.5.3.2.2 School-wide ILC

The school-wide ILC was particularly focused on peer-to-peer research sharing. This focus was selected by design early on by the facilitator who established the ILC out of an existing initiative focused on research in inclusive STEM education. One participant, Simon, explained how coalescing around research brought people together: *"And I think that's kind of what unites people in the learning community, although very diverse people like all over different campuses and programs" (Simon)*. Research dissemination was further benefited by the discipline-based variation among the members. This ILC included faculty members across all STEM disciplines, which interviewees described as being beneficial in terms of learning how other fields implement inclusive practices. However, Sabrina described tradeoffs between keeping the group size manageable to *"make decisions as a body and, and talk about research directions in depth…"* and limited transferability across a wide range of disciplines and expertise. She continued, "*Now you have, like two people from any given department, and so sometimes things are not as transferable as one might hope."*

One of the most prevalent barriers for the school-wide ILC was related to challenges navigating a geographically large campus. All three participants from this ILC archetype described the hurdles faced to attend in-person meetings (i.e., navigating traffic, spending time on transportation, and paying for parking). Often, despite the desire to attend in person, the burden of the commute alone could discourage in-person attendance: *"So I would say, that's one of the main barriers is that if you want to have people meet in person, but you want to include [the university] broadly, there are those transportation barriers. And zoom is great, but it's not the same to be in person rather than on a screen" (Simon).*

4.5.3.2.3 Institution-wide ILC

While faculty ILC members at the institution-wide ILC were free to pursue projects of interest related to inclusive teaching, the role of the ILC reflected a somewhat top-down approach. In this case, the ILC facilitator held expertise in inclusive teaching, rather than engineering, and aimed to introduce specific training and tools to the members of the ILC in ways that would benefit their specific context. As a result, the engagement of members largely hinged on their interest in being coached: "*So, so it just kind of depends on my colleague, and how little or much they want me to be engaged, but my role is to be your support" (Ian)*. Unlike the other two ILC archetypes, funding for faculty participation in the institution-wide ILC may have played a role in member engagement. For one participant, Isla, the main benefit to participating was receiving project funding suggesting that the extrinsic reward may have been a key driver for her participation. Similarly, Isabelle and Isla noted that the program "*came with funding what, you know brought in more folks, I think more interest in it. It helped improve engagement."* Notably, Sabrina explained that a similarly funded program at her institution (school-wide ILC) saw a reduction in engagement at the end of the program: *"So most faculty that were interested in inclusive teaching went through* *that as a paid fellow. To my knowledge, very few are still participating in the community of practice once they're funded period was over."* Among the three archetypes, the institution-wide ILC had the lowest frequency of meetings, which may have been a result of the emphasis on individual projects that were complemented with occasional workshops and feedback from the ILC as needed.

4.6 Key Findings

Three key findings are highlighted from the development of the ILCs: the importance of considering institutional context, catalyzing trust and vulnerability, and maintaining LC engagement.

4.6.1 Key Finding 1: Institutional context must be considered when developing and planning LCs.

One of the major key findings from this chapter was that when developing a FLC, the context of the institution needs to be considered. The ILCs were developed with the same focus and goals; however, they differed in archetype (e.g. department, school, or institution-wide), their meeting structure and flow, and how they leveraged existing people or groups which were all context-specific. The department-wide ILC was a part of an existing diversity and inclusion committee voluntarily led by faculty and included faculty, staff, and student members at both the graduate and undergraduate levels. Since the membership of the committee was so broad, the ILC was able to use one of the facilitator's previous experiences in faculty development to help manage the meetings. However, this was not a recognized position, but rather a voluntary one that aligned with their strengths. On the other hand, the school-wide ILC existed as a part of an inclusive STEM education research center and was able to leverage people in previously recognized positions within the center to help with the logistical side of the ILC such as meeting planning and communication. This allowed for all of the ILC's faculty members to fully participate in the meetings instead of having dual roles as a leader and a member of the community. The institution-wide ILC, though similar to the school-wide ILC in leveraging an institutional opportunity, differed as it developed in tandem to a teaching grant awarded to the institution as opposed to an established research center. The teaching grant had the similar goal of providing both teaching and research faculty with inclusive-focused practices for their classrooms, but the grant also had other goals that may have competed with the ILC goals and thus impacted the ILC meetings and participant experience. All the ILCs leveraged existing institutional opportunities, however, due to context-specific differences, they all impacted the development of each ILC archetype. This finding highlights the importance of considering an institution's context when developing an LC but also when considering the sustainability of the community past the confines of a study or project. Ian, the facilitator of the institution-wide ILC, mentioned in their interview that it's important *'to understand there is no silver bullet [in inclusion and diversity work]. You have to take all of these ideas and tools and then decide what makes sense for your particular institutional context'*.

4.6.2 Key Finding 2: Catalyzing trust and vulnerability are required for inclusion-focused LCs.

In addition to considering context, one finding was that it was important to develop communities that fostered trust and provided members the space to be vulnerable with one another, especially considering the topic of inclusion and belonging. A key element to successful ILCs is providing a safe, trusting space that encourages sharing and co-collaboration among members [92], [98], [103], [112], [127]. However, considering the focus of the ILCs, this was even more essential as participants may have confronted their cultural insensitivities and lack of training in inclusive education [112]. One of the ways the ILC facilitators helped catalyze trust and vulnerability was through their leadership style. As a facilitator, they had the responsibility of creating a trusting, brave space for the members but also needed to create a space that allowed them to continue to lead and be vulnerable themselves during discussions. In their interview, the department-wide facilitator Denise, mentioned intentionally having a *'distributive leadership structure'* that incorporated participant feedback into the ILC as it evolved in order to create a space that the community felt they were crafting together rather than it being solely dictated by the facilitator. Simon, one of the school-wide ILC members, mentioned *the 'importance of having an involved leader who can make the decisions and set the stage… but who also listens and is willing to be steered as well'*. It was essential for the facilitators to consider what leadership style they used for their ILC as it could directly impact how much the members trusted one another to be vulnerable and feel safe in this community.

In addition to how participants could feel during the ILC meetings, they may have also entered the ILCs with biases, defensiveness, and anxiety about the topics being discussed. To help encourage difficult discussions in the communities, the facilitators utilized different tools such as icebreakers, research discussions, and books. For example, Dani and Sabrina, a member and facilitator from the department and school-wide ILCs, respectively, mentioned the use of a book in their community which helped encourage these discussions. Dani, in their interview, felt that their ILC had better discussions in response to what they were reading which *'helped to open some avenues of conversation that wouldn't have been approached otherwise'*. Since they were *'speaking to a text rather than [only] on personal experience, it made it a little bit safer to talk about topics that would otherwise be difficult to broach'*. In addition to using different tools to encourage discussion, it was also essential to incorporate inclusive practices into the communities as the ILCs developed. One of the ILCs, in particular, experienced members harshly criticizing others' contributions to the space and necessitated the addition and enforcement of "ground rules" for their community. The research team utilized inclusive practices when initially developing the ILCs, however, as the communities continued to grow and progress, we learned how important it was to reinforce and highlight those practices within the ILCs.

4.6.3 Key Finding 3: Sustaining active engagement from ILC members can be difficult given institutional opportunities and faculty demands.

The third key finding was there may be challenges when trying to maintain active engagement from ILC members over a period of time. Two of the ILCs, the school and institution-wide, were able to incentivize their members through research center affiliation and a stipend from the teaching grant, respectively. But, depending on the institutional context, the opportunity to provide individual participant incentives may not be possible like in the department-wide ILC. However, when developing ILCs, taking the time to develop a value proposition could also help keep members actively engaged. Sabrina, the school-wide ILC facilitator, talked in their interview about *‘crafting the value proposition’* and *‘providing clarity’* on the ILC’s purpose and membership expectations for members to see how they would benefit from the ILC. Thoughtful planning from the early stages of developing an LC can lead to consistent and sustainable engagement and effort from members and could also help in providing flexibility as the community develops. However, if the value, goals, and mission of the LC are not as clearly defined, this could lead to confusion and varying participation from members.

ILC meeting modality and time constraints also contributed as major barriers to participation. The department-wide ILC maintained a virtual modality throughout the study which contributed to *‘waning intensity’* and *‘zoom fatigue’* (Denise and Dani) whereas the school-wide ILC had a hybrid modality that offered members multiple settings to meet in. However, almost all of the faculty who participated in the interviews, regardless of ILC archetype, mentioned how time constraints were a major barrier to their and possibly others’ participation. Members from all three ILC archetypes mentioned how busy their schedules are and the positional demands they have to balance with *‘things they care about which are both recognized and not’* (Sara). The school-wide ILC, due to the layout of their campuses, also experienced engagement barriers due to geographical distance. They had a hybrid meeting model, however, since the campuses operated separately, some members may have had limited engagement due to things out of their control. Ian, the institution-wide ILC facilitator, stated that *‘if we want to keep moving this [inclusion and equity-focused] needle, we’ve got to create more space and time for people to do this work’*. Many different barriers could impact how faculty engage in inclusion-focused work; however it is essential to actively recognize them and develop creative solutions that will provide faculty the opportunity to do so.

4.7 Limitations

This portion of the IUSE-PIPE project presented in this chapter had a few limitations that may have impacted the conclusions drawn. When designing the faculty participant survey, we did not collect information on discipline and demographic-based information from participating faculty. We collected information about the classes and how many students the participants taught, but not specific information on them as individuals. We suggest that future studies on faculty LCs should consider collecting faculty demographics in order to provide further context to results.

The IUSE-PIPE project's data collection occurred over multiple years and semesters and so inherently, some structural changes occurred within the three ILC archetypes. For example, some facilitators and key personnel leading the ILCs took sabbaticals or left their institution for other opportunities which resulted in leadership changes across the archetypes. Additionally, the needs and goals within the ILCs naturally shifted over the course of the project. However, we found that the ILCs balanced shifting priorities by adapting meeting frequency and modality as well as changing the types of activities they did. While these changes may have influenced the data collection and findings, they are also realistic representations of changing personnel and cultural influences that are not unique to these three ILC archetypes.

Finally, because there was only one institution representing each ILC archetype, we caution against generalizing to all institutional contexts. Two of the three institutions involved were predominantly white institutions which also could impact the generalizability of the ILCs. However, our findings may be transferable to other educational contexts where faculty are coalescing around inclusivity. Future research should examine similarities within the archetypes to illuminate potentially generalizable trends more closely. For example, two of the archetype facilitators were trained in technical engineering while one participated in specific, national programming to develop skills in training others in inclusive teaching which may have impacted the participants' experiences in their ILCs. Though these limitations have been highlighted, we agree that the faculty participant results have shown valuable and unique contributions to the engineering education body of research.

4.8 Conclusion

In order to support faculty's implementation of the inclusive engineering practices menu, ILCs were convened at each partner institution. The ILCs were developed from a new or existing group of faculty who expressed interest in learning about and incorporating inclusivity into their engineering classrooms. The ILCs at the participating institutions represented three different archetypes: 1) department-wide, 2) school-wide, and 3) institution-wide. We used both surveys and interviews to examine faculty experiences in their respective ILCs over the course of two years, finding key differences at each context.

The three key findings from this chapter are: 1) Institutional context must be considered when developing and planning FLCs, 2) Catalyzing trust and vulnerability are required for inclusion-focused LCs, and 3) Sustaining active engagement from ILC members can be difficult given institutional opportunities and faculty demands. These findings can help inform improvements to LCs and support faculty in implementing inclusive strategies in their classrooms, which ultimately will create better learning environments for students.

As part of a broader project examining inclusive learning practices, Chapter 5 will build on these findings through analyzing the final semester of student and faculty data, Fall 2023, and sharing final conclusions on the project overall. This study on supporting faculty using inclusive practices in their engineering classrooms through ILCs is a part of the IUSE-PIPE project which will continue assessing the impact of the inclusive engineering practices menu in engineering classrooms at three institutions. Using ILCs to promote the use of the inclusive engineering practices menu for faculty is one piece of a larger instructor toolkit that will encourage instructors to weave inclusivity into the fabric of their class design and teaching and ultimately, shift the culture around inclusivity in engineering classrooms.

5.0 Improving Inclusivity in Undergraduate Engineering Classrooms: Reflections from Three Partner Institutions

This chapter addresses research questions 1 and 2 and provides conclusive findings on the IUSE-PIPE Project. The research presented is a reproduction of an article submitted to the *European Journal of Engineering Education.*

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5.1 Introduction

5.1.1 The Current Diversity, Equity, and Inclusion (DEI) Landscape in Higher Education

Now more than ever, DEI initiatives are facing threats from politics, state educational regulations, and campus culture. The Chronicle of Higher Education has been tracking legislation that would prohibit colleges from participating in DEI-related activities such as prohibiting them from having DEI offices or staff, banning major diversity training, forbidding institutions from using diversity statements in hiring and promotion, and barring colleges from considering race, sex, ethnicity, or national origin in admissions or employment [1], [2], [3], [4], [5]. Since 2023, 85 bills in 28 states have been introduced, 14 have final legislative approval, 13 have become law, and 41 have been tabled, failed to pass, or vetoed which further necessitates the need to make systemic changes that encourage efforts and engage conversations around DEI [1]. A number of these bills define DEI to include Critical Race Theory (CRT), the body of scholarship focused on studying and transforming the relationship among race, racism, and power, anti-racism, implicit bias, health equity, social determinants of health, and other instructional topics including race, sex, and gender identity [2], [3], [5], [6]. Public attacks on CRT and these other topics have helped to lay the groundwork for policies and laws prohibiting teaching and research on them [7]. Historically, the United States education system has firm roots in anti-literacy and anti-Blackness and these bills and laws are legislative legacies of that history [5], [7], [128]. However, literature has also highlighted the importance of DEI in higher education and has provided possible responses and recommendations for institutions combatting these policies.

Milem et al. highlighted that in 2003, the Supreme Court determined the important role diversity in the student body plays in fulfilling the educational mission of higher education and opposing efforts threaten the opportunity for students to benefit from racially and ethnically diverse learning environments [10]. Ong et al. shares a similar sentiment that educational institutions have the obligation and motivation to develop learning environments that benefit students of all backgrounds to alleviate social disparities among groups and generate an increasingly diverse and innovative workforce [23]. Lange et al. urges that responses to the onslaught of anti-DEI bills must include both systemic and deeply human responses and require both campus leaders and administration to address these issues head-on [129]. Some of the responses to anti-DEI legislation by institutions thus far have included mandating faculty commit to DEI as an effective job requirement by incorporating mechanisms for evaluating faculty contributions to DEI (University of Texas, Austin) and coalescing faculty together in adopting a resolution that rejects attempts to the faculty which restrict or dictate university curriculum or pedagogy including matters related to racial and social justice (Jackson State University, Mississippi) [4], [5]. Literature has also shared some recommendations for institutions such as developing statements of action that explicitly name systemic racism and describe plans to cultivate an anti-racist institution where all racially marginalized groups are valued and respected and all members of the institution are responsible for achieving that goal [24]. Opposing regulations and policies require the support of DEI efforts throughout all areas of higher education, particularly at levels where policy is developed. However, there is also a focus on efforts that are led using a bottom-up approach that is discipline-specific.

5.1.2 DEI in Science, Technology, Engineering, and Math (STEM) Disciplines

Over the past two decades, STEM faculty have been working to provide a more inclusive experience for collegiate students, particularly those who are historically marginalized and minoritized [8]. One of the ways faculty have begun to address this is by focusing efforts on improving the classroom environment. However, even when instructors value diversity and inclusivity and have a desire to incorporate that into their courses, Casper et al. found they were unlikely to integrate diversity and inclusivity unless their department and institution were supportive of it [9]. Previous education research has highlighted the need to improve inclusivity in the classroom to encourage student belonging and persistence, however, these efforts also necessitate sustained institutional commitment and support from key stakeholders [10], [11], [12], [13], [14].

In response to this, we conducted a National Science Foundation (NSF) project focused on providing actionable guidance to engineering faculty, and more broadly STEM faculty, aiming to improve inclusivity and belonging in their classrooms, aptly titled the IUSE-PIPE project (NSF Award No. 2021204). As a part of this project, we developed the inclusive engineering practices menu and an accompanying decision matrix. This menu is a list of evidence-based practices organized by suggested timing for implementation based on the traditional collegiate semester (e,g, pre-semester, syllabus), as well as by the Aspire Alliance's Inclusive Professional Framework's core domains [28], [119]. To support participating faculty in implementing these practices, we also convened inclusive learning communities (ILCs) at each of the three partner institutions involved in this study [130]. To assess both faculty experiences with the menu and in the ILCs as well as the experiences of students in participating classrooms, we developed an assessment plan which included surveys and semi-structured interviews and reported on results in our previous publications [119], [130]. Chapter 3 discussed the development of the inclusive engineering practices menu and student survey results for the duration of the IUSE-PIPE project (every Fall and Spring semester from Fall 2021-Fall 2023) [119]. Chapter 4 detailed the development of the ILCs at each partner institution and shared results from both the faculty survey and semi-structured interviews on faculty's experiences in their ILCs [130]. *This chapter, Chapter 5, specifically, reports the key findings and a summary of all the study outcomes from the duration of the study including further analysis on the full student survey data set (Fall 2021-Fall 2023 semesters), faculty implementation results, and lessons learned and recommendations from reflexive interviews with some of the authors*. This chapter also shares a novel conceptual framework that frames this study using a systems-level perspective when considering change around inclusivity in the classroom.

5.2 Our Conceptual Framework

Sustainable change at an institution, particularly regarding DEI, depends on the historical and social context it operates within. Organizational demography theory proposes that the culture, climate, and circumstances within an organization can be affected by the different social groups that exist within and outside of it [51]. We conducted the IUSE-PIPE project across three different institutional contexts: 1) the University of Pittsburgh, a predominantly White institution (PWI) with both an engineering school- and university-wide DEI office, 2) Arizona State University, a Hispanic-serving institution with a university-wide DEI office, and 3) Colorado School of Mines, a PWI STEM-focused institution with a university-wide DEI office. Inclusive Learning Communities (ILCs) within each institution were created and were also context specific. The ILCs existed within different parts of each institution due to different institutional structures and needs (department-, school-, and institution-wide). Throughout the project, we considered the impact that each institution's contextual differences could have on the tools and assessments used during the study. To reflect on the project, we utilized the social reality under investigation (SRUI) mapping method [131] to develop a conceptual framework, which visually depicts our study from a systems-level perspective (Figure 11).

Huff et al. SRUI mapping process connects the investigation of a phenomenon within a larger social system to the social structures, actors, and dynamics surrounding the phenomenon of interest [131]. Huff et al. utilized this method to articulate and further understand how the elements within their study interacted with one another [131]. Other studies have utilized Huff et al. or similar methods focused on socially constructed reality to investigate the social worlds of engineering students related to elements such as expectations, shame, and experiences from the interplay of instruction and other influences from the learning environment [132], [133].

We utilized this method to create a conceptual framework that illustrates the IUSE-PIPE project goals and outcomes within the system of higher education and the interplay of the structures, actors, and dynamics within a university or institution. Following Huff et al. method, we began by answering generative questions including what are the elements of the system and how they connect, what people or groups play a role, and what structures are important within this system [131]. After answering these questions, we constructed a map that centered the actors involved in the study within a university's structure (university administration, faculty, staff, and students) and drew connections between them based on how they physically connected or traditionally interacted with one another (Figure 11). We then considered how each actor could impact one another's experiences and drew connections based on that. For example, university administration traditionally enacts policy that impacts faculty, staff, and student experiences at an institution (Figure 11). Another example of impact is within the context of the project, the participating faculty utilized the inclusive engineering practices menu to implement evidence-based inclusive teaching practices in their classrooms, which impact student classroom experiences with their instructors and peers (Figure 11) [119]. The ILCs convened to support participating faculty and staff and the surveys developed to assess faculty and student experiences also exist within this system at the faculty-staff and faculty-student levels, respectively (Figure 11) [119], [130].

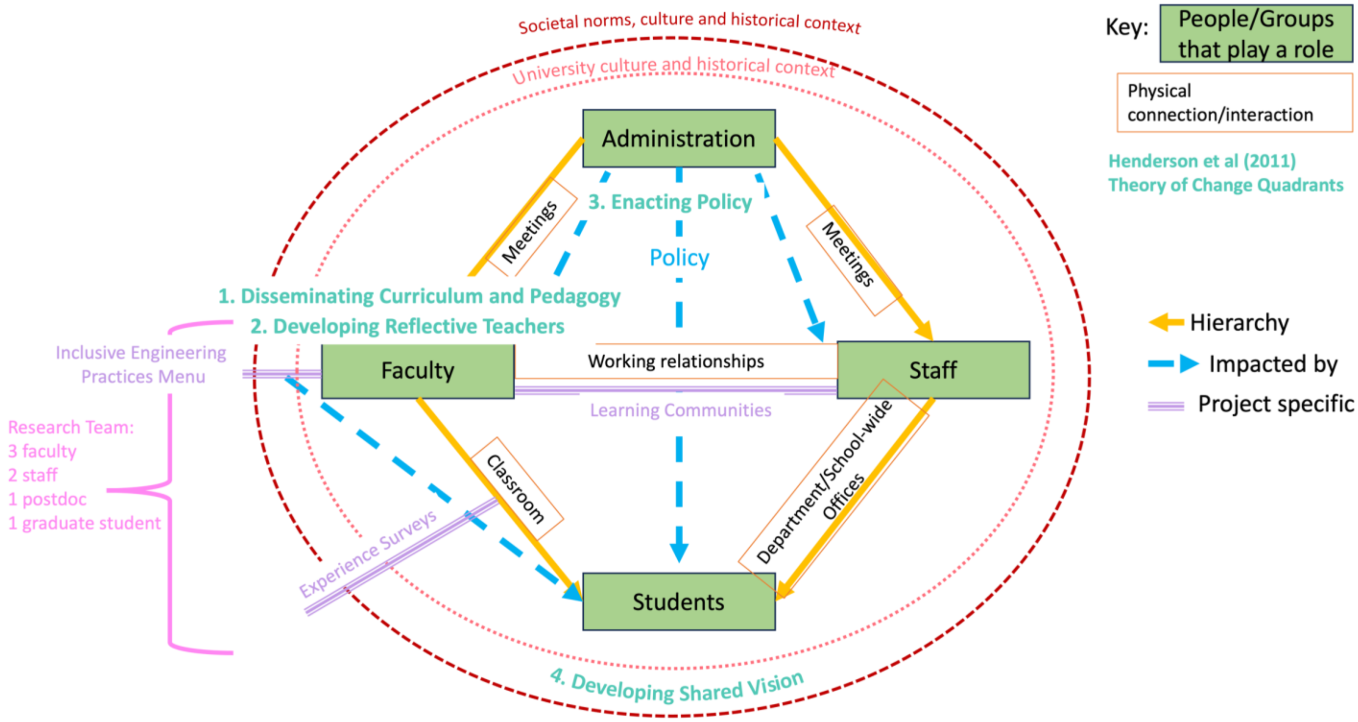

Figure 11. IUSE-PIPE Project conceptual framework using Social Reality Under Investigation mapping method [131].

The IUSE-PIPE project was aligned with Henderson, Beach, and Finkelstein's Theory of Change (TOC) for change strategies in undergraduate STEM disciplines [59]. The TOC is comprised of four quadrants of change strategies include: 1) Disseminating curriculum and pedagogy, 2) Developing reflective teachers, 3) Enacting policy, and 4) Developing a shared vision [59]. The TOC guided our SRUI mapping. Quadrants 1 and 2 applied to faculty, Quadrant 3 to administration, and Quadrant 4 to the entire university community. Towards the end of the mapping process, we considered the social system and historical contexts that a university community exists within and how that impacts all four of the actors from the project (students, faculty, staff, and administration). The smaller concentric circle that surrounds all four of the actors describes the university or institution's culture and historical context that the actors exist within (Figure 11). This circle is also where the fourth quadrant from Henderson et al. TOC exists as a shared vision develops among all stakeholders involved in the university community (Figure 11) [59]. The final piece of the conceptual framework is societal norms, culture, and historical context, which are represented by an outer circle encompassing all of the actors, elements, and university community and their impacts (Figure 11). Though a university's community is largely impacted and operated by the actors within the university culture and historical context, there are also impacts from society as a whole which greatly impact the university community and experiences that all of the actors have.

5.3 Key Finding 1: Employing and Implementing Inclusive Practices

While integrating inclusive teaching practices brings consciousness to the forefront, students from different identity groups can still experience challenges within and outside of the classroom.

5.3.1 The Inclusive Engineering Practices Menu

As described in Chapter 3, we developed the inclusive engineering practices menu during the first year of the project. The menu is a list of evidence-based inclusive teaching practices for faculty participants to utilize in their engineering classrooms, which aligned with Quadrant 1 from Henderson et al. TOC model [59]. The practices included in the menu were sourced from a comprehensive review of both peer-reviewed literature and university teaching and learning center websites and spanned across multiple types of inclusivity including race, gender identity, and ability-level [54], [55], [69], [70], [71], [72], [73], [74], [75], [76]. The inclusive engineering practices menu was unique when compared with other inclusive classroom tools because it not only included the strategies and their descriptions, but also provided suggestions for when instructors should employ them in relation to the traditional collegiate semester and class structure (Pre-Semester, Syllabus, In-Classroom Engagement, and Discussion Tools). Further details on the development of the inclusive engineering practices menu as well as the menu itself can be seen in Chapter 3 [119].

5.3.2 Faculty Use of the Menu and the Student Experience

To assess how participating faculty utilized the inclusive engineering practices menu, we developed a post-semester faculty survey, which was administered at the end of each semester during the study. The faculty survey, which can be seen in Chapter 4 [130], was designed to elicit instructors' use of the practices and feedback on their ILC experiences. The faculty survey was approved by each of the partner institution's Institutional Review Boards (Pitt and Mines #STUDY20050402 and ASU #14693). Chapter 4 shared practice implementation results from the faculty survey up through the Fall 2022 semester, however the faculty results presented in this chapter are from the duration of the IUSE-PIPE project across all three partner institutions which includes every Fall and Spring semester from Fall 2021- Fall 2023 [130], [134], [135], [136]. Overall, there were twenty-eight completed faculty surveys (n=28) and the faculty respondents taught civil engineering courses, other courses often included in engineering curriculum, and a few taught other STEM courses such as Biology and Math.

Across all semesters of the project, the most used strategies by timing category included: building availability into their schedules for students (100%), making course goals explicit in their syllabi (89%), employing interactive teaching techniques (86%), and not judging student responses to questions or discussion points in class (93%) (Table 8). Across all semesters and the full menu, there were twenty-one strategies utilized by over 70% of participating faculty illustrating that the participating faculty were willing to engage with the menu and try multiple strategies across the categories and core domains. These results also informed us which strategies faculty felt confident utilizing in their classrooms without additional training.

Table 8. Most and Least Used Practices by Faculty Participants for the duration of the IUSE-PIPE Project (n=28).

Semester Timing	Most Used Practices	Least Used Practices
Pre-Semester	Build availability into your schedule for students (100%)**	Stereotype Replacement technique (43%)***
Syllabus	Make course goals explicit (89%)*	Set up processes to receive student feedback on classroom climate (21%)**
In-Classroom Engagement	Employ interactive teaching techniques (86%)**	"Multiple Hands, Multiple Voices" and "Whip Around" classroom techniques (7%)**
Discussion Tools	Do not judge student responses to questions or discussion points (93%)***	Taking perspectives of others in the class (25%)***

Note: *Identity **Relational ***Intercultural

The least used strategies from the menu, by semester timing category, included: using the stereotype replacement technique (43%), setting up processes to receive student feedback on classroom climate (21%), the "Multiple Hands, Multiple Voices" and "Whip Around" classroom techniques (7%), and taking perspectives of others in the class (25%) (Table 8). Faculty may have steered away from implementing these strategies due to unfamiliarity and may have wanted more instruction or training on incorporating them into their courses. Across the menu, there were six strategies utilized by less than 30% of the faculty participants including interrupting blatantly racist behavior in class (32%) and utilizing pre-class asynchronous activities (18%). These results confirmed that the faculty participants utilized a large proportion of the menu throughout the project as well as where supplementary instructions and resources could be helpful to instructors using the menu. The survey also asked faculty to report inclusive practices they implemented in their classrooms which were not included on the menu and these can be found listed in Appendix C Table 21. These additional strategies were important to gather as the menu is not an exhaustive list of all evidence-based inclusive teaching practices and these can be added as the inclusive engineering practices menu gets updated over time.

To further explore faculty use of the menu and to provide ideas on how to evaluate practice implementation, we mapped student survey responses to faculty practice implementation results from the duration of the project (Table 9). For some strategies, there was a large proportion of faculty participants who reported implementing a strategy which was aligned with students reporting experiencing that strategy often in their classroom environment. For example, 86% of faculty reported using the Syllabus strategy of explicitly naming goals for the course in their syllabi (Table 9). From the student survey results, about 93% of students reported that course goals were often explained clearly in their classroom experience (Table 9). The strategy implementation and student survey results both exhibited a similar trend in being used often by faculty participants and experienced often by participating students showing a possible link between the two (Table 9).

Table 9. Alignment Between Faculty Practice Implementation and Selected Student Survey Results.

Semester Timing	Strategy	Percentage Use by Faculty (n=28)	Student Survey Question	% Student responded as experiencing often in class (n=219)
Syllabus	Explicit Goals	89%	Clearly explained course goals	93%
	Multiple perspectives on course topics	46%	Included diverse perspectives in material	81%
In-Classroom Engagement	Incorporate small groups or stations into classes	64%	Asked students to discuss solutions together	84%
Discussion Tools	Multiple and diverse examples	68%	Included diverse perspectives in material	78%
	Perspective Taking	25%	Tried to understand others perspectives	81%
	Do not judge responses	93%	Felt judged based on questions, comments, or responses in class	81% said they never experienced this in class

However, there were also some practices that faculty participants reported not implementing as often; however, students reported experiencing that inclusive practice often in their classroom experience (Table 9). For example, only a quarter of faculty reported utilizing the discussion tool of perspective taking (25%), however about 80% of students reported experiencing this often in their classes (Table 9). By mapping the faculty strategy implementation to student experiences in the classroom based on the student survey results, we were able to further show the possible positive impact the inclusive engineering practices menu had on participating students' classroom experiences.

5.3.3 Student Participant Experiences

We assessed the students in participating classrooms on their sense of belonging and their in-classroom experiences. The questions on the student survey combined three existing survey instruments which asked about the classroom and university environment as well as their interactions with their peers and instructors [81], [82], [83]. See Chapter 3 for further details about the development of the student survey and questions as well as the student participant results for the duration of the IUSE-PIPE project [119]. Chapter 3 shares the analysis of the student results in aggregate as well as by self-identified demographic groups for race and gender identity. For race, the student participant data compared Majority students, students who identified their race as White or White with another race, to their Non-Majority peers, students who identified as any other race or combination of races not including White. For this work, the races included in Non-Majority were Black or African American, Latinx or Hispanic, Middle Eastern or North African, Another Race, Multiple Races, and Prefer not to respond.

To further explore the experiences of Non-Majority student participants, we also chose to conduct pairwise ANOVA tests, in order to see if there were significant differences in the means among the groups within the Non-Majority group and compared with their Majority peers. The tests were conducted using Tukey's method at a 95% confidence interval (alpha=0.05) and the null hypothesis was that the difference in means between the two racial groups would be zero. If the Tukey p-value between the two groups was less than 0.05, that would reject the null hypothesis showing there is a statistically significant difference in the means between the two groups. For this analysis, we evaluated the student survey questions that were previously reported showing statistically significant differences between Majority and Non-Majority students as shown in Chapter 3. Table 10 shows the results from the pairwise ANOVA statistical tests using Tukey's method.

Table 10. Statistically Significant Results for Pairwise ANOVA using Tukey's method for Student Survey Questions (n=202).

	Comparison					
Question	Race 1	Race 2	Contrast	SE	t-statistic	p_{Tukey}
Discussing gaps in knowledge	Middle Eastern or North African	White	0.92	0.214	4.31	.001
	Another Race	White	0.70	0.212	3.32	.024
Reluctant to speak	Middle Eastern or North African	White	0.99	0.227	4.37	.001
	Another Race	White	0.72	0.227	3.18	.036
Wary trusting others in class	Middle Eastern or North African	White	0.74	0.223	3.30	.025
Felt judged based on question, comment or answer	Another Race	White	0.53	0.144	3.70	.007
	Another Race, prefer not to respond	White	2.83	0.738	3.83	.004
	Middle Eastern or North African	Hispanic or Latinx	0.57	0.180	3.15	.040
	Another Race, prefer not to respond	Hispanic or Latinx	3.00	0.746	4.02	.002
	Another Race, prefer not to respond	Middle Eastern or North African	2.43	0.744	3.27	.027
	Another Race, prefer not to respond	Another Race	2.30	0.744	3.09	.047
	Two or more Races	Another Race, Prefer not to respond	-3.00	0.899	-3.34	.022

The pairwise ANOVA results using Tukey's method showed there were four student survey questions where there was a significant difference between how a Non-Majority group of students answered the question in comparison with their Majority or other Non-Majority peers. For example, for the question asking students how wary they were of trusting others in their class, the ANOVA confirmed that the difference between how Middle Eastern or North African students and their White peers answered this question was statistically significant (Table 10). The contrast reported between the two groups was 0.74 indicating that Middle Eastern or North African students felt more wary trusting others in their class as compared with their White peers (Table 10). From all six of the Non-Majority race options, most of the significant differences were found between students who identified as Middle Eastern or North African, Another Race, or Two or More Races in comparison with their peers who identified as White, Hispanic or Latinx, and the aforementioned races (Table 10). As compared with the other Non-Majority races of students, these groups made up a large proportion (over 85%) of the student population surveyed. This pairwise analysis allowed us to further explore the student survey results and begin elucidating differences within the Non-Majority groups of students to provide more granular analysis of some of the student survey data.

5.4 Key Finding 2: Developing Support Tools and Systems for Employing Inclusive Practices

Tools such as a decision matrix and learning communities, especially when supported by administrative leaders, can be powerful in supporting faculty who are actively trying to improve inclusivity in their classrooms.

In order to support the faculty participants implementing inclusive teaching practices in their engineering classrooms, we utilized two tools for support: a decision 'matrix' for the inclusive engineering practices menu and convening ILCs at each partner institution. Faculty learning communities (FLCs) have emerged across higher education, particularly over the last five years, focused on a myriad of topics including improving teaching and designing new courses or curricula [38], [114]. A large proportion of these emerging FLCs are focused on diversity, equity, and inclusion within the classroom, namely inclusive teaching [39], [115], [117], [137]. Literature names support from leadership, supportive structural and relational conditions that foster trust, personal and professional growth and development, and the opportunity to receive feedback on teaching from peers as key components for successful FLCs [8], [14], [103], [104], [110], [112], [127]. Our ILCs were convened at different infrastructure contexts for each partner institution and were described by three archetypes: department-wide, school-wide, and institution-wide. The ILCs were developed as research- and topic-based LCs and employed the core ideas an LC from the Center for the Integration of Research, Teaching, and Learning (CIRTL) such as creating and fostering functional connections among learners [61]. It was imperative to design the ILCs to be inclusive learning environments for the participants to foster trust and sharing among members. Further discussion on the development and historical documentation of the ILCs from this project can be found in Chapter 4 [130]. We also conducted semi-structured interviews with some of the faculty participants to further explore their experiences in their ILCs and information about the faculty survey participants, development of the survey and interview questions, as well subsequent analysis methods can be found in Chapter 4 [130].

In addition to convening the ILCs to support participating faculty, we also developed a decision matrix for the inclusive engineering practices menu. Both the ILCs and the decision matrix align with Quadrants one, two, and four in Henderson et al. TOC which guided the design of this study [59]. More specifically, the decision matrix aligns with quadrant one, disseminating curriculum and pedagogy and the ILCs align with quadrant two, developing reflective teachers, and quadrant four, developing a shared vision among stakeholders [59], [119], [130].

5.4.1 The Decision Matrix

In order to support engineering faculty in implementing inclusive practices and in response to feedback from instructor workshops hosted as a part of this project, we developed the inclusive engineering practices decision matrix [138], [139], [140]. The decision matrix is an interactive version of the inclusive engineering practices menu which utilizes *Qualtrics Survey Software* to create a personalized list of practices from the menu based on answers to a few questions [89]. The four questions prompted instructors to answer based on their interests and class information including semester/course timing (Pre-Semester, Syllabus, In-Classroom Engagement, Discussion Tools), difficulty level of implementation (Easy, Medium, Complex), Aspire Alliance category (Identity, Relational, Intercultural), and class modality (In-person, Online Synchronous, Online asynchronous). These questions were chosen based on the existing organization of the menu as well as from the suggestions instructors provided during workshops [138], [139], [140]. The new categorizations we developed for the practices as a part of creating the decision matrix were the difficulty level of implementation and class modality. We developed the difficulty categories using data from previous faculty surveys administered at the end of each semester during the study. For example, if more than 70% of faculty utilized a practice throughout the study, that was labeled as an 'easy' practice since it was used by a large proportion of participants and likely did not require extra training or experience to incorporate into their class(es). However, if a practice had less than 30% use by participating faculty during the study, it was labeled a 'complex' practice and the remaining practices between 31%-69% use were labeled as 'medium'. We also considered class modality as this project was launched shortly following the COVID-19 pandemic and a number of courses had shifted from only in-person to also include online modalities.

Following answers to these questions as well as an optional question for adding their name to a contact list, users were sent a shorter, more specific version of the inclusive engineering practices menu to their emails to reference throughout their semester. In addition to this version of the menu, users were also provided with a link to the public project website which has the full menu as well as other information from this study [141]. The structure of the inclusive engineering practices menu, as mentioned previously in Key Finding 1, aided faculty in choosing the most effective practices for their classrooms by categorizing the practices by semester and course timing and the Aspire Alliance core domains. However, the decision matrix provided even more guidance to faculty since they were able to create a shortened, more personalized version of the menu which could further encourage faculty to utilize the practices since their list is based on their own choices rather than the full menu which could be overwhelming. For those interested in viewing or using the decision matrix mentioned in this chapter, please contact Dr. Melissa Bilec (mbilec@pitt.edu).

Our results, congruent with previous literature, showed the effectiveness of developing and providing support tools for faculty implementing inclusive practices in their classroom [14], [105], [108], [109], [111], [112], [113]. Support tools such as a decision matrix for practice prioritization and ILCs provide instructors not only with supportive learning environments but also can encourage further use of inclusive practices outside of the scope of this project. Increased use of inclusive practices can also encourage student belonging and retention, which connects back to Key Finding 1, where student success has been linked to classroom environments that prioritize inclusivity and value the cultural wealth of all students [8], [109], [112], [113].

5.5 Key Finding 3: Reflections and Recommendations from the Authors

As the researchers who implemented this project, we learned that a) prior facilitation and DEI training could be beneficial as a leader, b) institutional culture and context are essential to consider when planning efforts, and c) to be creative about implementing and

weaving inclusive practices into course(s) and curriculum and this is what we recommend to others looking to implement at their institutions.

Reflection/reflexivity among researchers can be beneficial by encouraging researchers to be aware of their connection to their research, by illuminating how they have changed as a result of the research process and how that impacted the research, and by exploring things that have shaped their individual thinking and actions in relation to their research [142], [143], [144]. To accomplish these things, we conducted a focus group interview with three of the investigators leading this project (Dr. April Dukes, Dr. Kristen Parrish, and Dr. Melissa Bilec) at the conclusion of the study co-led by Dr. Amy Brooks, who joined the project most recently, and Vaden. In their roles as both researchers and faculty, the three participants aimed to generate research findings about the adoption of inclusive teaching practices to support the broader engineering education community, while also aiming to integrate inclusive teaching practices in their classrooms. This duality among them led us to conduct a virtual focus group interview with some of the researchers to provide a space for reflection and elucidate recommendations they have for other faculty who endeavor to conduct a similar effort at their institution. This group interview aligned with the second quadrant from Henderson et al. TOC, developing reflective teachers [59].

Previous literature exemplifies the use of interviews to evaluate studies or interventions which aim at improving the classroom environment, however, they have largely focused on conducting interviews with study participants, not necessarily the researchers [144], [145]. Some studies have incorporated reflexive interviews among researchers in the educational context. For example, Patkin (2020) and Palaganas et al. (2017) both conducted reflexive interviews after their studies to expand their understanding of guiding the study design, reflect on lessons learned, and acknowledge changes they experienced in their own lives as a result of the study [142], [143]. This group interview followed a similar construction to Patkin and Palaganas et al. reflexive interviews to serve as a culminating reflection of some of the researchers' experiences as leaders and participants during the IUSE-PIPE project [142], [143].

5.5.1 The Focus Group Interview Protocol

We conducted a virtual focus group interview with three of the project principal investigators (PIs), Dr. Bilec, Dr. Dukes, and Dr. Parrish, who also served as facilitators in their ILCs, to understand the leadership responsibilities, challenges, and affordances associated with leading and managing ILCs. The focus group interview was a reflexive, semi-structured interview designed to elicit descriptions of the facilitators' perceptions of their roles and related responsibilities, how their institutional culture influenced their experience in the role, and any lessons learned from their experience (see exemplary questions in Table 11). The focus group interview was held during the Spring 2023 semester and lasted 47 minutes. The interview was recorded, transcribed, and checked for accuracy using Microsoft Teams and Microsoft Excel. Due to the nature of self-study and the research team's willingness to share their experiences and lessons learned, we did not anonymize the transcript. We used similar descriptive and in vivo coding as we did in Chapter 4 to analyze the interview transcript and the interview goals were utilized as the coding themes [130]. This analysis included highlighting quotes from the transcript which related to the three interview goals, role and responsibilities, institutional culture, and lessons learned, and examining them for similarities and differences among the three interviewees. We reviewed the thematic coding and interview quotes together as the final step in the analysis of the focus group interview to provide consensus and further detail on the analysis.

Table 11. Summary of reflexive focus group interview protocol goals and questions.

Interview goal	Exemplary questions
Role and Responsibilities	In your own words, please describe your role on the IUSE-PIPE project. What were the primary responsibilities associated with this role? How did you prepare for the role?
Institutional Culture	How did your institutional culture impact your experience as a facilitator? Where or with whom did you find support for your role?
Lessons Learned	What, if any, lessons did you adopt in your own role as a faculty member or teacher?

5.5.2 Role and Responsibilities

The first three questions in the reflexive focus group interview asked the three PIs to describe their roles, primary responsibilities, and if they had any preparation for their roles for this project. In their faculty roles, Bilec and Parrish engage in both research and teaching, while Dukes holds a leadership role within a teaching and learning center at their respective institutions which impacted their perspectives and roles during this project. All three of the PIs reflected on serving more than one role during this project including being a '*part of the learning community and a leader in the learning community' (Bilec)* as well as '*making sure that we were discussing the inclusive teaching practices and faculty experiences in each of our [ILC] meetings' (Parrish).* As a Co-PI on the project and their '*background for the last seven years in educational research and in facilitation'*, Dukes often '*helped guide some of the activities or some of the things that we [wanted] to try in order to create that inclusive learning space for lots of folks' (Dukes)*. Dukes also reflected on bringing their extensive experience in facilitation to the project from their institutional role which involved '*facilitating things on campus online, locally through the*

University of Pittsburgh, [and] through the CIRTL network. [She was also able to tap] into the CIRTL network [which is] one of the advantages of being a part of a group of folks who want, you know, teaching to be more inclusive and to improve belonging' (Dukes).

Though Bilec and Parrish did not have as much experience facilitating prior to this project, they both had some formal and informal experiential training from previous roles or jobs which were beneficial to them as leaders in this project. Parrish noted that '*having trust-based relationships with [their] colleagues around inclusion and a shared passion for making classrooms more inclusive'* was *'a lot more helpful'* during this project than their formal training. However, Bilec mentioned they '*did not have adequate training on inclusivity and in diversity and equity [and] felt like [they] needed training in order to do a better job at [being a leader in the ILC]. That's one thing that [they] wish [they] would have done beforehand knowing [their] personality and how [they] respond to things. Like when we were in a learning community [meeting] and difficult subjects would come up, [they] would freeze and be unable to be the facilitator [and] that's a recommendation of like I wish I had more training' (Bilec).* Parrish echoed this sentiment when reflecting on a situation that occurred in their ILC where another member gave harsh criticism in response to their presentation. They were '*disappointed that [the other ILC co-facilitator] really didn't have enough tools in [their] tool belt to recover the conversation. In that role, [they] didn't feel like [they] could be the facilitator [because they were] the presenter of the project' (Parrish).*

All three PIs had multiple roles as a part of this project including as ILC co-facilitators, ILC members, and researchers and entered this project with varying levels of facilitation experience. However, variation in their university roles was beneficial to the research team as they were able to utilize one another's strengths throughout the project. The research team also included a doctoral candidate (Vaden), postdoctoral fellow (Dr. Brooks), another teaching and learning center staff member (Dr. Amy H. Nave), and a faculty member who has also served multiple roles at their institution (Dr. Amy Landis) which further increased the diversity in experiences the team could capitalized from during the study. Parrish reflected the research team's '*shared values and [how] we have all endeavored to be in positions of acting as change agents to advance our values in our own institutions'* made for a *'really strong'* team. In addition to the benefits of multiple perspectives and roles, the PIs responses also highlighted a recommendation for those who endeavor to do similar work at their institutions. Bilec and Parrish's reflections on their lack of training with inclusivity as well as Dukes experience with CIRTL, an inclusive teaching and learning center, emphasize that formal diversity, equity, and inclusion training could be beneficial prior to beginning this type of work to help aid with not only facilitation, but also difficult or sensitive topics and situations that could arise in the ILCs.

5.5.3 Institutional Culture

The second portion of the reflexive group interview asked the PIs about their institution's culture and how that impacted their experience as an ILC facilitator and what their support system looked like during the project. One of the major challenges they highlighted about institutional culture was the need to have buy-in from participating faculty as well as support from leadership to have a successful ILC. At Parrish's institution, '*this project was so aligned to [their] Charter as an institution [and they] never really felt like [they] needed to get anyone to help convince my colleagues to try something new in the classroom. The Charter [is] supposed to guide everything that we do at our institution that mandates that we define ourselves by whom we include and how* *they succeed'* and inherently focuses on inclusivity within the classroom and larger institutional community.

However, at Bilec and Dukes's institution which is not guided by a Charter and instead has a '*more fragmented leadership structure' (Bilec)* which depends more on '*local leaders' (Dukes)* by school as opposed to across the wider institution, this support can be more difficult to gather. This was particularly a challenge at their institution because during the project '*we had a Dean change, a Provost change, and a Chancellor change and so there was a lot of transient leaders and so setting an overall direction regardless of the topic was really challenging' (Bilec).* The ILC at Bilec and Dukes's institution existed at the Department level, modeled after a recommendation from one of Bilec's colleagues, which relieved some of the pressure from these leadership changes, as compared with Parrish's ILC which existed within a school-level inclusive research and teaching center. Dukes reflected '*our particular learning community [was] within a department [and] I think the folks that were there knew each other fairly well. When you're talking about very sensitive subjects like diversity, equity and inclusion, having a close-knit community can help people dive deeper into some of the topics and maybe be more open than they would if they [didn't]' (Dukes).* However, Bilec noted that '*the [departmental] leader has to set the overall stage and the spirit of the department.' (Bilec).* Reflecting overall about the benefits and challenges associated with institutional culture, Dukes noted that '*at other places, you have to take into consideration the folks that would be in the room with you and how supportive that leadership structure is. Otherwise, this kind of learning community, [similar to the ILCs from this project, are] not going to work if [both of] those are not supportive elements' (Dukes).*

5.5.4 Lessons Learned

The last question of the reflexive group interview asked the PIs to reflect on their lessons learned and what they adopted into their own roles as a faculty member or teacher from their experiences with the project. Reflecting on their role as an instructor, Parrish mentioned that they '*found the most like kind of transformative thing that [they] learned through this project is that and the syllabus has a little bit more power than [they] had previously expected' (Parrish).* Bilec also talked about the power of the syllabus and how they *'included explicit language in their syllabus'* for students who may need to report sensitive or challenging situations to the institution. Bilec mentioned one of their students expressed their appreciation of seeing this in the syllabus and that *'very much resonated with [them because] you never really know how that's going to land on an individual person, especially in a STEM program [and this] was a very positive [and transformative experience' for them as an instructor] (Bilec)'.* Dukes also reflected on changes they made in their classroom which included '*taking a critical look at the content that [they] teach [and] finding areas that [they] can trim that content so [they] can encourage students to dive deeper into things that are more meaningful to them, but also related to the content. And so [they are] just being more mindful of how we [as instructors] set those interactions up because it also models good inclusive practices for [students] as they move on to their next part of life (Dukes)'.* Dukes concluded that one of their '*main takeaways [was] that not every inclusive practice works well for all people and [institutional contexts], your discipline, your personal preferences, and even a particular student in your class may respond in different ways [which Parrish agreed with earlier in their reflection]'.* Dukes continued that *'it's okay if something that worked prior just doesn't work this semester [and encouraged faculty to] just keep trying new things to find what what's working for [their] particular context' (Dukes).*

One of the other lessons learned the PIs reflected heavily on was the timing of this study. The study began during the Fall 2021 semester which was in the midst of the COVID-19 pandemic and the shift from fully remote to hybrid teaching and learning and *'there was like zero bandwidth for anyone to do anything'* (Parrish). Parrish continued that *'getting that sort of buy-in and critical mass was virtually impossible when everyone was in the midst of COVID [and] they did not have [a community established] before that'*, to which Bilec also agreed (Parrish). In addition to the challenges from the pandemic, Parrish and their ILC co-facilitator '*were on sabbatical for the 2021-2022 academic year, so [that] also like really created challenges for [them]' (Parrish).* Though this time was marked by flexibility and adaptability, it also created challenges for all of the PIs which impacted the ILC experience for participating faculty. Discussion about how we adapted in response to some of these challenges can be found in Chapter 4 [130]. Parrish mentioned that '*one of [their] lessons learned [was] like while you can certainly have an online community, I think it probably was really helpful to have had [a community] prior to the pandemic [because] starting a new community only online when people were starting to like use the word zoom fatigue in their vernacular was real [and very challenging]' (Parrish).* In reflecting overall as leaders, members, and co-facilitators of the ILCs in the study, Bilec concluded their thoughts by saying '*learning communities are tough. I think that there's definitely a good space for them, but the ebb and flow, the location, [and other elements of them] was very, very challenging' (Bilec).*

5.6 Conclusions and Future Work

This project, the IUSE-PIPE project, was an NSF-funded study designed to provide engineering faculty with resources and support tools to improve inclusivity and belonging within their undergraduate engineering classrooms. We conducted this study across three contextually different institutions including predominantly White institutions, a Hispanic-serving institution, and a STEM-focused institution. As a part of the project, we developed and piloted the inclusive engineering practices menu, a list of practices organized by suggested implementation time in the semester and by the Aspire Alliance's inclusive professional framework core domains [28], [119]. We also developed an accompanying decision matrix to provide faculty with a refined menu of practices based on their interests and preferences. As a part of the project, we also developed and piloted inclusive learning communities (ILCs) at the three partner institutions to provide faculty with a learning space with their peers to share lessons learned and recommendations for implementing inclusive practices [130]. Throughout the project, the authors assessed the participating faculty and their students using end of semester surveys and semi-structured interviews which were designed to elucidate classroom and ILC experiences, respectively, in regard to inclusivity and belonging [119], [130].

This chapter shared a novel conceptual framework (Figure 11) which centered this project's tasks and Henderson et al. TOC on higher education change strategies by using Huff et al. social reality under investigation (SRUI) method [59], [131]. Further, this chapter provided further analysis and findings of the full student and faculty survey datasets spanning the duration of the project (five academic semesters in total from Fall 2021 – Fall 2023). This chapter also shared reflections and recommendations from the reflexive focus group interview conducted with three of the project PIs who held various roles throughout this study. The three key findings from the IUSE-PIPE project, overall, are: 1) While integrating inclusive teaching practices brings consciousness to the forefront, students from different identity groups can still experience challenges within and outside of the classroom, 2) Tools such as a decision matrix and learning communities, especially when supported by administrative leaders, can be powerful in supporting faculty who are actively trying to improve inclusivity in their classroom and 3) As the researchers who implemented this study, we learned that a) prior facilitation and DEI training could be beneficial as a leader, b) institutional culture and context are essential to consider when planning efforts, and c) to be creative about implementing and weaving inclusive practices into course(s) and curriculum and this is what we recommend to others looking to implement at their institutions.

Overall, the goal of this project was to develop inclusive classroom tools and support tools to aid engineering faculty in weaving inclusivity into the fabric of their classes. Though this project has concluded, the findings from this project provide additional, unique inclusive classroom tools to the broader higher education community, particularly for those in STEM disciplines. These findings, congruent with previous literature, highlight the need to continually improve inclusivity within STEM classrooms, particularly for historically marginalized and minoritized students, and to, long-term, assess student feelings about their classroom experiences, peers, and instructors to determine the most impactful inclusive practices. Additionally, these findings also show the importance of supporting faculty at all levels of an institution as they implement inclusive practices in order to further encourage their use and ultimately, shift the traditional culture in engineering classrooms, in departments, and at institutions to prioritize inclusivity and belonging for all students. This project, and others similar to it, are especially prevalent now given the constant attacks on DEI in higher education and further studies are needed to develop systemic solutions that are student- and learner-oriented where students, faculty, and staff can all thrive at their institutions.

6.0 An Educational Virtual Learning Experience on Ambient and Indoor Air Quality at Kakenya's Dream

This chapter addresses research question 3, *air quality problems and female genital mutilation occur regardless of issues surrounding the COVID-19 pandemic response. As engineering educators, how can we continue to provide support and deliver effective international educational experiences that lead to understanding and empowerment?* The research presented is a reproduction of an article under review in the *Discover Education.*

Vaden, J. M., Bilec, M. M. (2024 Under Review). "An Educational Virtual Learning Experience on Ambient and Indoor Air Quality at Kakenya's Dream". Under Review, Discover Education.

6.1 Introduction

6.1.1 STEM Education

At the global level, science, technology, engineering, and math (STEM) education initiatives and programs reflect the interplay of cultural, economic, and social beliefs and are critical for personal and national prosperity [17], [18], [146]. This is paramount considering a number of the United Nation's Sustainable Development Goals (SDG) are related to quality digital and in-person STEM education experiences [17], [18], [146]. For example, SDG four aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all [93]. Literature has emphasized the importance of internationalizing engineering education research to allow for the development of broader understandings across contexts and meet the challenges of globalization such as having an increasingly interconnected world through both technology and people [100], [147].

ABET's 2020 Engineering Criteria states that future engineering graduates should have the broad education necessary to understand the impact of engineering solutions in a global and societal context [56]. The American Society of Engineering Education also states that important attributes of engineers of the 2020s include being prepared to 1) face a world in which the population of people affected by technology will be increasingly diverse and 2) social, cultural, political, and economic forces will continue to shape technological innovation [148]. While previous research has emphasized the importance of globalizing engineering education, there are challenges to implementing engineering education efforts across cultures and contexts, particularly in rural and low-income locations.

STEM education around the world, with its importance emphasized throughout the literature, has been successful in higher-income countries as the element of quality is intertwined with access [17]. However, the need for quality STEM, and more specifically engineering education experiences in lower-income countries and more rural settings is critical as it is both central to personal and societal betterment and diversifies the fields of STEM and education through new perspectives and contexts [18]. This was especially prevalent during the COVID-19 pandemic when schools and institutions had to switch to a virtual instruction modality and some low-income countries and regions struggled [16]. Particularly in African contexts, online STEM education was largely unexplored before the pandemic and affected students in rural settings the most due to connection issues and the costly price of data [16], [17].

In addition to challenges associated with connectivity, technology availability, language, and cultural differences also contribute to the difficulty of operationalizing STEM education internationally [149]. Some studies that have successfully implemented STEM initiatives internationally via online modality have cited several best practices including designing the course or curriculum to target a specific international audience, providing detailed information in advance of the project, training and providing ongoing support to participating instructors, and evaluating policies on international education [149], [150]. Previous research has also highlighted that the most effective out of school time engineering-focused educational programs are responsive to youths' interests, experiences and cultural practices and make connections between their in-classroom learning and the more informal educational experience [30].

The project described in this chapter focused on developing and delivering an international, engineering virtual education program focused on air quality (AQ) with a school in rural Kenya and assessing the learning outcomes of the curriculum using student assessments. The curriculum developed for this project aimed to provide accessibility to engineering concepts and design through utilizing educational and teaching frameworks which emphasize context-specific and place-based learning which are shown to improve inclusivity and student learning in the classroom environment.

6.1.2 Existing Virtual Learning Environment Air Quality Projects

While developing the curriculum for this project, we explored existing environmental-focused and project-based learning (PBL) educational experiences that utilized in-person and VLE techniques to learn best practices that we could implement in our project. For example, the Clean Air Outreach Program, a pilot AQ project by Khalaf et al. (2023), installed a network of AQMesh monitoring stations near elementary schools in Ontario, Canada and simultaneously, implemented an outreach education project for local elementary-school-aged students [151]. Their curriculum focused on ambient and indoor air pollution, utilized AQ data as a teaching tool, and employed virtual learning sessions due to the project occurring during the COVID-19 pandemic. Their project goals outlined providing both education and empowerment to the participating students and teachers about AQ and included student surveys that collected both experiential feedback and tested them on knowledge learned [151]. D'eon et al. (2021) project-based learning experience also focused on AQ, however, it was explicitly framed as a PBL, citizen science learning experience and worked with senior high school, early undergraduate and graduate students [152]. As a part of the project, participating students independently directed their own projects following introductory learning sessions focused on IAQ [152]. D'eon et al. learning objectives included providing students the opportunity to make educated decisions related to methodology and instrumentation when designing their own projects and analyzing and interpreting analytical data [152].

In addition to these aforementioned projects, we also explored fully developed AQ classroom resources that were developed for elementary school teachers to add to their science curriculum [153], [154], [155], [156]. The goals of these projects differed as some of them focused heavily on communicating AQ results. At the same time, other programs were more focused on sharing results about the student experience and educational benefits they gained from participating [153], [154]. Each of these programs were developed for various grade school levels on AQ, however they occurred prior to the COVID-19 pandemic so they did not emphasize nor highlight best practices for conducting these programs as VLEs. All of these programs and curricula exemplify a large proportion of how grade school educational programs and initiatives focused on AQ are conducted and administered.

Compared to these previous studies, our project was contextually unique since we collaborated internationally with Kakenya's Dream (KD), an all-girl's school located in rural Kenya, while a number of previous related studies have occurred in higher income countries where traditional beliefs about girls' education may be less prevalent. Exploring these existing programs highlighted some best practices for AQ-focused VLE programs including using project-based and citizen science frameworks to build the curriculum. Previous literature also highlights that successful approaches for increasing diversity and equity in STEM disciplines and engaging students, particularly for girls and students of color, include engaging them in hands-on activities and having the experience be led by mentors or teachers who match them in gender, racial, and ethnic characteristics which were both a central part to this engineering VLE [30]. However, the literature also illuminated the novelty of our project with KD as it was an international, citizen science, VLE program focused on ambient and indoor air pollution that engaged students from middle through high school age during multiple cultural and global challenges that can impact students' educational outcomes and experiences (female genital mutilation (FGM), child marriage, and COVID-19).

6.1.3 Study Context

6.1.3.1 Kakenya's Dream (KD)

Founded in 2008, Kakenya's Dream (KD) is a nonprofit organization that supports girls holistically with a foundation in quality education and community-based health. They also host leadership programs designed to empower girls to become agents of change in communities in rural Kenya by teaching the students about vital life and leadership skills, their legal rights, and how to effectively advocate for themselves and their peers in difficult situations [157]. Dr. Kakenya Ntaiya was born and raised in a rural Maasai community where women's accepted roles in society are as wives and mothers and harmful traditional practices such as female genital mutilation and child marriage mark an end to girls education [157]. As the organization expanded, Dr. Ntaiya built the Kakenya Centers for Excellence (KCE) to provide primary school education to girls, the first of its kind in the village [158]. The school began as a single primary school for thirty girls and has since expanded into two world-class boarding schools for grades kindergarten through twelve as well as several education, health, and leadership programs that serve people throughout rural Kenya [158]. The KCE II campus is located about 342 km (around 212 miles) from Nairobi, Kenya's capital.

6.1.3.2 Sugarcane Bagasse and Air Quality (AQ)

This collaborative project was developed in response to the emissions and pollution from a nearby sugarcane processing factory that was impacting the KCE II campus, where the KD upper middle and high school students attend and live (Figure 12). This sugarcane factory is located about 5.6 kilometers (around 3.5 miles) from the campus on a hill above it. Previous research has shown that emissions from agricultural burning include particulate matter (PM), carbon monoxide (CO), and nitrous oxides (NO_x), which are known to impact the health of local populations and cause a reduction in air quality [159]. At large-scale locations, some processing plants have moved to manual harvesting without pre-burning, but for some smaller-scale plants, including within African countries, pre-harvest burning is a relatively common practice [159]. Literature has also connected the sugarcane biomass burning process to impacts on the indoor air quality (IAQ) of environments and residences in close proximity to where the sugarcane is processed [160]. Ash from sugarcane processing trash has also been shown to be a potential source of respirable airborne particulates and should be considered both an acute and chronic respiratory hazard to local populations [159], [161]. Impacts from processing and burning are particularly pronounced in vulnerable groups such as young children and the elderly [159], [160]. The sugarcane harvesting season typically lasts for six months which can result in prolonged and repetitive exposures to nearby populations [159].

Literature has also shown that chronic exposure to air pollution positions children with a higher lifetime risk of developing health problems such as asthma, obesity, and hypertension [162], [163]. Chronic PM2.5 exposure over a person's life also contributes to a high burden of premature deaths as well as cardiovascular and respiratory health problems [162], [163], [164]. Air pollution is the largest environmental risk to health and is a leading contributor to diseases and cancer worldwide and this is exacerbated in communities with high proportions of low socioeconomic status and marginalized groups of people [165]. Increased ambient air pollution can also lead to poorer IAQ and higher indoor concentrations of PM and volatile organic compounds (VOCs) [165], [166], [167]. IAQ concentrations can be two to three times larger compared to outdoor levels because there is less space for the molecules to dissipate over [165], [166], [167]. Significant contributors to indoor air pollution within residential buildings are source fuels, building materials, and cooking methods in addition to poor ambient AQ conditions [165], [168].

An initial response to the IAQ problem at the KCE II campus and surrounding areas was led by Natural Justice, a local environmental justice group. Our collaborators at KD shared that some of the students and instructors at KCE II complained of asthma-like symptoms and sickness and have seen ash present in different areas of the school which could be related to the proximity of the factory to the school as well as some impacts from other local pollution including an on-campus construction site. Natural Justice developed a scoping report in order to highlight these issues which helped the authors further define the scope of this project [169]. The report also detailed the community's dichotomous view of building the factory which resulted in an increase in jobs and investment, but also created an inevitable air and water pollution problem [169].

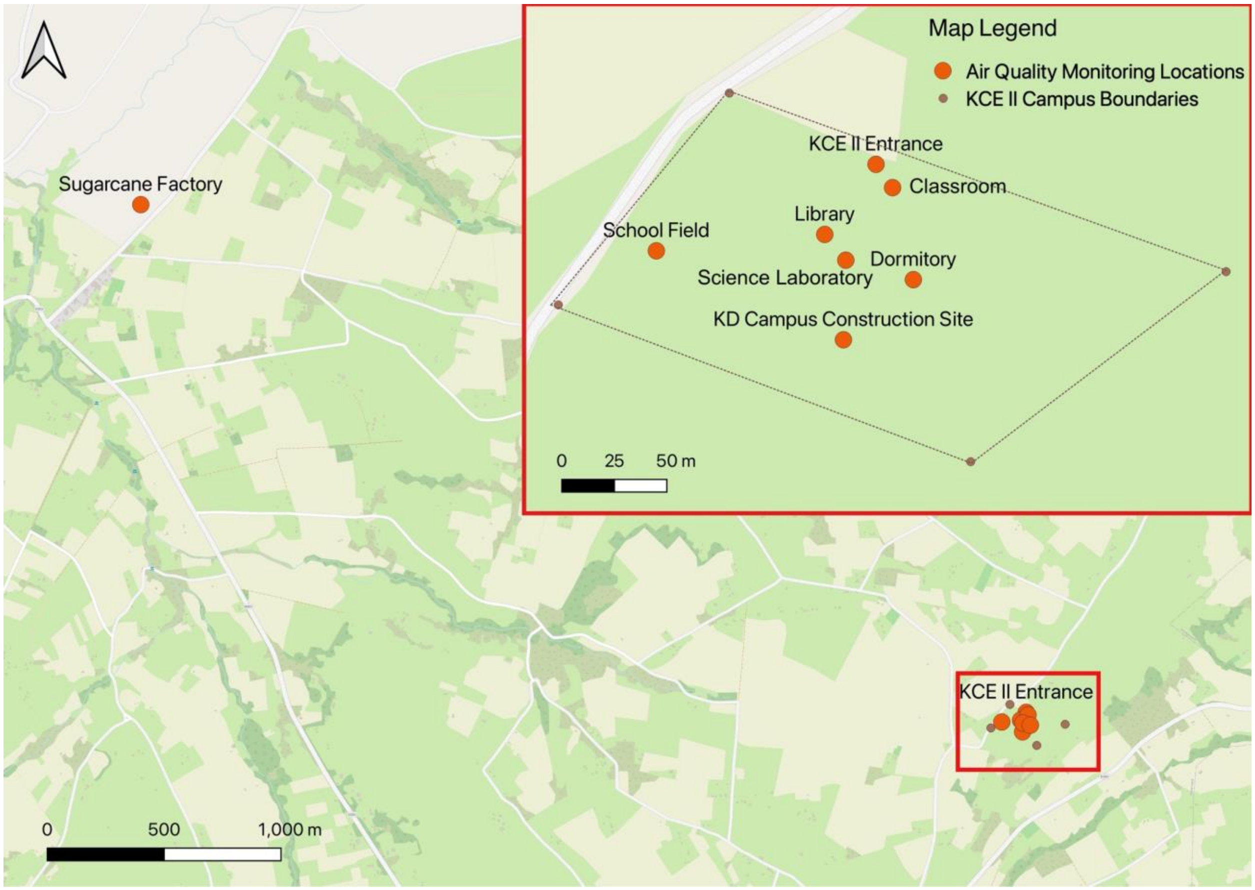

Figure 12. Map of Kakenya Center for Excellence high school campus boundaries (KCE II), the Sugarcane factory nearby, and the air quality monitoring locations from the duration of the project.

6.1.4 Study Aim

In response to this ambient and indoor AQ problem, we developed an international engineering VLE focused on AQ aiming to provide education to the KD students, at middle and high school grade levels and their instructors, using citizen science and project-based learning frameworks. This chapter details the development and delivery of the engineering education curriculum which utilized AQ monitoring to educate the students and instructors about their local AQ. This chapter also shares and discusses the AQ data collected over the duration of the study. We also describe the development of the student assessment which assessed the learning outcomes of the curriculum and provided students the opportunity to give feedback on their experiences.

6.1.5 Teaching Approach

6.1.5.1 Virtual Learning Environments (VLEs)

The curriculum developed for this project was delivered virtually to the students at the KCE campuses through the Zoom Web Conferencing application due to geographical constraints and the COVID-19 pandemic. The COVID-19 pandemic forced many schools and universities to switch to teaching fully remote classes; however, virtual learning environments (VLEs) have previously existed for various learning purposes. Dillenbourg et al. (2002) argued that VLEs are identified as designed information and social spaces where educational interactions occur and the virtual space is explicitly represented [170]. They also note VLEs often overlap with physical environments and integrate multiple technological and pedagogical approaches [170]. The literature on distance learning environments states that the student’s ability to self-monitor and accurately evaluate their comprehension of classroom material, particularly instead of verbal and nonverbal feedback, is essential to the classroom experience [171]. However, previous research has shown that informal learning settings, such as online synchronous spaces, provide students with high-impact learning experiences that allow for academic growth and interest in new content without the constraints of national learning standards or other accountability requirements [172].

6.1.5.2 Problem-Based Learning and Citizen Science

In addition to the teaching and learning occurring remotely and virtually, this engineering VLE was framed as both a citizen science project and a problem-based learning (PBL) experience. Previous research defines citizen science as engaging the public in a scientific project driven by a research question or program that fits into a public organization's science or conservation mission [173], [174]. This citizen science perspective provided the collaborative partners with deciding power on how the data was collected, analyzed, and utilized for decision-making and solution development. Additionally, framing the VLE as a PBL experience in addition to the citizen science framework, meant the learning experience was driven by scientific questions. In PBL, students utilize an 'inquiry method' to seek knowledge and solutions by investigating the source of a problem as the starting point for the learning process [35]. Learner-centered approaches such as PBL, particularly when contextualized to a student's experiences or local environment, are beneficial because they allow learners to exercise autonomy in problem-solving, critical thinking, and creativity by applying their in-classroom learning to solving everyday local problems [33], [34]. Previous research reports that students understood science better and were more interested in the material when instructors utilized local contexts to mediate curriculum because students were able to connect on a more personal level to their learning [33]. Research has also shown that students who are exposed to PBL and engineering design concepts in their educational experiences, whether in or outside of the classroom, help students develop 21st century skills including higher levels of creativity, collaboration and communication skills, and persistence in the face of challenges [30], [175] This is especially important in the Kenyan context because the Kenyan school curriculum has traditionally been characterized by exams with memorization as the dominant learning method [33]. Teaching and learning methods that deviate from traditional styles and are used in collaboration or accompany in-classroom learning with outside entities can also improve the accessibility to new material, such as engineering concepts, and provide more opportunities to students who may not have had the opportunity otherwise including girls and students from lower income families [30].

6.1.6 Educational Approach

The development of the curriculum and module sessions for this project utilized two guiding educational approaches: Morris's Experiential Learning Cycle and Britain and Liber's Conversational Framework (Figure 13). Morris's Experiential Learning Cycle is an expansion and revision on Kolb's original experiential learning cycle which denoted similar phases of learning [36]. Morris found that community engagement was central to experiential learning where learners were central to the context. Morris also noted that knowledge construction is a social process, bound in time and place, which necessitates the inclusion of historical and social contexts within the learning [36]. Morris's learning cycle also highlights that experiential learning is a process that deliberately pushes learners out of the traditional realm of learning experiences and what they are familiar with [36].

Though Morris's experiential learning cycle framed our VLE overall, Britain and Liber's Conversational Framework guided the development of the module sessions. Britain and Liber's framework applies to academic learning drawing from Laurillard and Pask and Scott's Conversation Theory, which emphasized the importance of two-way dialogue in effective academic learning [37]. Traditionally, this framework is utilized in an in-person learning environment but can also be supported through a VLE provided it has those mechanisms that support conversations between students and the teacher. The tools used in VLEs need to allow for dialogue and action to mutually influence each other between the teacher and students throughout the learning experience [37]. For this project in particular where the curriculum and modules were largely developed before instruction, there needed to be an element of flexibility and creativity to them so that they could change or evolve based on interactions and conversations had during the sessions. Both Morris's Experiential Learning Cycle and Britain and Liber's Conversational Teaching Framework allowed for creativity during module development as well as flexibility to adapt to students' comprehension (Figure 13).

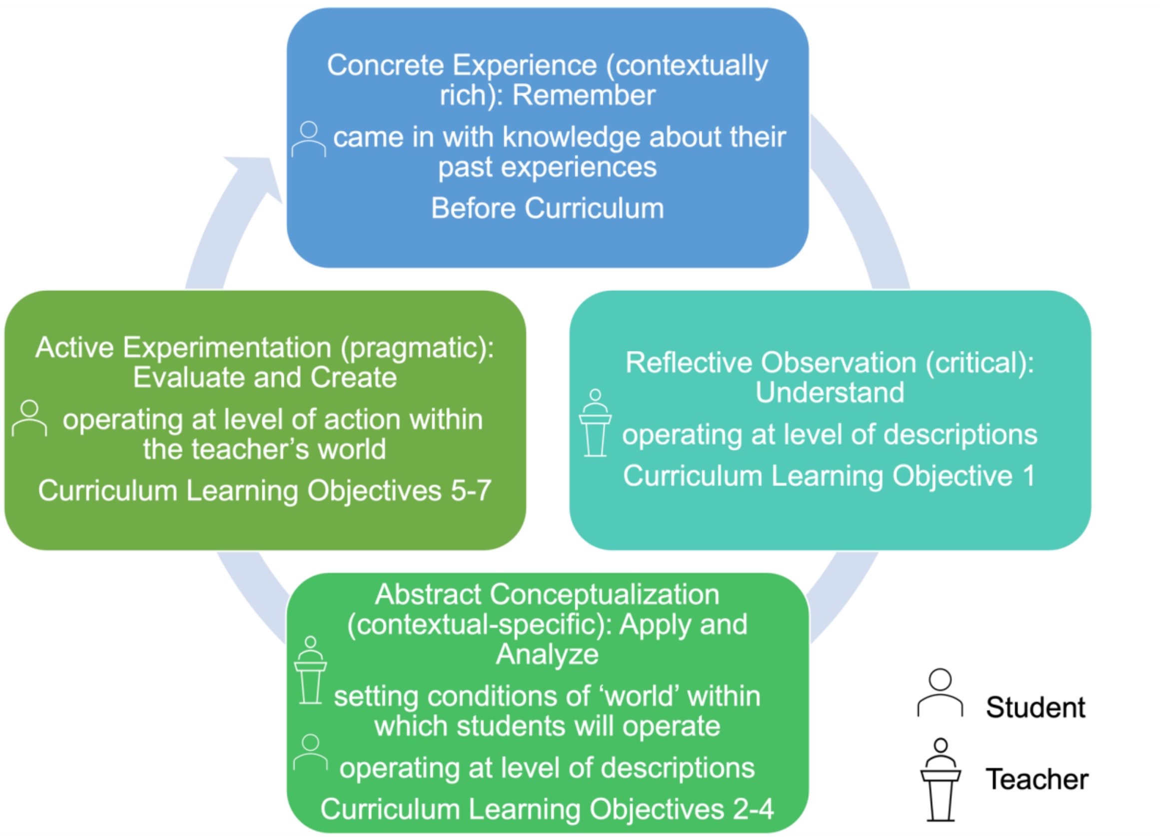

Figure 13. Conceptual framework combining Morris's Experiential Learning Cycle, Britain and Liber's Conversational Teaching Framework, and Bloom's Taxonomy aligned with the Air Quality Curriculum objectives for this project [36], [37], [176].

(Note: See Table 6 for further description of learning objectives.)

Figure 13 represents a conceptual framework that combines both Morris and Britain and Liber's educational frameworks with Bloom's Taxonomy to show and describe this study's curriculum and learning process [36], [37], [176]. Both Morris and Britain and Liber's frameworks are cyclical in their descriptions of experiential and academic learning whereas Bloom's Taxonomy describes the cognitive processes in which thinkers encounter and build upon their knowledge [36], [37], [176]. The conceptual framework begins with a concrete experience which is contextually rich (Morris) and students enter the curriculum with knowledge of their past experiences [36]. In the context of this project, the KD students' previous experiences with AQ at their school represent their concrete experience. At this point in the learning experience, students can answer the questions: What? Who? And Where? in regard to their AQ experiences which are represented by the first level of Bloom's Taxonomy, Remember, where a learner can recognize and recall what they experienced [176]. The next phase in the cycle includes reflective observation (Morris) where students are beginning to understand (Bloom) how AQ could impact their daily lives [36], [176]. At this level, Vaden, who was the lead instructor during this VLE experience, taught at a level of descriptions (Britain and Liber) and provided the students with descriptive information that introduced them to AQ, the first learning objective of the IAQ curriculum (further described below in the Methods section) [37].

The third phase in the cycle includes context-specific conceptualization (Morris) where students applied their knowledge of AQ and drew connections between what they learned and their experiences with AQ (Bloom) [36], [176]. During this phase, the virtual instructor Vaden, began setting the conditions and boundaries in which the students' learning experiences would continue and the students were able to answer questions at a level of descriptions (Britain and Liber) [37]. Learning Objectives two through four focused on the basics of ambient and indoor AQ and introduced students to different AQ sensors. During these objectives, we employed different activities and encouraged participation from students in order for them to begin applying and analyzing (Bloom) the information they learned thus far [176]. The final phase of the learning cycle was active experimentation (Morris) where students engaged in activities within the learning boundaries set during phase three (Britain and Liber) [36], [37]. These learning objectives, five through seven, were characterized largely by student participation and students were able to evaluate the information they learned previously and create AQ monitoring plans (Bloom) [176]. By the end of the learning cycle, students were also able to propose possible technical and sustainable solutions to implement at KCE II in order to reduce some of the AQ impacts they experienced.

Through the use of Morris's experiential learning cycle, Britain and Liber's Conversational Teaching framework, and incorporating context-specific and place-based learning using the engineering design process, we were able to develop an inclusive-focused and accessible engineering education experience. Long et al., in their study on the positive role of Kolb's model (which Morris's cycle is reflective of) and engineering design in K-12 STEM learning, illustrated how Kolb's model is a fundamental theory for STEM learning and engineering design as it encourages students to reflect and learn from a real-world problem and apply their learning to construct solutions to that problem using technology and design [29]. Long et al. also cites Kolb's model and engineering design as a potentially useful pedagogical strategy for the K-12 classroom which is in alignment with the National Academy of Engineering and the National Research Council [29]. Britain and Liber's Conversational framework emphasizes two-way dialogue between instructors and students and values and celebrates students' contributions to the learning process [37]. Classroom and curricular practices that prioritize students' connection to their in-classroom learning and prioritize and center their experiences have been cited to improve student learning and interest and have also been linked to successfully weaving engineering concepts into student learning [29], [30], [175].

6.2 Methods

6.2.1 Student Participants

Over the duration of this project, we worked with two cohorts of students based on recommendations from the KD team. Cohort 1 included N = 27 eleventh graders, and Cohort 2 included N = 20 seventh graders on the KCE II campus. We piloted the IAQ curriculum VLE with Cohort 1 between September 2021 and March 2022. We met with students once a week for one hour at the end of their school day, less holidays and scheduled school break periods, using the Zoom Web Conferencing Application. During Cohort 1's VLE, there were some connectivity issues that caused some of the module sessions to be canceled or moved to subsequent weeks which created some scheduling challenges. However, Cohort 1 was able to experience a majority of the sessions as detailed in the curriculum in the next section. Due to scheduling, there was a long break between working with the students in Cohorts 1 and 2. During this break, the Kenyan government restructured some of the educational curricula the KCE students were taught. In response to this, the KD team suggested we work with the seventh graders at the KCE II campus, and from the end of May 2023 through July 2023, we adapted and delivered IAQ curriculum to 20 seventh graders at KCE II using Zoom again (Cohort 2). During Cohort 2's VLE, there were again some connectivity issues while using Zoom that impacted some of the sessions similar to Cohort

1, however, we were able to adapt the schedule to ensure the students experienced as many of the module sessions from the curriculum as possible. The author's Institutional Review Board deemed this work does not meet the definition of "Human Subjects" research.

6.2.2 The IAQ Curriculum

6.2.2.1 The Modules

Utilizing the guiding theory and framework and mimicking the engineering design process, we developed the IAQ curriculum and module sessions utilizing similar previous studies and teaching resources that were focused on engineering concepts, particularly those focused on air quality (Table 12) [151], [152], [153], [154], [155], [156], [166], [167], [177]. The IAQ curriculum was delivered to the KCE students during weekly, virtual 60-minute module sessions led by the first co-author and included a lecture component accompanied by an in-session activity or post-session assignment to reinforce the material learned during the session. Each subsequent session also started with a review of the previous week's material and an opportunity for students to ask questions. The IAQ curriculum was comprised of seven learning objectives (LO) that ranged from introductory information about ambient and indoor AQ and its connection to health through using the PurpleAir PA-II-SD sensor to monitor and analyze AQ data (Table 12). For example, LO 1 focused on fostering connections between the students and the authors by introducing ourselves and sharing about our surrounding environments. The material and discussions from LO 1 were reinforced over the next week using an activity adapted from the University of Michigan that simulated measuring air pollution [177]. The activity instructed the students to create "pollution catchers" using paper plates and Vaseline to physically demonstrate and comprehend what we would do in later modules using the PurpleAir PA-II-SD sensor [177]. LOs 1 through 4 and their module sessions followed a similar format until LO 5 once the AQ monitoring began.

The sessions in LOs 5 through 7 incorporated different instructional tools such as "Think-Pair-Share" which shifted the sessions from lecture-style learning to co-collaborative and problem-based learning because the students would begin applying the concepts they learned in LOs 1 through 3 to their activities in remaining modules. Through this co-creation process, the students also relied on their knowledge about their school campus and what locations could be the most impacted by air pollution sources. The cohorts were split into smaller groups who were then assigned to each of the student-determined locations which included the dormitory, library, science laboratory, classroom, and others. The monitoring plan also detailed the tasks each group would need to follow each week: (1) install the air monitor at the group's designated location, (2) download the data with their instructor to send back to the authors for analysis, and (3) report back to the class in the subsequent session about their monitoring week and their experience.

Table 12. Summary of learning objectives (LO) and module session learning activities.

Learning Objectives	LO Goals	Description of Activities
LO 1: Introduction and the Environment	Foster connections between the students and the authors	Introductions and sharing about our surrounding environments
	Simulating measuring air pollution	Cohort 1: "Pollution Catchers" activity** Cohort 2: Activity Logs
LO 2: Learning the Basics of Air Quality (AQ)	Defining AQ and its importance	Cohort 1: Activity Logs
	Exploring the AQ at KD	
LO 3: Learning the basics of IAQ and Connection to Health	Defining IAQ and its importance	
	Connecting IAQ and your health	
LO 4: Developing Competencies with AQ Sensors	Basics of IAQ sensors	"Hands-on" exploring the sensor during session
	Exploring different IAQ sensors	
	The PurpleAir PA-II-SD Sensor	
LO 5: Creating a monitoring program and Collecting data	Creating a monitoring program	Think-Group-Share to develop monitoring program
	Collecting ambient and indoor AQ at KD	
LO 6: Synthesizing Data	Exploring data analysis methods	Small group work using examples and their locational data
	Analyzing the AQ data	
LO 7: Developing Technical and Sustainable Solutions*	Learning about different solutions	Think-Group-Share
	Proposing our own solutions	

Note: *Only Cohort 1 experienced LO 7 due to scheduling conflicts with Cohort 2. **Activity sourced from *Measuring Air Pollution Experiment, n.d.*

The students at KD, largely due to the rural location of their school and limited resources, have minimal experience using computers. The school's curriculum does not have a strong emphasis on using computer programs to learn and reinforce in-classroom concepts so they had limited experience performing data analysis. In response, LO 6 was first focused on reviewing data analysis methods including how to develop and understand tables and graphs to communicate information about data collected. Following this review, LO 6 continued by providing the student groups time series plots of their monitoring location data to provide them the opportunity to learn how to effectively translate their data into conclusions for their peers. The remaining modules from LO 6 occurred while the students collected the AQ data and they had a different format from previous modules including (1) a review of the last session and the monitoring plan, (2) the plan for the current session, and (3) student group presentations on their graphical analysis. The IAQ curriculum and LOs were initially developed for Cohort 1 (11^{th} grade) and were adapted for Cohort 2 (7^{th} grade) based on their sixth-grade educational milestones. For example, one notable difference between the cohorts' curricula was that due to academic scheduling conflicts, Cohort 2 did not experience LO 7 focused on brainstorming technical and sustainable solutions for the AQ issues at the school. Though this could be resolved with a possible visit to the KD campus focused on this project, the Cohort 2 students experienced the majority of the curriculum including learning about ambient and indoor AQ and monitoring the campus's air. The adjustments made to the curriculum for Cohort 2 can be seen in full in Table 12.

6.2.2.2 Air Quality Data Collection

As a part of the curriculum, we utilized the PurpleAir PA-II-SD AQ sensor to both collect ambient and indoor AQ data and as a citizen science engineering education tool for the students and KD teachers. This low-cost sensor is easy to install and transport does not require internet for data collection or storage, and has a friendly user interface, which was ideal for our student participants. Additionally, the sensor is capable of collecting data on particulate matter 2.5 microns (PM2.5) or smaller, which has been linked to asthma and other respiratory problems [167]. PM1.0, PM2.5, and PM10 particle count and concentration data were measured in real time along with other weather-related data including temperature, humidity, dewpoint, and pressure [178]. In August 2021, prior to starting the module sessions, we conducted a virtual training session with the KD teachers involved in order to familiarize them with the curriculum and to prepare them to help students use the IAQ sensor and share the downloaded AQ data with us. Several previous studies, as noted by Mahajan et al., have utilized collecting AQ data as a citizen science activity to improve people's understanding of air pollution and many have also utilized low-cost sensors to engage people in the data collection process [179]. In addition, previous research also cites instruction based around a technological system, such as an AQ sensor, has been found to increase student interest and engagement during the educational experience as well as in exploring engineering as a potential career option [30]. This was especially important for our project since the students involved were all girls and were from a rural area where they were less likely to be exposed to engineering-related experiences that would introduce them to new technology, AQ monitoring, and AQ data analysis methods [29], [30] For our VLE, we utilized the PurpleAir sensor and data collection as a citizen science educational tool for both the students and teachers at KD, and this was central to the IAQ curriculum and its learning activities.

6.2.3 Data Analysis Methods

6.2.3.1 Student Assessments

We developed a summative assessment based on the LOs to explore what the students learned and retained from the curriculum as well as provide them the chance to give feedback (Table 13). This assessment format allowed the authors to ask high-level, overarching questions from the modules. Typically, summative assessments are given at the end of a unit or chapter to assess student learning holistically [180] and aim to test students' comprehension of related classroom material through different question types such as multiple choice, fill-in-the-blank, and open-ended [180]. The different question types allowed us the opportunity to ask students to identify the information they learned during the modules and also could provide students the opportunity to show deeper understanding and personal opinions or viewpoints [180].

Table 13. Student assessment questions with grading rubric.

(Note: Cohort 2 adaptations in italics.)

Question	Possible Response	Points Possible
1. Name three things within or surrounding the KD campus that can impact air quality/produce air pollution.	List out three things	3
2. In your own words, define the term air quality.	Open Ended Response	4
3. Cohort 1:What are the two components in our air that make up about 99% of the air we breathe in every day? *Cohort 2: Pick two things in our air that can be bad for us to breathe in.*	Cohort 1: a) Oxygen (O_2) b) Ozone (O_3) c) Nitrogen (N) d) Particulate Matter (PM) *Cohort 2: a) Oxygen (O_2) b) Ozone (O_3) c) Lead d) Nitrogen (N) e) Particulate Matter (PM) f) Sulfur Dioxide (SO_2)*	Cohort 1: 2 (1 for each) *Cohort 2: 4 (2 for each)*
4. Indoor concentrations of air pollutants can be 2-3 times higher than outdoor concentrations. True or False?	True or False	Cohort 1: 2 *Cohort 2: 4*
5. Fill in the Blank, a) PM2.5 is a category of particles that have ________ (more or less) than a 2.5 micrometer diameter. b) PM2.5 can be inhaled into the ___________ (smallest or largest) parts of our lungs and cause health problems.	More or Less Smallest or Largest	Cohort 1: 3 for each *Cohort 2: 4 for each*
6. The COVID-19 pandemic has had a large impact on our lives, particularly on our indoor spaces due to how easily it can be spread among people. How has our behavior and indoor spaces changed since the beginning of the pandemic?	Open Ended Response	4
7. In your own words, explain what an air quality monitor does.	Open Ended Response	4
8. During the monitoring, we used the PurpleAir PA-II-SD air quality sensor. How was the data collected from the sensor?	Open Ended Response	4
9. Cohort 1: The locations that were monitored by groups in the class included the dormitory, construction site, science lab, grade 11 classroom, and library. Write a few sentences about your location and why it was chosen as a monitoring location. *Cohort 2: The locations that were monitored by groups in the class included the school field, classroom, construction site, and the science laboratory. Write a few sentences about your location and why it was chosen as a monitoring location.*	Open Ended Response	4
10. Cohort 1: Below is a picture of the time series plot for the Science Lab showing the temperature, humidity, and PM2.5 concentration over the course of a few days. Infer why there are some higher “spikes” of PM2.5 concentrations at certain time points on the graph compared to others. *Cohort 2: Below are pictures of two graphs for the Science Laboratory showing the temperature, humidity, and PM2.5 concentrations over a few days.* *a) Do any of the graphs have any trends? If there are, explain what those trends say?* *b) Make one conclusion about the PM2.5 graph.*	Open Ended Response	6
11. Give an example of a possible solution/intervention that will improve the indoor air quality at the KD campus and why?*	Open Ended Response	6
12. In a few sentences, write about your overall experience with the Air Quality modules. You can reflect on the monitoring process, the learning sessions, or anything of your choosing. The goal of this question is to learn about your experience and also give you the opportunity to provide feedback.	Open Ended Response	0
		Total Possible Points: 45

*Only a Cohort 1 Question **Point adjustments made to keep total possible points equal for both cohorts for comparative purposes

The assessment was initially developed for the students in Cohort 1 and was adjusted for Cohort 2 given the differences in the curriculum and grade level which can be seen in Table 13. Before administering the assessments, they were shared with the KD teachers to receive approval on content and language based on the student's grade levels and a language barrier between the authors and the students. After approval, the assessments were sent to the KD teachers who administered them to the students and they were returned to the authors for grading. Due to scheduling conflicts, Cohort 1 was administered the survey 13 months following their educational experience whereas Cohort 2 was administered directly following their experience.

The assessments were graded on a 45-point scale rubric which can also be seen above in Table 13. The grades were analyzed in aggregate and summary statistics were calculated for both cohorts of students including the minimum and maximum grades, class average, and question-by-question performance to see which pieces of information most students retained and comparatively, how well cohort one and two performed especially relative to the long break the students in cohort one had between their modules and taking the assessment.

6.2.3.2 Ambient and Indoor Air Quality Data

The ambient and indoor AQ data for this project was collected using the PurpleAir PA-II-SD monitor across several locations on the KCE campus. Cohorts 1 and 2 monitored five and four campus locations, respectively, for at least three days during the modules. From November 2021 through February 2022, Cohort 1 monitored the dormitory, construction site, science lab, grade 11 classroom, and library. From July 2023 through August 2023, Cohort 2 monitored the school field, classroom, construction site, and science laboratory. Figure 12 shows these locations in relation to one another and the sugarcane factory. From these monitoring sessions, the KD team emailed the PurpleAir data to the authors to provide time series plots for the student group classroom presentations which were created using Microsoft Excel. The AQ data used during this project included the date and time, current temperature in Fahrenheit, current humidity in percentage, PM2.5 particulate mass concentration in ug/m^3 and PM2.5 particle count. For this project, this data was used to create diurnal profiles for the students to use during LO six for their peer presentations. The remaining data from each location were not used within the scope of this project but could still be used in order to provide further information to KD about their air quality.

6.3 Results and Discussion

6.3.1 Ambient and Indoor Air Quality Results

Cohort 1, the eleventh graders, monitored five locations: the classroom, construction site, dormitory, library, and the science lab; and Cohort 2, the seventh graders, monitored four locations: the classroom, construction site, school field, and the science laboratory. Both Cohort 1 and 2 monitored for three to five days in each location from November 2021-February 2022 and in July 2023, respectively. Table 14 below displays the average and standard deviation, over the course of 3-5 days depending on location, for temperature, humidity, dewpoint, PM2.5 concentration in ug/m^3 and PM2.5 particle count in count/ft^3 for all monitored locations for both Cohorts over the aforementioned time periods. The days monitored for each location varied during the project due to connectivity issues and miscommunication so some of the locations were monitored for less days than others. During Cohort 1's monitoring period, the Library had the highest average PM2.5 concentration and particle counts during the monitoring period, 34 ug/m^3 and 4,095 count/ft^3 respectively. In comparison with the other monitored locations, the library is the closest in distance to the sugarcane factory which may have contributed to the higher averages. There also may have been an increased use of the Library during the monitoring period which could also contribute to the concentration of particles in that location.

During Cohort 2's monitoring period, the construction site location had the highest PM2.5 concentration and particle count, 30 ug/m^3 and 3,706 count/ft^3 respectively, which was likely due to the combination of increased particles from construction activity and ambient air pollution from the sugarcane factory. However, the largest standard deviation in both PM2.5 concentration and particle count during both Cohort's monitoring periods were from locations with a lower average compared with other locations. During Cohort 1, the largest standard deviation in concentration and particle count was from the construction site location (3,426 count/ft^3) and during Cohort 2, it was from the school field location (1,740 count/ft^3) (Table 14). Though the average for both concentration and count were low at the construction site in comparison to the other locations, the higher standard deviation indicated that there were likely some days where an increased amount of construction activity occurred during the Cohort 1 monitoring period which also may have produced more air pollution and increased the AQ impacts the KD campus experienced. In addition to the air pollution from the sugarcane factory, the particles from construction likely contributed to a higher PM2.5 concentration and particle count. Similarly, the higher standard deviation in concentration and particle count in the school field were likely higher due to its proximity to the sugarcane factory and impacts from other nearby air pollution including the construction site.

Table 14. Summary of the 3-5 day average and standard deviation of monitored air quality locations for both Cohorts.

(Note: Red boxes indicate highest PM2.5 concentration and particle count. Orange boxes indicate highest standard deviation in PM2.5 particle count.)

Cohort 1 (monitored during November 2021- February 2022)										
	Temperature (F)		Humidity (%)		Dewpoint (F)		PM2.5 (ug/m^3)		PM2.5 (count/ft^3)	
Location	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Classroom	76.5	2.9	47.5	4.1	54.7	2.6	22	15.1	2994	2771.1
Construction Site	74.5	3.5	50.9	5.1	54.8	1.6	11	18.3	1890	**3425.7**
Dormitory	78.9	3.4	44.6	5.5	55.1	2.8	13	5.8	1760	766.7
Library	78.1	3.4	45.4	3.9	55.0	1.9	**34**	15.0	**4095**	1887.4
Science Lab	77.2	4.2	44.4	6.1	53.3	2.9	16	8.9	2413	1322.8
Cohort 2 (monitored during July 2023)										
	Temperature (F)		Humidity (%)		Dewpoint (F)		PM2.5 (ug/m^3)		PM2.5 (count/ft^3)	
Location	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Classroom	79.3	6.9	36.6	6.9	49.8	1.8	20	6.6	2493	938.6
Construction Site	76.3	3.5	44.9	4.6	52.9	2.6	**30**	12.4	**3706**	1575.8
School Field	72.8	3.5	48.7	5.9	51.9	1.3	18	8.3	2537	**1740.1**
Science Lab	75.5	5.1	39.2	7.4	48.2	3.0	21	13.2	2679	1735.3

For the in-session virtual presentations, students were given time to analyze their diurnal profiles and were encouraged to make observations about any trends and to make conclusions about their data based on the classroom material they learned. For example, the student group in Cohort 1 who monitored the classroom shared these observations: ‘The PM2.5 concentration spikes a few times in comparison to the rest of the time, particularly in the morning hours across a few of the days. This is most likely due to either early morning construction around the campus or the students utilizing the classroom at different points during the day adding to the particles in the room’. The student group who monitored the science laboratory shared these observations: ‘There are chemicals present in the science laboratory and they are used for experiments. This is probably why there are high concentrations of PM2.5 particles throughout the monitoring period. This location is also indoors so the temperature and humidity following the same pattern each day makes sense.'

The ambient and indoor AQ data from the monitoring locations highlighted the AQ issues around the KCE II campus and indicated the need to institute interventions that could improve the AQ the students and instructors experiences. Both the ambient and indoor AQ results from the monitoring showed high concentrations and particle counts of PM2.5. The United States Environmental Protection Agency's (US EPA) National Ambient Air Quality Standard (NAAQS) for health-based annual PM2.5 exposure is currently 12 ug/m^3 and they are proposing to lower it between 9-10 ug/m^3 [181]. Compared to this standard, the average PM2.5 concentrations found at most of the monitored locations during this study are above both the current and proposed standards. Though long-term AQ monitoring could better determine and compare the average PM2.5 concentrations on the campus to the US EPA NAAQS, it is still essential to both take action, if possible, to reduce the exposure to PM2.5 on the campus and to communicate these results with the KD Team more broadly.

Previous studies have cited improving indoor air filtration and ventilation, using more efficient and cleaner-burning cooking methods, and trying to implement behavioral changes through education on air quality as possible solutions to improve IAQ conditions [182], [183], [184], [185], [186]. However, there may be social and cultural norms as well as geographical limitations that could impact the operationalization of these solutions. Some low-cost improvements the KD team could implement that could improve the IAQ around the school such as placing and utilizing floor mats at entrances and exits to campus buildings to reduce particles brought inside through footwear and improving the air ventilation within campus buildings by installing improved air filters or fans. Another behavior-based improvement they could make is keeping the windows in campus buildings closed more often since they often open them for ventilation or install screens to help filter some pollution from entering the building.

6.3.2 Student Assessment Results

6.3.2.1 Overall Comparison of Both Cohorts

The results from both cohort assessments were first analyzed in aggregate to determine how well the students performed as a class (Table 15). The lowest and highest scores from Cohort 1 were a 44% and 91%, respectively. The average assessment score for Cohort 1 was a 66% and the standard deviation was about 4.9 points (11%). Though higher scores on the assessment across Cohort 1 could indicate a higher level of retention and understanding of the module material, it is important to note there was a total of thirteen months between their last module and taking the assessment due to academic scheduling conflicts which likely impacted their scores. For Cohort 2, the lowest and highest scores were 62% and 91%, respectively. Cohort 2's class average was an 82% with a standard deviation of about 3.5 points (8%). Compared with Cohort 1, Cohort 2 performed better than them with a higher-class average and a smaller standard deviation, indicating a higher level of material retention for Cohort 2.

Table 15. Summary of overall student assessment grades from Cohorts 1 and 2.

	Cohort 1 (*N*=27)	Cohort 2 (*N*=20)
Lowest Grade (%)	44	62
Highest Grade (%)	91	91
Average Grade (%)	66	82
Standard Deviation (%)	11	8

Following this analysis in aggregate, the student assessment results were also analyzed by question to see which information was retained the most by students across the LOs (Figure 14). For comparative purposes between Cohorts, this analysis was only completed for questions that were similar between the assessments. Two of the assessment questions asked about LO 2 material which was focused on the basics of AQ. Compared to Cohort 1, at least 90% of Cohort 2's students received full credit on both LO 2 questions whereas most of the Cohort 1 students only received full credit on one of those questions (Figure 14). Four of the assessment questions focused on LO 3 material, IAQ and its connection to health. For three of these questions, at least 95% of Cohort 2 students received full credit, however only around half of Cohort 1 students did so on those questions (Figure 14). However, one of the questions asked students to choose whether PM2.5 can be inhaled into the smallest or largest part of their lungs and Cohort 1 performed better on this question than Cohort 2 (44% and 0% full credit, respectively). Most of the students in both Cohorts were able to explain what an AQ monitor does, one of the questions asking about LO 4 material, which focused on PurpleAir and other AQ sensors. The second LO 4 question asked more specifically about the data collection process using the PurpleAir monitor to which a majority of Cohort 2 students answered correctly, but only 26% of Cohort 1 students received full credit (Figure 14). The last similar question between both Cohorts assessments asked students to write about their monitoring location and provide reason for why it was chosen to monitor in. At least half of the students in both Cohorts received full credit on this question, however there were more Cohort 1 students who answered correctly compared to Cohort 2 (Figure 14).

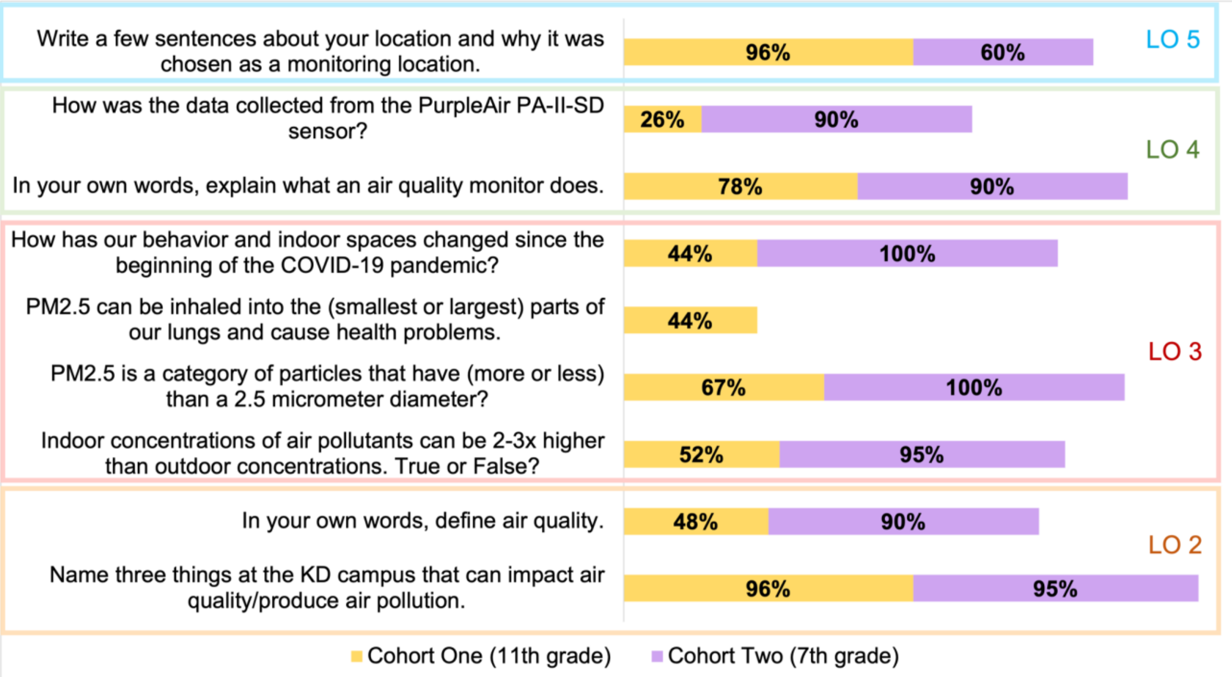

Figure 14. Percentage of fully correct answers on student assessments by Cohort and Learning Objective (LO). Inspired by [151].

One of the final questions on both Cohorts' assessments asked students to make inferences and conclusions about an example PM2.5 diurnal profile from one of the monitored locations. This profile was similar to the profiles each monitoring group received during the VLE which showed temperature, humidity, and PM2.5 concentration over a few days. Though the wording of this question was different between the two Cohort assessments, the question overall asked both Cohorts about material from LO 6, synthesizing and analyzing data. The majority of Cohort 1 students (78%) did not receive any credit for this question due to their answers indicating that PM2.5 concentration changes were caused solely by changes in the humidity and vice versa. Though PM2.5 concentration and humidity can change concurrently, the question was instead asking students to connect the data on the graphs to the location's surrounding environment that could have impacted the PM2.5 concentration. In Cohort 2, only a few students (10%) received full credit on the question, but most of the students (70%) received partial credit. Most of their answers explained how the data changed over time, however they did not describe specific patterns or trends that could be seen on the profiles. Specifically, during Cohort 2's VLE, an extended amount of time and additional activities were utilized during LO 6, considering they were not as familiar with graphing given their grade level. However, their lack of practice with interpreting graphs likely negatively impacted how well the students were able to answer this question.

The question-by-question analysis revealed that questions asking the students about topics that were repeatedly reviewed or things they directly interacted with were answered correctly at a higher rate. For example, a high proportion of students in both Cohorts received full credit on the questions asking them to identify three sources of air pollution in or around their school (LO 2) and to explain what an AQ monitor does in their own words (LO 4). In the modules, material related to both of these questions was reviewed throughout the curriculum and utilized student participation. Though Cohort 2 performed better than Cohort 1, overall, with a class average of 82% versus 66%, it is important to note Cohort 2 was assessed within two weeks of finishing the VLE whereas Cohort 1 was assessed about one year following the end of their VLE sessions which likely contributed to their lower class average. Considering this curriculum was the KCE students' first introduction to AQ and its connection to health and well-being, they may have had difficulty retaining information from their learning experience. However, overall, both of the Cohorts scored, on average, above a 60% on the student assessments indicating students' both learned and retained information from their experiences with the curriculum.

6.3.2.2 Student Assessment Feedback from Both Cohorts

The final question, question twelve, on the student assessment asked students to reflect on their experiences with the curriculum and modules. Most of the students in Cohort 1 indicated they learned about *'air pollution and its sources and the effect it has on the environment as well as the* *respiratory system'*. Some of the students from both Cohorts reflected on learning about air monitoring and how to use the PurpleAir monitor. Some of the students from Cohort 2 wrote specifically about *'learning how to collect, download and interpret the AQ data'*. However, there was also some student feedback that indicated some of the students from Cohort 1 incorrectly remembered some of the material they learned. For example, some students indicated they learned that the PurpleAir monitor can collect polluted air. The source of this confusion could be that during the module focused on AQ monitors, we discussed that there are fans within the monitors that cycle air through them in order to count the number of particles present. Some of the students may have misremembered the information from how it was taught or they remembered that the air passed through the monitor but were unable to articulate that in their responses. Overall, the students from both Cohorts reflected positively on their experience and reported learning new information about AQ pollution and its importance in relation to their health and surrounding environment.

6.4 Limitations and Challenges

Throughout the duration of this project, there were a few challenges we experienced which impacted the VLE experience for both the KCE students and instructors as well as the project timeline. Three of the challenges we want to highlight from this project include: 1) the unstable wireless internet connection at the KCE II campus, 2) scheduling impacts and time constraints, and 3) possible language barrier between students and the virtual instructor (Vaden). During this project, the KCE II campus sometimes experienced unstable wireless internet connection and power outages which impacted some of the module sessions and may have impacted the AQ monitoring results. Some sources that may have impacted the connectivity included the rural location of the KCE II campus, harsh weather conditions, and low internet bandwidth levels. We utilized the PurpleAir PA-II-SD sensor for the AQ monitoring which did not need a wireless connection to collect the data, however power outages could have impacted the sensor's continuous data collection. There were no large time gaps found in the AQ data results (more than 6 hours), however missing data still has an impact on the collected AQ data and analysis. However, unstable wireless connectivity had a larger impact on some of the module sessions during the project. In response to these impacted sessions, we were able to adjust the module and curriculum schedule to ensure the students in both Cohorts received all of the learning material in subsequent sessions. Due to conflicting schedules, this may have impacted later module sessions and likely impacted student learning and could have improved the VLE for the students in both Cohorts. Future projects that experience similar connectivity problems due to unstable internet connection could plan for outages by pre-recording lecture material in order to provide students with the full curricular experience.

Another challenge we encountered during this project was scheduling and time constraints, particularly due to the KCE students school schedule. The module sessions for this project occurred after the KCE students' school day ended, however, there were still scheduled breaks and exams which impacted the module session schedule. Prior to beginning the project, the KD Team shared the school schedule and most of these conflicts were incorporated into the curriculum planning for this project. However, it is important to note that these scheduled school breaks and examination periods may have impacted the students' learning and retention throughout the VLE experience. One last major challenge we experienced during this project was a language barrier between the KCE students and the VLE instructor (Vaden). The KCE students are taught and speak

English as a part of their school curriculum, however they also use their native language, Kiswahili, to communicate both within and outside of classroom settings. When combined with internet connectivity issues, this language barrier was exacerbated at times and it may have impacted the students' learning and understanding of the VLE material. During every module session with both Cohorts, there was an KCE II instructor that was in person with the students in order to help alleviate some of the language and cultural barriers, however this still may have impacted the learning experience. Though we, the KCE students and instructors, and the KD Staff experienced some challenges in the duration of this project, everyone involved was adaptable and offered creative and efficient solutions which aided in the success of the project.

6.5 Conclusion

In response to a local AQ problem at the KCE II campus, we collaborated with KD on a project that would both educate the KCE students and instructors about AQ as well as monitor the air on the campus. For this project, we developed a problem-based engineering VLE which focused on both ambient and indoor AQ and utilized AQ monitoring as a citizen science educational tool during the curriculum. The curriculum utilized a combination of Britain and Liber's Conversational Teaching Framework and Morris's Learning Cycle, along with Bloom's Taxonomy and engineering design principles, to guide the development of the module sessions and learning materials (Figure 13). This curriculum was virtually administered to two groups of KCE II students, Cohort 1 (11th grade) and Cohort 2 (7th grade), and following their VLE, were given a summative assessment to assess their learning and gather their feedback on the experience. A part of this curriculum and VLE involved student groups co-developing an AQ monitoring plan and using a PurpleAir sensor to collect AQ data from different locations around the campus which was developed using a citizen science lens. The analysis for this project was two-fold: to first, analyze the AQ data collected from the different locations in order to provide information about the AQ to the KD staff and instructors as well as recommendations for alleviating some negative impacts that the AQ may have on the campus. Second, the summative assessments were also analyzed for both Cohorts of students in order to assess how well students understood and retained information from their learning experience. The AQ data analysis showed that at the majority of the locations monitored around the campus, the average PM2.5 concentrations (between 11-34 ug/m^3) were higher than the US EPA NAAQDS standard of 9-10 ug/m^3 [181]. Some low-cost improvements we will suggest to the KD team include improving air ventilation within campus buildings by installing improved air filters or fans and trying to keep the windows in campus buildings closed more often since they often open them for ventilation. The analysis on the student assessments showed that both Cohorts averaged at least a 66% on their assessments indicating they learned and retained information from their VLE. The assessments were analyzed both in aggregate and by LO and question and about 15% more students received full credit on questions asking about LOs where the material was either repeated throughout the module sessions or involved a hands-on experience for the students as compared with LOs that did not. Students, overall, indicated in their feedback that they enjoyed the experience and learned about AQ, its importance, and the impacts it can have on human health. As this project continues to wrap up, we will share the data, our concerns, as well as some recommendations with Dr. Ntaiya, the KD founder, and the rest of the KD Team. This collaborative project with KD was both rewarding and eye-opening for all participants involved and also illustrated the strength and positive impact that a citizen science, problem based VLE that is contextually specific can have on students and instructors.

7.0 Conclusions and Future Work

The overarching aim of this dissertation was to offer new perspectives and resources to the broader engineering education community across educational contexts, higher education and K-12, and cultures. This goal was achieved through two objectives which addressed two sectors of the engineering education community: higher education and K-12. The IUSE-PIPE project focused on providing engineering faculty from three different institutions with 1) a menu of inclusive teaching practices to improve inclusivity and belonging in their engineering classrooms for all students and 2) to provide them with support tools and resources to support practice implementation. This project resulted in a new inclusive teaching resource for the broader higher education engineering community, shared the participating faculty and student results from the pilot of the resource and learning communities, and provided recommendations and lessons learned for faculty who endeavor to do this work at their institutions. This inclusive classroom project also resulted in a conceptual framework which describes an undergraduate student's educational environment and articulates the people and groups that impact their experience, which partially addresses Objective 3. The second project, with Kakenya's Dream, focused on developing and piloting an international, engineering VLE for middle and high school grade (7^{th}-12^{th}) students at their all-girls school in rural Kenya. This study resulted in a new curricular resource for the K-12 engineering education community that is grounded in citizen science and problem-based learning as well as the engineering design process and utilizes a context-specific environmental problem to guide student learning. The ambient and indoor AQ results as well as some low-cost, sustainable recommendations were shared with the school and organization, Kakenya's Dream, to improve the AQ impacts their students and teachers experience. Fundamentally, using the results from this research overall, we aimed to explore different aspects of the STEM educational experience across cultures and contexts in two engineering education communities, higher education and K-12.

Throughout, this dissertation referenced and developed a number of different educational and teaching conceptual frameworks. As a part of the IUSE-PIPE project, we developed a conceptual framework of the STEM higher education environment which is described in Chapter 5 (Figure 11). Objective 3 for this dissertation was to synthesize Objectives 1 and 2 and develop a conceptual framework of the STEM educational environment. Though Chapter 5's conceptual framework focuses on the higher education environment, this framework can also be viewed from a K-12 perspective. The key groups in the framework included students, faculty, staff and administration and depicted how those groups interact and impact one another's experiences within the STEM educational environment. In the K-12 STEM education environment, these same key groups exist and the tools employed and developed in the IUSE-PIPE project could be adjusted for use in the K-12 environment.

One consideration for future work, is to expand Chapter 5's conceptual framework by more specifically, focusing on the STEM student educational experience. In addition to referencing the conceptual framework from this dissertation, this new conceptual framework also references Yao et al. Humanizing STEM Education framework and Dahlgren and Whitehead's Rainbow Model of Health Inequities to weave together students' educational, social, and cultural experiences in the context of their STEM education (Figure 15). Dahlgren and Whitehead's Rainbow Model is a socioecological model of the social determinants of health (SDOH) and highlights potential policy interventions that could improve people's health outcomes [187]. The SDOH framework, as described by the US Department of Health and Human Services (DHHS), are the non-medical factors that can impact a person's health and well-being and includes the conditions that people experience their lives within [20], [188]. The socioeconomic-political context of the SDOH consists of broad structural and cultural aspects of society that require action on the social determinants to be addressed at both the individual and community levels by public health organizations and their partners in multiple sectors including education, which is the focus of this new framework [21], [188], [189]. The literature affirms the need to expand and challenge the original SDOH framework and provide new perspectives which engage the agency of disadvantaged and marginalized communities and the responsibility of leaders across sectors, particularly in the face of new challenges such as the COVID-19 pandemic and the attack on DEI in education [190], [191], [192], [193].

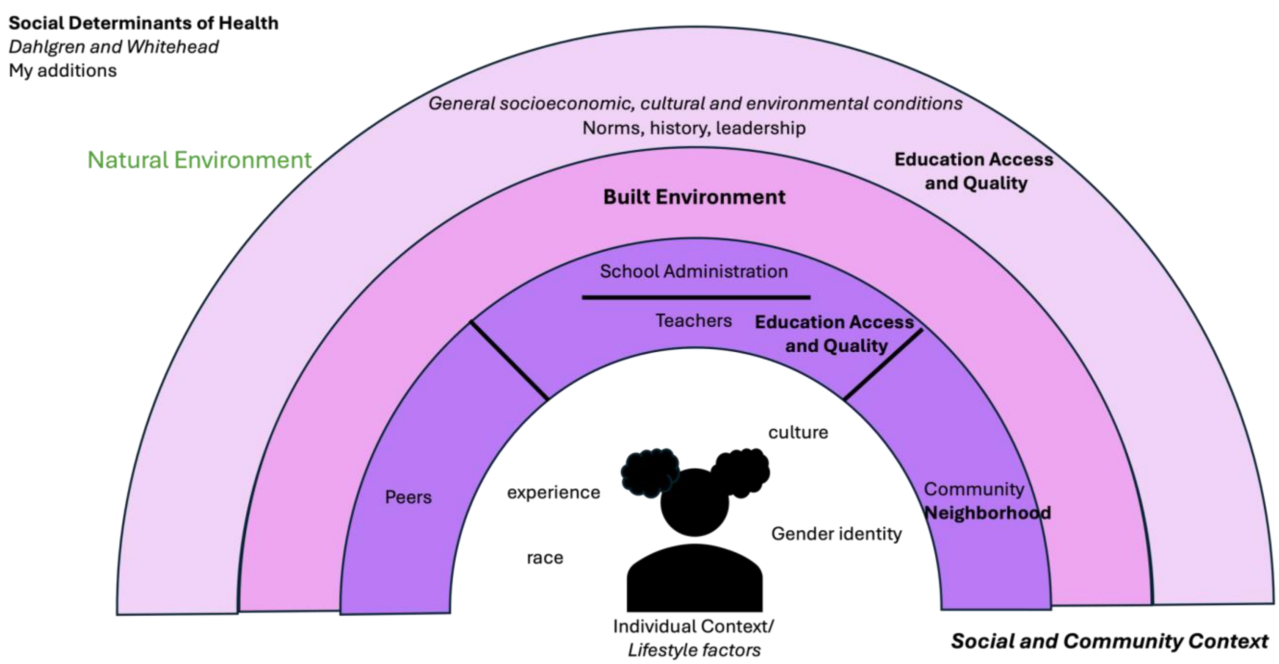

Figure 15. The Social Determinants of a STEM Student Conceptual Framework.

This framework, aptly titled the Social Determinants of a STEM Student, offers a new perspective on the STEM educational environment from a wholistic and humanistic perspective and centers student identities and experiences in relation to the people and groups who impact their educational experience (Figure 15). This framework is presented as a consideration for future work and will continue to be refined over the course of my career in the engineering education field.

In addition to this framework, other future work considerations include sharing and refining the inclusive classroom resources and tools developed in the IUSE-PIPE project by employing them in other institutional contexts across the higher education engineering community. Additionally, the VLE curriculum developed during the Kakenya's Dream project could also be piloted with other schools and grade levels, both nationally and internationally, to strengthen its adaptability across cultures and contexts.

The impetus of this dissertation to provide new perspectives and resources to the broader engineering education community resulted in recommendations, tools, and conceptual frameworks for both the higher education and K-12 engineering education communities. These results shown offer the engineering education community solutions to improve the education of future engineers, throughout the entire educational pipeline (Kindergarten through undergraduate levels), by wholistically considering and valuing the cultural and social wealth and experiences of students as equally as their technical education.

Appendix A

Supporting Information for Developing and Implementing an Inclusive Practices Menu in Undergraduate Engineering Classrooms (Chapter 3)

Appendix A.1 Inclusive Engineering Practices Menu

Inclusive Engineering Practices Menu

This menu of practices is intended to help faculty and instructors make their classrooms more inclusive for all students. It is organized by the traditional timing of a collegiate semester: Pre-Semester, Syllabus, In-Classroom Engagement and Discussion Tools.

° = I have used this strategy in the past and plan to use again.

✓= I plan to use this strategy

X = This strategy does not apply to my teaching context and/or I would not use it

☆= I would like to try this, though I may need more information or resources

Key

Identity – Mitigate bias in class design, content, grading, and group/teamwork

Relational – Build trusting relationships, Encourage student belonging, Active listening to students, Inclusive communication, Conflict resolution

Intercultural – Supporting student connections to content, Encouraging students to be their authentic selves, Creating opportunities for peers to connect, Addressing stereotype threat

These categories are adapted from the Aspire Alliance aspirealliance.org

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Quick Links

Pre-Semester

Practices to help instructors when they are preparing for the upcoming semester

Identity

- ❑ Examine the assumptions you currently have and have made previously about your students – This is a mental check-in for yourself that can provide reflection on your own implicit bias. Actively commit oneself to the process of self-actualization to increase awareness of your own worldview.
- ❑ Learn different teaching techniques to vary teaching methods during the semester and ensure they are all accessible to all students
- ❑ Learn about implementing techniques that can decrease the potential intimidation that students feel towards instructors
- ❑ To the best of your ability, ensure that the classroom is physically accessible and usable by all students and plan for accommodations for students whose needs are not fully met by the instructional design

Relational

- ❑ Anticipate and prepare for potentially sensitive issues that may come up during discussions – Try to be versed in current events, especially those that could/would affect students (whether that is based on age or marginalized group). Devise personal strategies for managing yourself and the class to turn those potentially heated moments into powerful learning experiences.
- ❑ Build your schedule to ensure your availability for your students both inside and outside the classroom – Preparing this before the semester intentionally can make a difference to both you and students during the semester

Intercultural

- ❑ Stereotype replacement – Actively replace stereotypical responses for non-stereotypical ones. This helps to recognize personal stereotyping and recognizing how our responses reflect that.
- ❑ Counter-stereotypic imaging – This is like stereotype replacement, but rather it involves imagining in detail when counter-stereotypes are used for others. This strategy makes positive examples salient and accessible when challenging a stereotype's validity.

Syllabus

Practices to help instructors when they are preparing and creating their syllabus

Identity

- ❑ Be explicit about the goals for the class
- ❑ Ensure course content does not marginalize nor draw undue attention to differences between students
- ❑ Create a civility statement with behavioral expectations to create a welcoming environment for everyone
- ❑ Develop the syllabus in a way that explores multiple perspectives on the course topics
- ❑ Review curriculum/course content for hidden forms of oppression and marginalization and make changes
- ❑ Adopt practices that reflect high values with respect to both diversity, equity, and inclusiveness
- ❑ Differentiate instruction – React responsively to learner's needs through content, process, and product. If possible, offer students choices on how and by what means they learn course material
- ❑ List contact information for tutoring and writing centers, disability services, and other services that may be helpful on campus

Relational

- ❑ Establish and reinforce ground rules for interaction between people in the class
- ❑ Set up processes or surveys to get feedback on the climate – not necessarily relying on the school's assessment choice, like the OMETs
- ❑ Increase opportunities for contact with students - Seek opportunities to encounter and engage in positive interactions with students, particularly those who are underrepresented or within a minoritized group
- ❑ Invite students to meet with you to discuss disability-related accommodations and other learning needs – Review this in class multiple times to reinforce it as well
- ❑ Try not to fill every class with so many different activities that students are not able to process through them. Overfilling the class could also prevent in-depth discussions, whether on topic or not, from occurring during class.
- ❑ Promote empathy – Demonstrate empathy to your students and throughout the semester and lead as an example for your class to follow
- ❑ Create a classroom where failure is just diagnostic and not necessarily grade-oriented - You can encourage and offer the chance to revise, improve and redo things to encourage improvement

Intercultural

- ❑ Integrate multiple identity groups and multiculturalism into curriculum/course content through inclusion of cultural histories, local histories, and contributions. This is not just limited to diversity in race, but also in gender expression and other areas.

In-Classroom Engagement

Practices to help instructors when they are planning and outlining their classes for the semester

Identity

- ❑ Differentiate Instruction – React responsively to learner's needs through content, process, and product. If possible, offer students choices on how and by what means they learn course material
- ❑ Make interactions in class accessible to all participants
- ❑ Vary presentation strategies for delivering course material – This can be as small as incorporating videos into PowerPoint slides to incorporating a project into the course where the classroom is flipped (students getting the chance to teach)
- ❑ Multiple Hands, Multiple Voices – You can preface questions with how many responses you would like to receive to encourage different students to participate
- ❑ Work in small groups or stations when possible – Be intentional about how student groups and project teams are formed

Relational

- ❑ Be mindful of low-ability cues - using throwaway comments like "I'll be happy to help because I know girls have trouble with math" can impact students' identity with negative perceptions
- ❑ Do not ask individuals to speak for an entire group
- ❑ Address tensions in the classroom as close to when they arise as possible – do not delay on addressing them because they could get worst with time
- ❑ Recognizing effort and set goals with students - Regardless of how big, this helps students to realize that it takes effort and hard work to reach goals rather than just luck or needing to be smart to accomplish things
- ❑ Employ interactive teaching techniques – Utilizing technology can also help with this such as using different apps and websites for students to respond to questions or participate
- ❑ When teaching, use straightforward language and avoid unnecessary jargon and complexity
- ❑ "Whip Around" – Instructor poses a question and each student has less than 30 seconds to respond which could allow more participants, but also can encourage learning through the different types of explanations and responses that people give
- ❑ Do not judge responses to questions or discussion points – If judgement naturally arises in you, check this bias, and reflect on why this may have happened

- ❑ Use humor while teaching when appropriate – Definitely be aware and research the best ways to utilize humor without offending students and others whether they are present or not

- ❑ Perspective Taking – Encourage students to take the perspective in the first person of a member of a stereotyped group. This can help to increase the psychological closeness to the stigmatized group and could help reduce implicit bias in the classroom.

- ❑ Increase opportunities for contact with students - Seek opportunities to encounter and engage in positive interactions with students, particularly those who are underrepresented or within a minoritized group

- ❑ Utilize pre-class asynchronous activities – Use various resources before classes such as videos, podcasts, and more to both prepare students for class and encourage discussion from multiple students once class has begun

<u>Intercultural</u>

- ❑ Work in small groups or stations when possible
- ❑ Use multiple and diverse examples and comparisons to help students identify different connections
- ❑ Give students opportunities to apply skills or knowledge in diverse contexts
- ❑ Individuation – Help to prevent stereotypic inferences by obtaining specific information about group members. This will also help others to evaluate members of the target group based on personal attributes rather than group-based or visual stereotypes
- ❑ Use teaching methods and materials that are motivating and relevant to students with diverse ages, genders, and cultures
- ❑ Avoid segregating or stigmatizing students by drawing undue attention to a difference or sharing private information on them unless the student brings up the topic first
- ❑ Use student preferred names and pronouns in electronic and in-person communications
- ❑ Require small groups in the class to communicate in ways that are accessible to and inclusive of all group members
- ❑ Assign group work in which learners must engage and interact with each other using a variety of skills and roles
- ❑ Activate student voices throughout the entirety of the class – Engage students in more ways than one so they feel comfortable and able to share their thoughts
- ❑ Collaborate with students as co-constructors of knowledge and give them the opportunity to share for everyone to learn from them

- ❑ Incorporate "Think-Pair-Share" into course activities – This technique allows for students to take time to respond to a question on their own, whether written or not, and then discuss with their peers before sharing to the rest of the class. This will also allow for connections to build among students.

Discussion Tools

Practices to help instructors when they are preparing for and hosting discussions in their courses

Identity

- ❑ Respect different ways of knowing (demonstrating knowledge of something) from multiple approaches whether it be realistic, fantasy, correct, or incorrect, both inside and outside of the classroom

Relational

- ❑ Model the inclusive language, behavior, and attitudes you'd like to see reflected in the classroom
- ❑ Reinforce the ground rules set forth in the syllabus for interaction or create new ones for the purpose of discussion in class
- ❑ Anticipate and prepare for potentially sensitive issues that may come up during discussions
- ❑ Address tensions in the classroom as close to when they arise as possible – do not delay on addressing them because they could get worst with time
- ❑ Avoid segregating or stigmatizing students by drawing undue attention to a difference or sharing private information on them unless the student brings up the topic first
- ❑ Use student preferred pronouns and names in electronic and in-person communications
- ❑ Interrupt blatantly racist and discriminatory behaviors when they emerge in class and have students reflect on the situation – If the students are comfortable, it could be a good idea to have a class-wide discussion and reinforce the ground rules set on communication from the syllabus
- ❑ Have a longer wait time following asking questions for students to think and expand the number of participants

Intercultural

- ❑ Use multiple and diverse examples and comparisons to help students identify different connections
- ❑ Stereotype replacement – Actively replace stereotypical responses for non-stereotypical ones. This helps to recognize personal stereotyping and recognizing how our responses reflect that.
- ❑ Counter-stereotypic imaging – This is like stereotype replacement, but rather it involves imagining in detail when counter-stereotypes are used for others. This

strategy makes positive examples salient and accessible when challenging a stereotype's validity.

- ❑ Perspective Taking – Encourage students to take the perspective in the first person of a member of a stereotyped group. This can help to increase the psychological closeness to the stigmatized group and could help reduce implicit bias in the classroom.
- ❑ Invite students to share cultural experiences with other faculty and peers – This can help to increase participation, but also can create a richer learning experience because of sharing different perspectives
- ❑ Do not judge responses to questions or discussion points – If judgement naturally arises in you, check this bias, and reflect on why this may have happened

Appendix A.2 Classes Student Survey was Distributed To

Table 16. Classes Student Survey Distributed to.

	Pitt	ASU	Mines	Total
Civil Engineering Courses	11	0	2	13
Other Engineering Courses	0	1	5	6
STEM Courses	0	2	4	6
Course Titles				
Introduction to Construction Management, Fate and Transport in Environmental Engineering, Introduction to Environmental Engineering, Wastewater Collection and Treatment Plant Design, Life Cycle Assessment, Construction and Culture, Senior Design, Advanced Engineering Thermodynamics, Engineering Design and Society, Introduction to Probability, etc.				

Appendix A.3 Full Student Survey Questions

Table 17. Full Student Survey Questions

Question	Possible Response
Instructor Course Questions	
1. For this course, indicate the extent to which you agree with the following statements: a. I feel encouraged to ask questions. b. I feel uneasy exposing gaps in my understanding. c. I feel reluctant to speak openly in this class. d. I do feel a spirit of community in this class.	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
2. For this course, indicate the frequency in which your instructor has done the following: a. … asked students to discuss a solution or answer with others during class b. … clearly explained course goals and assignment requirements c. … provided feedback on an assignment, draft, or work in progress d. … connected your learning to societal problems or issues (unemployment, climate change, public health, etc.) to explain or provide context to class materials e. … tried to better understand someone else's views by imagining how an issue looks from their perspective f. … included diverse perspectives (political, religious, cultural, gender, etc.) in this course's discussions or assignments	Very Often, Often, Sometimes, Never
3. To what extent did the instructor provide flexibility given the effects of the COVID-19 pandemic on students?	Very Much, Quite a Bit, Some, Very Little
4. Indicate the quality of your interaction with the faculty member who invited you to complete this survey.	1 (Poor), 2, 3, 4, 5, 6, 7 (Excellent), NA
Peer Questions	
1. For this course indicate the frequency in which YOU have done the following: a. … felt judged based on a question, answer or comment you made in class	Very Often, Often, Sometimes, Never
2. For this course, indicate the extent to which you agree with the following statements: a. I feel connected to others in this course. b. I feel wary trusting other students in this course	Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
3. Indicate the quality of your interactions with other students in this course.	1 (Poor), 2, 3, 4, 5, 6, 7 (Excellent), NA
Department/University Questions	
1. Select the two options which have the largest impact on the statements below: a. I feel most respected by… b. Women are treated most fairly by… c. I feel the most belonging due to my interactions with… d. I feel the most valued by… e. Minoritized people are treated the most fairly by… f. In regard to my success in college, I can depend the most on g. I am the most comfortable voicing my concerns to…	My Peers, This Instructor, My Department, This University
Class Information Questions	
1. Which institution do you attend?	University of Pittsburgh, Colorado School of Mines, Arizona State University
2. What semester are you currently in?	Fall 2021, Spring 2022, Fall 2022, Spring 2023, Fall 2023, Spring 2024
3. What is the course name/number? For example CEE 2001 or ENGR 0012	Fill in the blank
4. Who is the instructor for the course?	Fill in the blank
Demographic Questions	
1. What is your class level?	First Year, Second Year, Third Year, Fourth Year, Fifth or more Years, First Year Graduate Student
2. What was your GPA entering this semester?	3.5 or above, 3.0-3.49, 2.5-2.99, 1.99 or below
3. How would you describe yourself? (Select all that apply)	American Indian or Alaska Native, Black or African, Hispanic or Latinx, Middle Eastern or North African, Hawaiian or Other Pacific Islander, White, Another race or ethnicity, Prefer not to respond
4. Are you a student-athlete on a team sponsored by your institution's athletics department?	Yes, No
5. Are you a current or former member of the U.S. Armed Forces, Reserves, or National Guard?	Yes, No
6. Do you have a disability or condition that impacts your learning, working, or living activities?	Yes, No, I prefer not to respond
A. If answered yes, which of the following impacts your learning, working, or living activities?	Sensory disability: Blind or low vision; Deaf or hard of hearing, Physical disability: Mobility condition that affects walking, Mobility condition that does not affect walking, Speech or communication disorder, Traumatic or acquired brain injury, Mental health or developmental disability: Anxiety, Attention deficit or hyperactivity disorder (ADD or ADHD), Autism Spectrum; Depression; eating disorder; schizophrenia, etc.), Another disability or condition: Chronic medical condition (asthma, diabetes, Crohn's disease, etc.), Learning Disability, Intellectual Disability, Disability or condition not listed
7. Which of the following best describes your sexual orientation?	Straight (heterosexual), Bisexual, Gay, Lesbian, Queer, Questioning or unsure, Other orientation, please specify:__________, I prefer not to respond
8. Are you an international student?	Yes, No
9. Are you a first-generation college student?	Yes, No
10. What is your gender identity?	Female, Male, Non-binary or gender-fluid, Another gender identity, please specify: ___________, I prefer not to respond

Appendix A.4 Student Respondents by University for the duration of the IUSE-PIPE project.

Table 18. Student Respondents by University for the duration of the IUSE-PIPE project (n=219).

Semester	Number of Classes Assessed	Total Student Respondents	% Pitt Student Respondents	% ASU Student Respondents	% Mines Student Respondents
Fall 2021	6	19	100	0	0
Spring 2022	2	10	100	0	0
Fall 2022	10	85	9.2	80.5	10.3
Spring 2023	5	3	66	0	33
Fall 2023	5	107	2.8	97.2	0
All	28	215	16.7	79.1	3.7

Appendix A.5 Complete Student Survey Results for duration of the IUSE-PIPE project.

Appendix A.5.1 Student Survey responses for how often instructors employed specified classroom techniques comparing Majority and Non-Majority students.

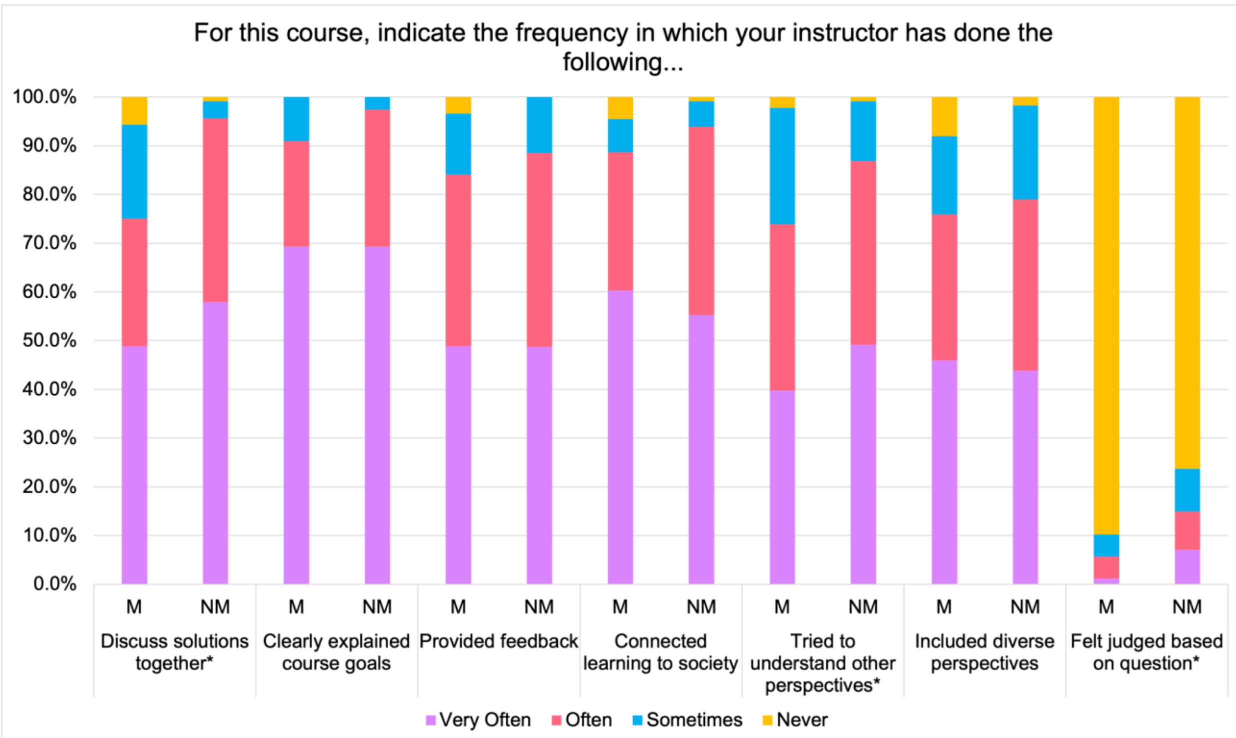

Figure 16. All student survey responses on how often their instructors employed specified classroom techniques comparing Majority and Non-Majority students (n=202).

(note: M – Majority: students who identified their race as White or White with another race; NM – Non-Majority: students who identified their race as a different option or a combination of options excluding White; *Asterik denotes significant difference found in 2-sample t-tests).

Appendix A.5.2 Student Survey Responses on their classroom experiences with peers and instructors comparing Majority and Non-Majority students.

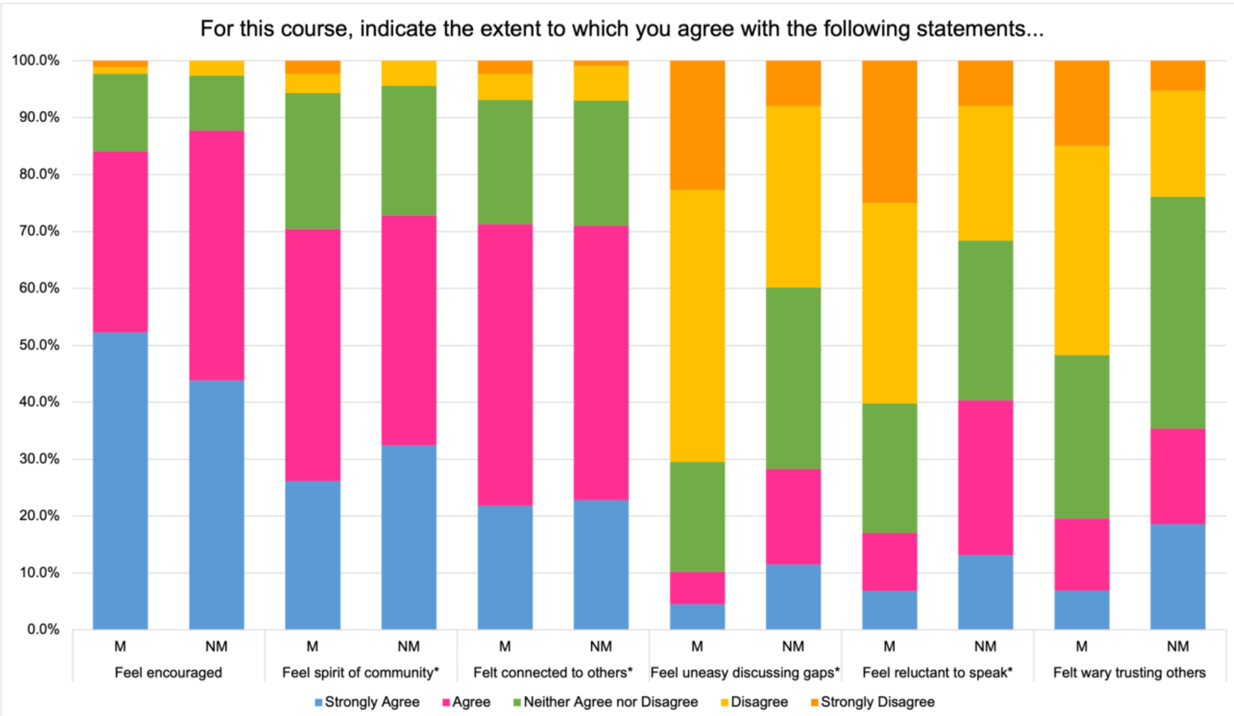

Figure 17. All student survey responses on their classroom experiences with peers and instructors comparing Majority and Non-Majority students (n=202).

(note: M – Majority: students who identified their race as White or White with another race; NM – Non-Majority: students who identified their race as a different option or a combination of options excluding White; *Asterik denotes significant difference found in 2-sample t-tests).

Appendix A.5.3 Student Survey responses for how often instructors employed specified classroom techniques comparing Male and Non-Male students.

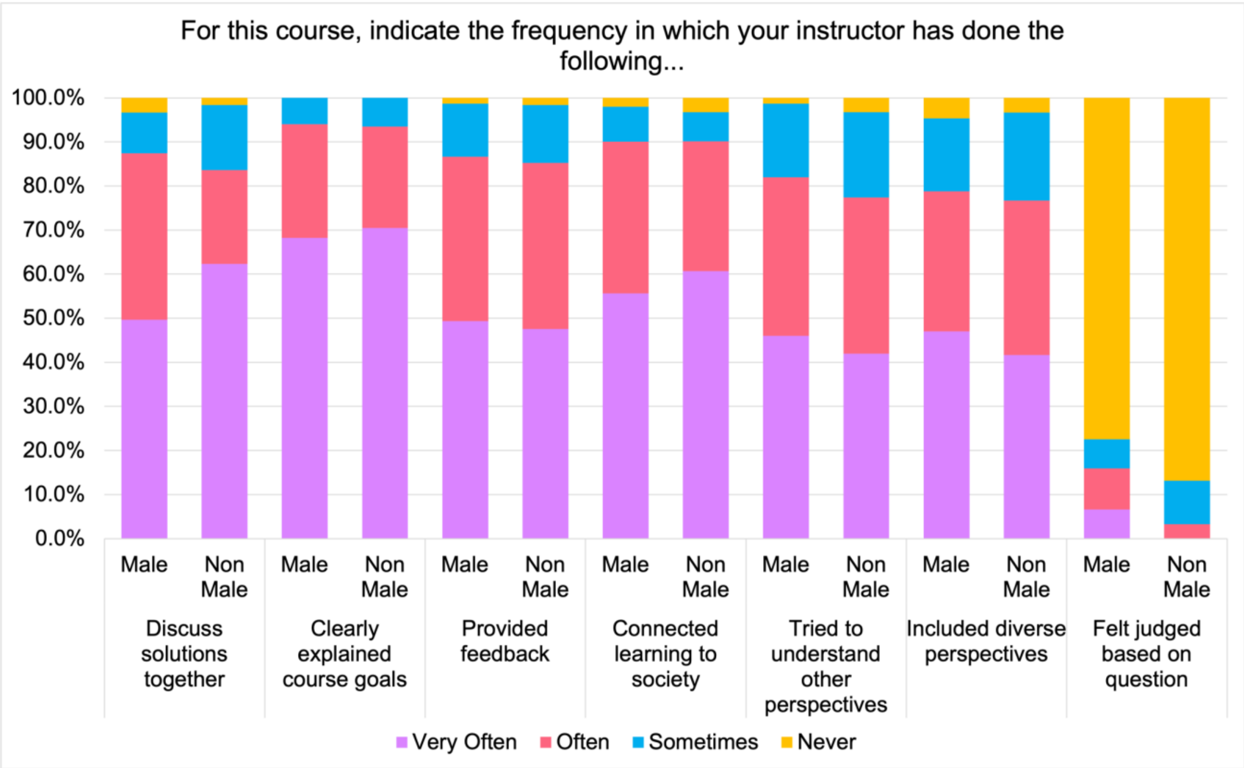

Figure 18. All student survey responses by self-identified gender identity on how often their instructors employed specified classroom techniques (n=202).

Appendix A.5.4 Student Survey Responses on their classroom experiences with peers and instructors comparing Male and Non-Male students.

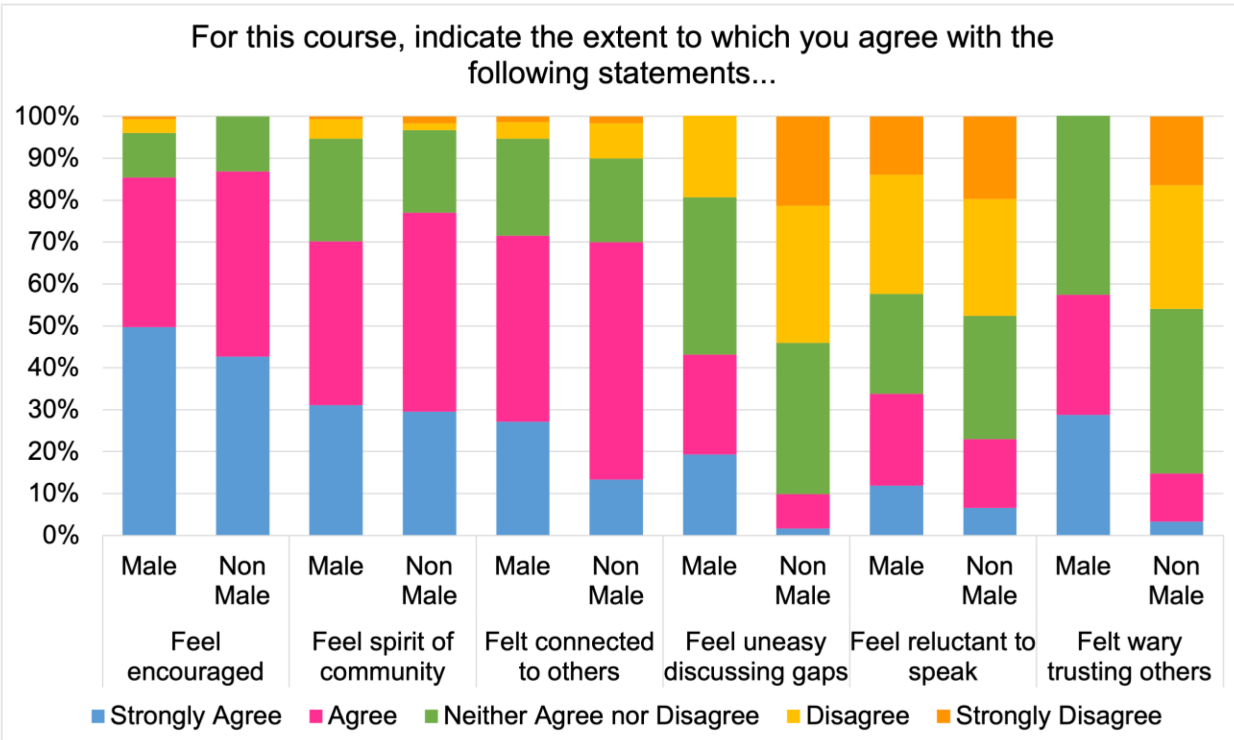

Figure 19. All student survey responses by self-identified gender identity on their classroom experiences with peers and instructors (n=202).

Appendix B

Supporting Information for Inclusive Engineering Classroom Learning Communities: Reflections and Lessons Learned from Three Partner Institutions

(Chapter 4)

Appendix B.1 Swimlane Diagrams for ILC Development at the Partner Institutions

Appendix B.1.1 University of Pittsburgh ILC Swimlane Diagram

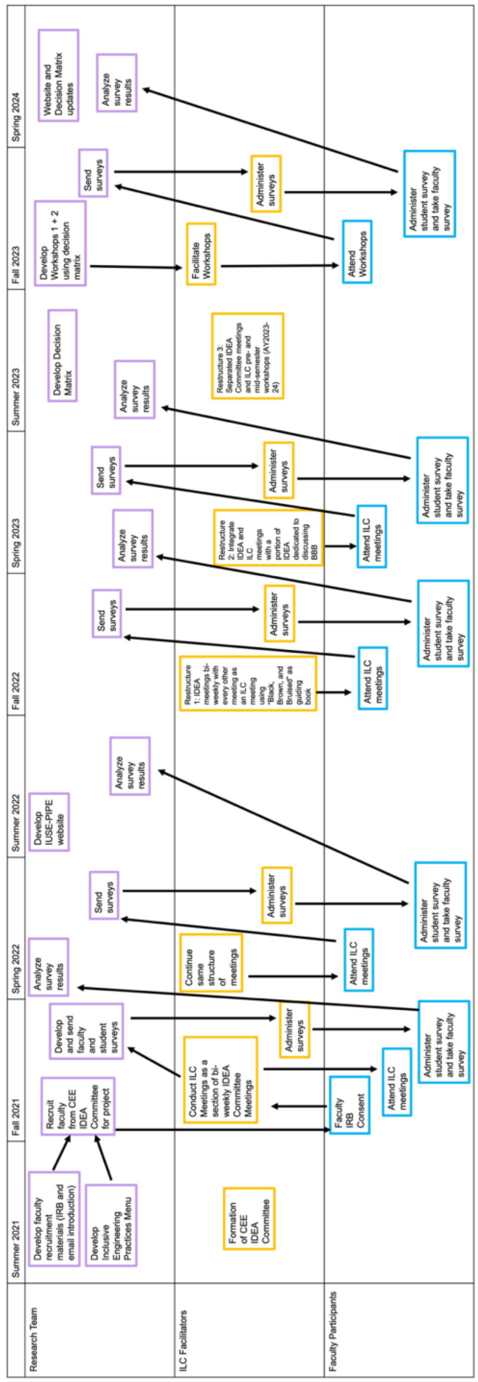

Figure 20. University of Pittsburgh ILC Development Swimlane Diagram

Appendix B.1.2 Arizona State University ILC Swimlane Diagram

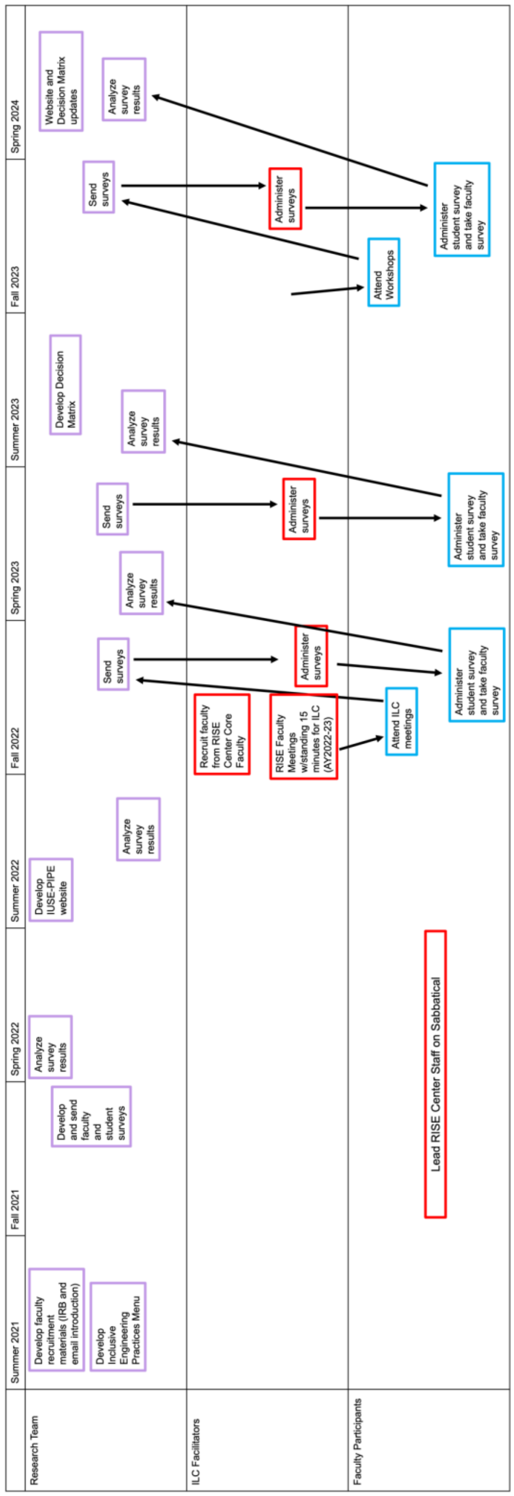

Figure 21. Arizona State University ILC Development Swimlane Diagram

Appendix B.1.3 Colorado School of Mines ILC Swimlane Diagram

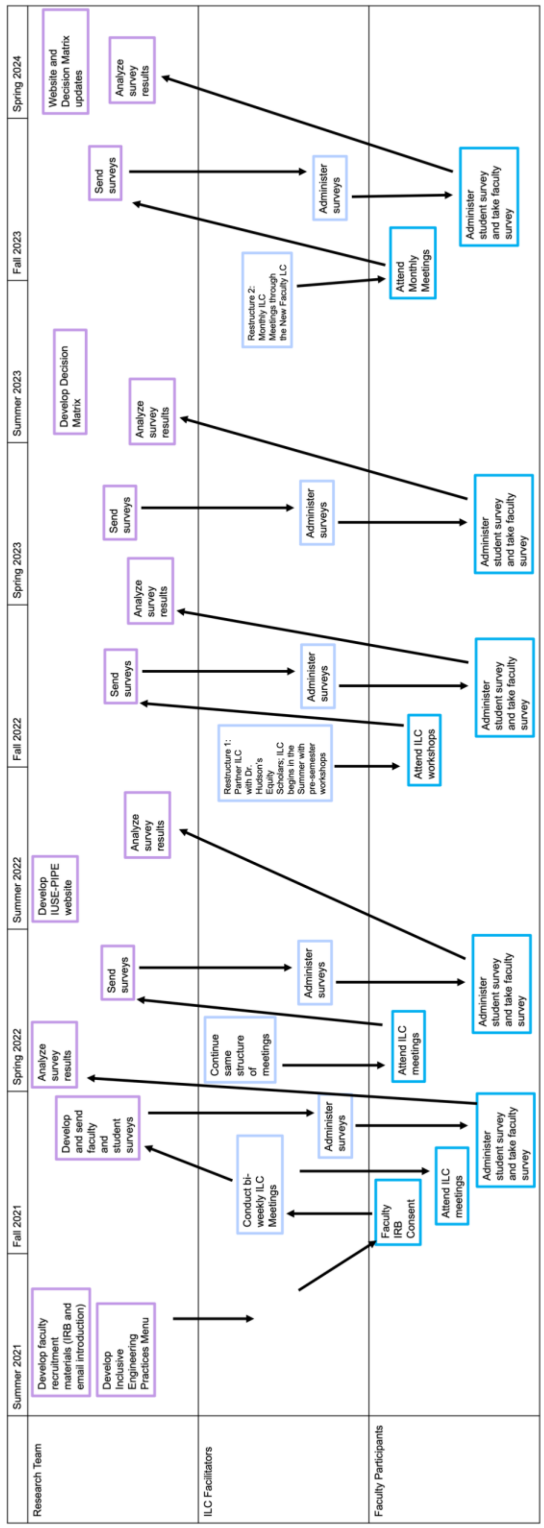

Figure 22. Colorado School of Mines ILC Development Swimlane Diagram

Appendix B.2 Full Faculty Survey Questions

Table 19. Full Faculty Survey Questions

Question	Possible Response
Instructor Information	
1. Please give yourself a color animal identifier in order to keep track of the responses for your course (e.g. Purple Cheetah).	Open Ended
2. What University do you teach at?	University of Pittsburgh, Colorado School of Mines, Arizona State University
3. What course(s) are you intentionally implementing inclusive strategies during the current semester? Please list course department, number, title, and number of students in course (e.g. CEE XXXX: Introduction to CEE - 20 students) If more than one course, please separate them by commas.	Open Ended
Strategies Questions	
Please check the strategies you have implemented for the current semester for your course(s) from the **Pre-Semester** section.	Select from the list of Pre-Semester strategies on the Inclusive Engineering Practices Menu
Please check the strategies you have implemented for the current semester for your course(s) from the **Syllabus** section.	Select from the list of Syllabus strategies on the Inclusive Engineering Practices Menu
Please check the strategies you have implemented for the current semester for your course(s) from the **In-Classroom Engagement** section.	Select from the list of In-Classroom Engagement strategies on the Inclusive Engineering Practices Menu
Please check the strategies you have implemented for the current semester for your course(s) from the **Discussion Tools** section.	Select from the list of Discussion Tools strategies on the Inclusive Engineering Practices Menu
If you utilized any other strategies, please write them out below. If writing more than one strategy, please separate them by numbering them.	Open Ended
Inclusive Learning Community Questions	
Please reflect on your experience in your Inclusive Learning Community.	Open Ended
Please list any suggestions or changes that you would make to make your Inclusive Learning Community in order to make it more impactful.	Open Ended

Appendix B.3 Faculty Survey Response Rate by ILC Archetype

Table 20. Faculty Survey Response Rate by ILC Archetype.

Semester	# Faculty Received Survey	# Total Faculty Responses (%)	# Department-wide Responses (%)	# School-wide Responses (%)	# Institution-wide Responses (%)
Fall 2021	19	7 (37)	4 (57)	0 (0)	3 (43)
Spring 2022	19	2 (11)	2 (100)	0 (0)	0 (0)
Fall 2022	35	10 (29)	4 (40)	1 (10)	5 (50)
Spring 2023	35	5 (14)	1 (20)	1 (20)	3 (60)
Fall 2023	35	5 (14)	1 (20)	2 (40)	2 (40)
All	108	29	12 (41)	4 (14)	13 (45)

Appendix C

Supporting Information for Improving Inclusivity in Undergraduate Engineering Classrooms: Reflections from Three Partner Institutions

Appendix C.1 Inclusive Practices Used by Participating Faculty during IUSE-PIPE project not included on the Inclusive Engineering Practices Menu

Table 21. Inclusive practices participating instructors employed in their classrooms that were not listed on the menu.

Made time during class for group work so students had a "neutral" meeting place and time built into their schedules.
Adoption of a learner's mindset, hence encouraging reward for learning instead of reward for achieving marks.
Brought guests into class including: • The University Librarian to discuss with my students the value, importance, and significance of literature reviews when one is tasked with writing a scientific report. • Professors from other disciplines to introduce the ideas of "Social Justice in Engineering Education", as well as "Making the Invisible Visible".
Set up project groups by ranked choice voting by topic but gave students option to request different assignment.
Provided a Zoom link and recordings to the classes for students not comfortable with the in-person experience.
Highlighted the scholarship of BIPOC faculty and scholars where I could.
Eliminated tests/exams and used "Assessments" as the language -- these were untimed and allowed students to demonstrate mastery.
Asked students to specifically think about how design decisions are directly impacted by considering *who* we are designing for. Will we identify different "optimal" designs by considering other (including marginalized) communities?
Students wrote a 1-2 paragraph "Gratitude Gesture" to acknowledge and thank those that helped them achieve their academic goals.
We discuss history in this class at length, and we discussed why European history is dominant. The professor then challenged students to consider who/how/why knowledge of all forms is documented and how that influences our worldview.

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