

Cultivating Future Academic Leaders: Innovative Mentorship and Leadership Interventions for Engineering Doctoral Students

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Renetta Garrison Tull, Ph.D., is the Vice Chancellor for Inclusive Excellence at the University of California Davis, and she is a past convenor for the University of California's system-wide (10 campus) Council of Vice Chancellors for Equity and Inclusion. Tull's undergraduate and doctoral degrees in electrical engineering and speech science are from Howard University and Northwestern University, respectively. She has had past faculty roles at UW-Madison, the University of Maryland College Park, and UMBC. At UC Davis, she is an Adjunct Professor in the Department of Electrical and Computer Engineering in the College of Engineering, and a faculty affiliate in the Interdepartmental Program on Human Rights Studies. As Vice Chancellor, her divisional portfolio includes the Davis-based Office of Campus Community Relations, and the Office for Advancing Mentoring and the Professoriate. The Sacramento headquarters houses the Office for Health Equity by Design for Inclusive Excellence, serving the medical school, nursing school, and medical center. Inclusive Excellence also covers medical clinics around California, and UC Davis' locations in the Bay Area and other parts of the state. Her portfolio also includes the Avanza initiative; the Police Accountability Board; the Center for Reducing Health Disparities; the Center for the Advancement of Multicultural Perspectives on Science; the Center for the Advancement of Multicultural Perspectives on Social Sciences, Arts, and the Humanities; and the Truth, Community Healing, and Transformation Center. She credits the success of Inclusive Excellence to talented teams and a supportive university environment. She is proud to be the Executive Sponsor for the UC Davis Principles of Community university-wide campus climate campaign, which highlights the key phrase, "We affirm the dignity inherent in all of us."

Before joining UC Davis in California, Tull was in Maryland at the University of Maryland Baltimore County (UMBC) and served as Assistant Dean for Graduate Student Development (GSD), Associate Vice Provost for GSD and Postdoctoral Affairs, and Associate Vice Provost for Strategic Initiatives. She later had a detail with the University System of Maryland (USM, 12 institutions), serving as the Director for USM Pipeline Professional Development Programs, and she had Co-PI and PI roles on National Science Foundation (NSF) grants within the LSAMP, Alliances for Graduate Education and the Professoriate, and ADVANCE programs. At Davis, she is PI for the NSF-funded PROMISE Engineering Institute (PEI - UC Davis and UMBC). PEI has developed an intergenerational mentoring engineering leadership network which has engaged engineering graduate students and senior leaders from UC Davis, UMBC, UC Irvine, UC Berkeley, UCLA, Stanford, University of Maryland College Park, Virginia State University, Rice University, George Mason University, and North Carolina A&T.

An international speaker on global inclusion in STEM, Dr. Tull, a member of Tau Beta Pi, has shared Humanitarian Engineering principles and work connected to the United Nations' Sustainable Development Goals at the United Nations Headquarters, and on every continent (except Antarctica). Through the Latin and Caribbean Consortium for Engineering Institutions (LACCEI), she has given bilingual talks across Latin America on topics related to engineering for all.

Tull was a finalist for the Global Engineering Deans Council/Airbus Diversity Award (announced in Italy and acknowledged in Dubai). In addition, she has received the ABET Claire L. Felbinger Award for Diversity, the Student Platform for Engineering Education Development Global Mentoring Award, and the Electrical and Computer Engineering Department Head Association's (ECEDHA) Diversity Award. She was a PI for Puerto Rico's ADVANCE Hispanic Women in STEM, she is the past President for LACCEI, and the current Vice President of Transformative Initiatives for the International Federation of Engineering Education Societies (IFEES). Tull is currently leading the "Alianza" project for LACCEI in partnership with the Organization of American States; she sits on the Board of Directors of the American Geophysical Union (AGU), one of the world's largest Earth and space science organizations; and recently, she has been invited to serve on engineering expert teams in Chile and China. Tull was a co-author for UNESCO Engineering Report II, and she participated in the UN Women CSW66 side event on "Role of Women in STEM in Addressing Climate Change" where she joined global leaders on the importance of women in engineering for climate action, disaster risk reduction, and sustainable development. She is an author of a chapter of "Rising to the Top," an IFEES book on global women in engineering, and was a co-author for the National Academies' "Impact of COVID-19 on the Careers of Women in Academic STEM," and "The Science of Effective Mentoring in STEM." She is also co-author for the "Matilda

y las Mujeres en Ingeniería” series, and her book chapter with a collaborative team of authors from several continents, “Models for International Collaborations to Nurture Students into Global Engineers,” in the Springer book, “Academic Leadership in Engineering Education: Learnings and Case Studies from Educational Leaders Around the Globe,” was launched in Australia. Tull enjoys her work as a global education policy strategist and champion for equity. She often travels with her husband of more than 30 years, Dr. Damon Tull, with whom she collaborates on work such as “The Success Equation,” and “Dark Matters: Metaphorical Black Holes...”, which creatively couples math, physics, and social science.

Dr. Maria C Sanchez, University of Maryland Baltimore County

Dr. Maria C. Sanchez is currently serving as the Director of the Engineering and Computing Education Program (ECEP) in the College of Engineering and Information Technology at the University of Maryland, Baltimore County. She obtained her B.S. degree from La Universidad de Los Andes in Bogotá, Colombia and her M.S. and Ph. D. in Mechanical Engineering from Virginia Polytechnic University in Blacksburg, Virginia. She has held faculty positions at California State University, Fresno (CSUF), University of Maryland, Baltimore County (UMBC) and University of Maryland, College Park (UMCP). She also served as Project Coordinator of the t-STEM Initiative, funded by the Bill and Melinda Gates Foundation, at UMBC. She is actively engaged in research and program development in the areas of Engineering for Social Change, increasing the accessibility of STEM education to under-represented groups, social responsibility thinking, and accreditation activities. Her technical interests are in the areas of Thermodynamics, Heat Transfer, and Energy Systems.

Mrs. Yarazeth Medina, University of Maryland Baltimore County

Assistant Director of Graduate Student Development and Postdoctoral Affairs with extensive experience in student recruitment, retention, and success initiatives in higher education, particularly for graduate students and postdoctoral scholars. Her work centers on advancing equitable access and outcomes in STEM, with a strong focus on supporting historically excluded populations, including first-generation students and women in science. She designs and delivers programs in career exploration, academic preparation, and professional development, with an emphasis on pathways to academic and research careers. She also brings expertise in grant budget development, administration, and financial oversight, having managed multi-institutional NSF-funded initiatives such as PROMISE AGE, LSAMP, and RISE UPP INCLUDES, as well as national collaborations like the PROMISE Engineering Institute.

Cultivating Future Academic Leaders: Innovative Mentorship and Leadership Interventions for Engineering Doctoral Students

Abstract:

This paper describes two innovative interventions for engineering PhD students from the NSF-funded PROMISE Engineering Institute Mentor Academy (PEI-MA). PEI-MA aimed to cultivate future academic leaders by training engineering PhD students in core skills related to engineering excellence and leadership. The project had two goals: designing and piloting a Leadership Model for doctoral engineering scholars that emphasizes community, skill development, and networking; and expanding successful Mentorship in Engineering models. As an addition to typical career mapping and goal-setting activities in professional development, the project features Legacy Statements and Mentor Maps as two innovative interventions to the previously studied leadership development models. Legacy Statements helped students reflect on meaning-making and see themselves as leaders as they envisioned their career paths. Legacy Statements were designed to be living documents that could evolve as students advance in their careers. The second activity involved developing Mentor Maps, which enabled students to reflect on the specific contexts where mentoring would be beneficial and to identify individuals who are currently serving or could serve as mentors in those contexts. When utilized in combination, these activities provide students with a sense of their multi-generational academic legacy, including their own academic lineage and the academic impact they could envision themselves having. Participants indicated that this holistic view deepened their commitment to complete their PhDs and strengthened their interest in becoming faculty members and eventually academic leaders.

Introduction

For decades, the academy has articulated aspirational values related to inclusion and access, yet it has struggled to translate these commitments into broadly representative graduate student cohorts, faculty ranks, or institutional leadership [1]. Particularly in the professoriate, the percentage of faculty of color in tenure-track positions has only slightly increased since the early 2000s, and has not increased for black faculty during this period until a very recent increase in the assistant professor ranks [2]. Specifically, the percentage of Black faculty has increased from 3.3 to 3.8 percent between 2002 and 2023, while the percentage of Hispanic/Latinx faculty has doubled, from 2.5 to 5%.

The PROMISE Engineering Institute Mentor Academy (PEI-MA) (described in more depth below) is an intervention that aims to encourage greater participation of racially and ethnically minoritized scholars in Engineering professoriate careers, and goes further to build skills and interest in becoming higher education executive leaders. The PEI-MA builds upon previously developed PROMISE programming that has been documented to build community among minoritized graduate students [3] as well as other Alliance for Graduate Education in the Professoriate (AGEP) programs that have demonstrated impact on the sense of belonging and well-being of historically underrepresented graduate students [4]. The PEI-MA includes several elements that have been previously shown to be effective, including the use of cohorts [5], [6], facilitating networking [7], [8], and group travel to conferences [9]. Interestingly, PEI-MA adds a novel element of engaging university presidents from similar racial and ethnic backgrounds of the participants based on research that demonstrates such connections can play a significant role

in the trajectory of a faculty member toward executive leadership [10], [11], along with activities to develop mindsets and skills that build toward greater leadership identity and a supportive network with which to grow in their academic career.

Literature Review

Despite decades of targeted diversity initiatives, the demographic landscape of STEM academia remains characterized by persistent stagnation in the representation of historically marginalized scholars [12], [13], [14]. This lack of progress is increasingly recognized not as a failure of individual talent but as a consequence of institutional structures that, particularly prior to 2014, provided minimal social or academic support for equity [8], [15]. The existing literature identifies a triad of barriers that systematically hinder progress: inequitable access to the resources required for degree completion [16], [17], [18], substantial disparities in federal research grant allocation [19], [20], and a profound lack of integration into the broader scientific community [4], [21]. As a result, the pipelines for engineering and doctoral attainment do not accurately reflect national demographics, thereby creating a significant void in leadership within both academia and industry [2], [11], [22].

The structural exclusion of marginalized scholars is compounded by a cold climate where the psychological toll of intersectional identities often dictates professional outcomes. Research into the lived experiences of scholars at the intersection of marginalized racial, ethnic, and gender identities shows that the academic environment is often marked by microaggressions, subtle but pervasive behaviors that undermine self-esteem and foster a sense of professional isolation [23], [24], [25]. These experiences are more than just interpersonal friction; they are predictive of decreased retention and a diminished perception of academia as a sustainable career path [22]. This isolation is especially severe in engineering, where microaggressions serve as constant, negative reminders of perceived outsider status, ultimately driving high-potential scholars away from the professoriate [16], [26], [27].

While many intervention methods have been proposed to increase participation and retention among marginalized students in academia [4], [8], [9], [28], [29], few studies have examined how to prepare, motivate, and train these students for leadership roles [30]. Central to addressing these disparities is the role of mentorship, which the literature increasingly defines as the primary vehicle for transmitting the cultural capital, the unspoken norms and institutional rules of the game, necessary for academic survival [31], [32], [33]. High-quality mentoring helps marginalized students feel a sense of belonging in an inclusive community, boosting their academic identity, increasing their achievement, and fostering ongoing professional growth in their fields [7], [34]. However, a significant mentorship gap persists: marginalized faculty and students consistently receive less frequent, lower-quality guidance than their overrepresented peers, leading to missed research opportunities and lowered expectations [8], [35]. While existing interventions have focused heavily on basic completion and persistence as outcomes, there remains a conspicuous absence of research on how to move beyond mere retention toward intentional leadership development in higher education [29], [36]. There is a growing conversation in medical training about professional identity formation and the associated rise in leadership aspirations among Underrepresented in Medicine (UIM) medical students [36], [37], [38]. The scholarly conversation in the other STEM fields and higher education more broadly must now close this gap, moving beyond simply supporting scholar retention and instead

focusing on identifying the specific pedagogical frameworks needed to prepare them to lead the next generation of STEM innovation.

Objectives

The project aims to achieve two goals: 1. Design and pilot a leadership model for doctoral students that prioritizes community, skills building, and networking [39], [40]; and, 2. Expand a successful engineering mentorship model by adding program evaluation and dissemination to allow scalability of the model to any STEM field [32], [41].

Program Description

The PEI-MA was designed as an NSF-funded bi-coastal collaboration between two R1 institutions: The University of California, Davis (UC Davis) and the University of Maryland, Baltimore County (UMBC). PEI-MA Fellows were recruited from UC Davis, UMBC, University of California, Irvine, and Stanford University. PEI-MA included the innovative approach of connecting scholars with former and current university presidents through a series of in-person and online sessions.

PEI-MA operates on the belief that the success of an academic career depends on the development of two sets of competencies: Engineering Excellence, focused on the mastery in creating and implementing innovations, publishing research, and expanding professional networks; and Leadership Skills, that encompasses the ability to envision oneself as a leader, navigate complex higher education structures, mentor others effectively, and understand the administrative challenges faced at the higher levels of university governance.

The research team aimed to answer one central research question: *How does the development of a generational engineering leadership identity factor into PhD persistence toward a faculty and higher education leadership track?* From this main question, five sub-questions emerged. This study addresses the following two sub-questions:

- 1. How does the PEI Mentoring Academy model impact career and leadership awareness, aspiration, and generational leadership identity formation of underrepresented graduate students in engineering?*
- 2. In what ways does the creation of inter-institutional systems of generational leadership identity development support PhD students?*

To answer these questions, the team employed a mixed-methods approach. A qualitative component examined the relationship between educational backgrounds, participation in mentoring activities, persistence through faculty pathways, and doctoral completion rates. Qualitative analysis was used to study participants' narratives to gain a deep understanding of how leadership identity is formed.

It was expected to realize these goals through several high-impact activities:

- Three-day Leadership Conference: An intensive in-person event hosted on campus at UC Davis. The Mentor Maps and Legacy Statements exercises discussed in the current paper took place during this event.
- Presidential Engagement: Ongoing virtual sessions with mentor presidents

- National Networking: Dedicated sessions at national engineering conferences or conventions.
- Career Success Workshop: A two-day workshop at UMBC focused on academic career navigation
- Global Integration: Support for participation in international conferences to foster globally aware engineering leaders.

Research Design

The PEI-MA project proposed a theory of change based on grounded theory: If culturally relevant academic engineering leadership identity development can be codified, taught, and put into practice, more engineers from historically marginalized groups will go on to become academic leaders [42], [43], [44]. This section introduces PEI-MA's two core activities, Mentor Maps and Legacy Statements, which aim to foster and supplement leadership and career development in academia. The section will describe the components of the activities separately, followed by the data collection and analysis approach.

Mentor Mapping

The Mentor Map exercise is a way to visualize the number and types of mentors one has throughout their doctoral student journey toward a fulfilling career, from academia to industry. PEI-MA used a Mentor Map adapted from the National Center for Faculty Development and Diversity mentor map [45] and the University of Michigan's Graduate Student Mentor Map [46]. Similar to the previous models, the Mentor Map consists of nine distinct groups of mentor networks: Substantive Feedback, Sponsorship/Access to Opportunities, Career Advice, Accountability, Professional Development, Emotional Support, Academic Leader Role Models, Intellectual Community, and Peer/Near Support.

All students participating in PEI-MA began with their baseline Mentor Map, which was completed during the cohort's first kick-off meeting. Throughout the grant term, Fellows were encouraged to reflect on and update their Mentor Maps on a shared cloud-based online drive after major professional events, such as national conferences, the three-day Leadership Conference in April 2025, and the Summer Success Institute in August 2025. The hope was that by archiving different versions, the research team could examine the longitudinal changes in mentor networks and understand how Fellows utilize the Mentor Maps.

The current study used two sets of Mentor Maps for six Cohort 1 students to analyze: the baseline Mentor Map from April 2024 and the updated versions from April 2025, following the PEI-MA's three-day Leadership Conference. While some might worry that the overall graduate school experience could act as a confounding variable in the networks, this effect is already addressed in the study's assumptions. In fact, by focusing on the structure and composition of mentor networks over time, the analysis will show how students' networks and communities of support evolve as they maintain, optimize, and reshape their mentors across professional, academic, and personal domains. The final analytic sample included twelve documents: six from the baseline data collection in April 2024 and six from after the April 2025 Leadership Conference, for descriptive analysis.

The Mentor Maps were analyzed using a mixed methods approach. Survey data collected in August 2025 were [47], [48] examined to understand the Fellows' perceptions of the Mentor

Maps and the mapping exercise. The Mentor Maps were analyzed using Grounded Theory [47], [48]. During the open coding phase, the research team examined the number of individuals in each mentor network group for both the baseline and follow-up maps. In the axial coding stage, the team evaluated changes in the number of people within the mentor network groups. During the selective coding phase, the team reviewed the types of individuals in the mentor network groups, such as role, relationship to the mentee, and institution, and identified whether there were any changes between the baseline and follow-up maps.

The current study is limited by a small data set. However, the combination of two data sources nonetheless provides rich insights into students' aspirations and motivations for a doctorate. Furthermore, the data collection from the current study will inform the empirical design of an upscaled version of the PEI-MA programming and the potential for a more focused follow-up study on individual student experiences.

Legacy Statement

All students attending PEI-MA's three-day Leadership Conference in April 2025 participated in the "What is Your Legacy" workshop to reflect on and create their own Legacy Statements. The workshop scaffolded students through a series of activities: first, students were asked to identify their core values, reflect on the impact they would like to have, and draft their legacy statement. Each step was followed by group share, affirmation, and peer feedback. In addition, the workshop leader facilitated a safe and supportive space for participants to further develop their aspirations and concretize their long-term goals and attainable short-term goals. The activity emphasized the organic nature of this document, termed "living document," meaning that the Legacy Statements would be constantly evolving, and used for career planning, grant applications, and personal reflection.

The study included Legacy Statements from $n=14$ participants from Cohorts 1 and 2. The Legacy Statements were analyzed using inductive coding in NVivo 14. Inductive coding was the ideal analytical approach given the nature of the statements being analyzed, the program participants' unique demographic characteristics, limited existing knowledge of similar programmatic interventions, and the program's novel contributions to STEM professoriate training. Although there was no specified limit, Fellows were asked to keep their statements to 1–3 sentences. We used four of the five steps of Thomas's [49], [50] inductive analysis approach, omitting the Data Cleaning step. The brevity of the statements and the sample size enabled analysis without loss of context. The four steps included (1) Close reading of the text; (2) Creation of categories or themes; (3) Reviewing overlapping coding and uncoded text; and (4) Continuing revision and refinement of the category system. The research team reviewed the themes to ensure inter-coder agreement and minimize potential bias.

The Legacy Statements were initially auto-coded to identify which codes emerged. In the initial query, we used word frequencies to identify codes in the responses. The term "Legacy" was omitted because it was considered referential to the statement's nature. Some terms were combined because they shared a common root (e.g., community and communities). Other terms were combined based on their thematic similarities (e.g., underrepresented, historical suppression, and diverse). While auto-coding and word frequencies provided the initial coding, the themes were identified and refined through manual deep reading of the Legacy Statements. The research team identified common themes in students' experiences, aspirations, and perspectives on the importance of mentors, community, multi-generational academic legacy, and

leaving their own legacies. Those themes were then iteratively tested against the data to identify overlaps and uncoded text until the following five final themes emerged.

- Positively impacting communities of concern
- Inspiring the next generation of scientists
- Changing the face of the academy
- Mentoring and leading with compassion
- Creating inclusive, accessible opportunities

Sample Size and Information Power

The sample sizes in this study were small compared to those in larger quantitative or qualitative studies. While this might seem to limit the study's power and generalizability, qualitative studies can be effective with small samples, especially when focusing on a specific case like this one [51], [52]. For this study, the sample was predetermined by selecting specific participants. Information Power includes five criteria in qualitative interview studies: (1) the aim of the study, (2) sample specificity, (3) use of established theory, (4) quality of dialogue, and (5) analysis strategy [53], [54]. Since the goal was to analyze the impact of PEI-MA programming on participants, the sample was limited to those individuals. This also suggested a level of study saturation, as participants from both cohorts and both institutions were included. We used well-established interview and survey techniques, and the analysis frameworks included inductive reasoning and grounded theory.

Results/Evaluation

Mixed Methods Assessment of Mentor Network Growth

A group (n=11) of Cohort 1 and Cohort 2 PEI-MA Fellows participated in a survey about the Mentor Map tool (see Figure 1). Data indicate sustained engagement with the tool since its introduction; when asked about usage frequency (including both PEI-specific activities and independent use), 63.6% of participants reported engaging with the map 2–3 times, while 36.4% reported engaging 4–5 times in the past year. Notably, no participants reported zero engagement or single-use interactions.

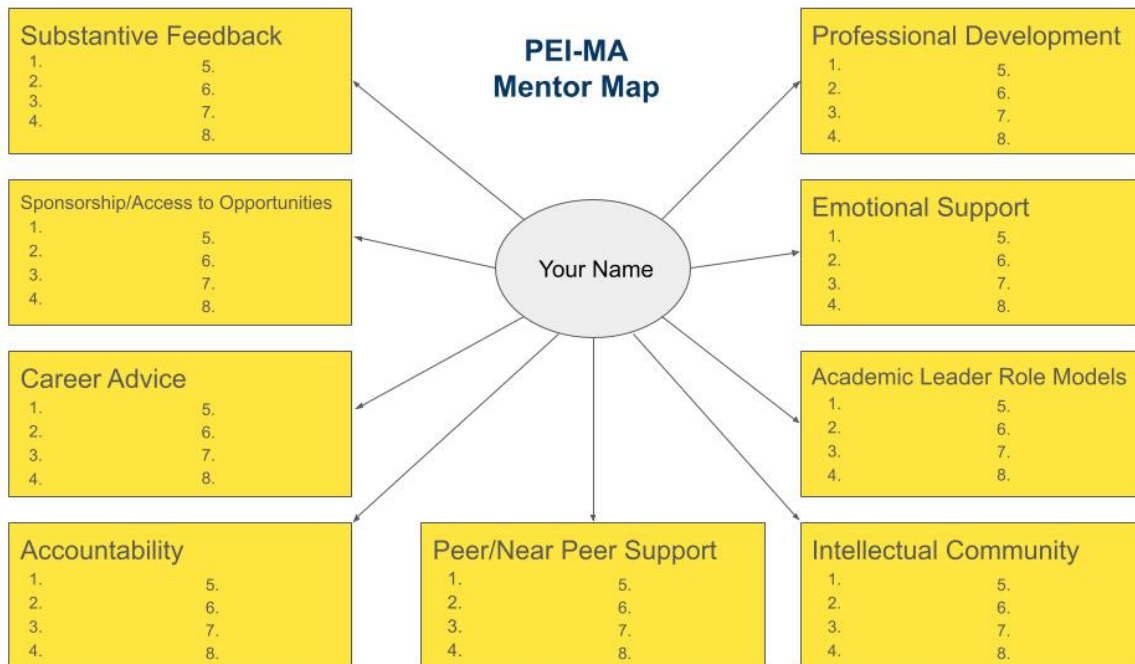


Figure 1. Mentor Map Tool.

Data also suggest that the intervention was highly effective in expanding their mentor networks, with 100% of participants reporting that their mentor networks had grown since the program's inception, 18.2% classifying this growth as "significant," and 81.8% as "slight."

This was validated in the open-ended comments provided in the Mentor Map survey.

"To be honest, mentorship was not something I was intentional about cultivating before PEI. Since my first session in the spring in UC Davis, I have reached out to several professors, collaborators and former internship mentors to reconnect! PEI itself has also provided me with new mentors." - Cohort 2 Fellow

When analyzing growth by specific mentorship categories, clear patterns emerged regarding where students successfully identified new support. Perhaps not surprisingly, 100% of participants who took the survey reported growth in the category of Academic Leaders/Role Models, and 81.8% reported growth in Peer/Near-Peer Support (see Figure 2). The next highest categories of growth were in mentors that supply Career Advice (54.5% reported growth) and those that supply Sponsorship and Opportunities (45.5% reported growth) (see Figure 2).

Conversely, growth was more limited in psychosocial and accountability domains. Only 27.3% of respondents reported growth in mentors supplying Substantive Feedback and Accountability and only 18.2% noted an increase in mentors that supply Emotional Support (see Figure 2). It remains to be determined whether this disparity reflects a programmatic gap in facilitating these specific connections or a lower perceived need for additional mentors in these categories among the cohort.

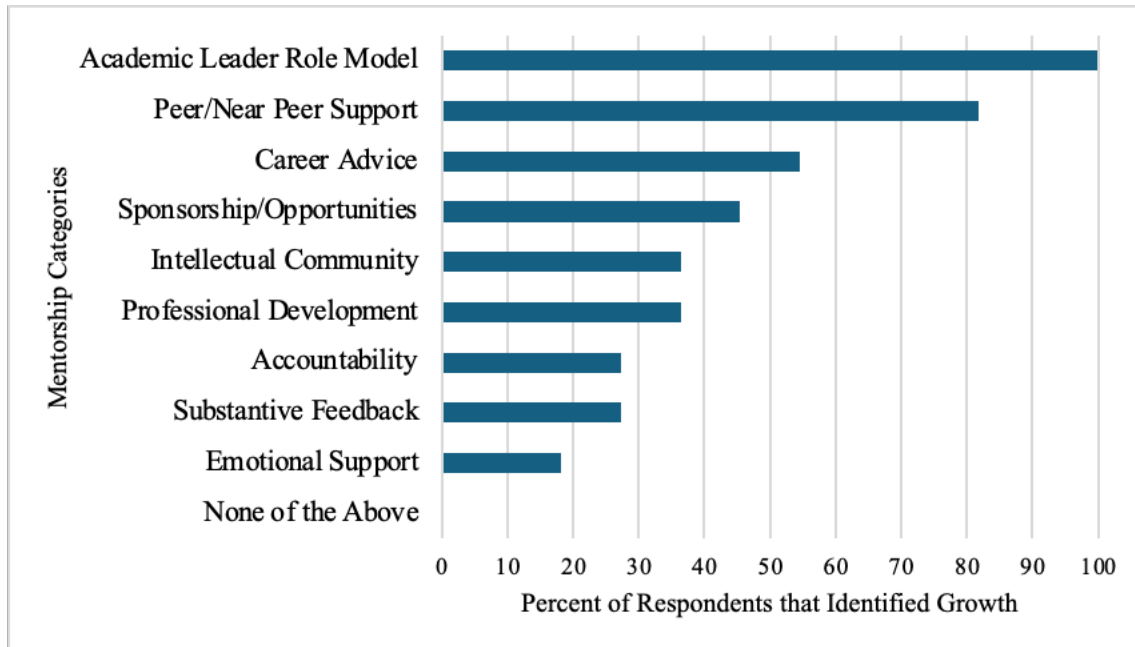


Figure 2. Self-Reported Growth in Various Mentor Map Categories since PEI-MA Program Start.

Despite these variations, the perceived long-term value of the intervention is high. When asked if the PEI-MA helped them realize they could actively grow their network, 100% of respondents agreed (63.6% strongly agreed). In the open-ended comment section following this question, several Fellows mentioned the usefulness of the map itself, appreciating its visual nature and the presentation of multiple mentor categories.

“With the mentor map, I see I shouldn’t go to one or two people for everything.” - Cohort 2 Fellow

“The visualization of the mentor map allowed me to see where I could best grow where I had too many mentors and see where I didn’t and pushed me to seek out more mentors.” - Cohort 2 Fellow

“Mapping it on paper made me see the gaps that need to be filled.” -Cohort 1 Fellow

Furthermore, over 70% of participants agreed or strongly agreed that they foresee a continued role for these specific PEI-obtained mentors even after the conclusion of formal programming. Some Fellows reflected about this positivity in the open-ended comment section of the survey after a question about having a continued role for PEI-obtained mentors:

“I feel equipped with new skills to keep these relationships alive and make them transformative not just transactional.” - Cohort 2 Fellow

“I think that while the mentorship might evolve over time I plan to keep in touch with the people that PEI has helped me find.” - Cohort 2 Fellow

It should be noted that at least one Fellow expressed concern about their ability to maintain the relationships, indicating the need for programming staff to consider ways to nurture and foster continued connection beyond program end and build greater confidence in the Fellows:

“I’m not confident that I have the ability to keep mentors when I leave a space, mostly in that I find myself feeling awkward and not wanting to waste people’s time” - Cohort 1 Fellow

Longitudinal Analysis of Mentor Map Artifacts

To contextualize the survey findings, a comparative analysis was conducted on individual Mentor Maps from the start of the cohort (March 2024) to the Leadership Conference (April 2025). This comparison highlights four distinct mechanisms of network evolution.

Elevation of Mentorship Tiers

Several artifacts demonstrated a shift from having mentors that were only faculty and mid-level administrative staff to the inclusion of high-level institutional leaders. For example, one participant’s initial map listed mid-level staff under "Academic Leader/Role Models," whereas the 2025 iteration included two named individuals at the Dean/President level. Similarly, another participant moved a university President from the "Academic Leader/ Role Model" category to the active "Career Advice" mentor category. This aligned with the motivation to have senior academic leaders serve as mentors, providing a broader view of academic careers. It also suggests the program successfully empowered fellows to convert aspirational figures into active mentorship connections.

Strategic Filling of Gaps

Overall, most mentor maps grew in terms of individuals identified between their first and second iterations. Participants utilized the maps to identify and populate previously empty mentorship categories. One participant, for instance, added specific names to the "Professional Development," "Sponsorship," and "Career Advice" categories—areas that were blank in the baseline artifact. Another participant demonstrated similar expansion in a single category, growing the mentors in their "Sponsorship" category from a single individual to four distinct names.

Development of a Cross-Coast Ecosystem

A recurring trend in the artifacts was the population of Mentor Map categories with PEI-MA participants from geographically distinct institutions/coasts. Specifically, PEI-affiliated staff and fellows from West Coast campuses frequently appeared in the “Peer/Near Peer Support”, "Accountability", and "Professional Development" categories of East Coast fellows, and vice versa. A few times, PEI-MA Staff were also listed in the “Sponsorship/Opportunities” category of mentoring, or PEI-MA Fellows from a different coast were listed in the “Intellectual Community” category of the mentor map. This is significant because it is not simply listing PEI-MA staff or PEI-MA Fellows from other coasts as emotional support or community, but rather in active roles to support their progression in their degrees and careers. PEI-MA Fellows being added to each other’s mentor maps also validates the survey finding that 81.8% of participants experienced growth in peer support (Figure 2). This indicates that the PEI-MA was not only a

successful program for identifying and connecting graduate students to seasoned, senior mentors but also as a mechanism for solidifying lateral support structures across the PEI-MA network.

Refinement and Pruning

Analysis also revealed that "growth" did not always equate to addition; in some instances, it appeared that a curation of the network was taking place, whether strategic or not. We observed numerous maps where names were removed or re-categorized into other categories. Ideally, this reflects a maturing perspective on the definition of mentorship. For example, one participant initially listed a 2024 PEI-MA speaker as a mentor in both "Academic Leader/Role Model" and "Career Advice" categories. By 2025, this individual was retained in the Academic Leader/Role Model category but removed from the Career Advice category. Without follow-up, there is no mechanism to understand the impetus for the removal. It could be that the quality of career advice mentorship was poor, that the mentee did not follow up or nurture the relationship, that the mentor was unavailable, or it could indicate that the PEI-MA Fellow gained a clearer understanding of the distinction between a mentor that provides inspiration versus active career guidance, and simply reorganized the map to be more accurate. Future studies of mentor map usage should potentially include a written or oral reflection on changes that could capture this kind of information.

Implications for Practice

Retrospective analysis suggests that Mentor Maps should be utilized not merely as an evaluation metric, but as an active diagnostic tool during the fellowship. Several critical network dynamics—such as the attrition of previous mentors or a conspicuous lack of support within a Fellow's current institution—were identified only during the post-program analysis. These findings represent missed opportunities for timely intervention. Consequently, we recommend establishing a structured protocol for real-time review of Mentor Maps. This would allow program staff to address support gaps and facilitate immediate, targeted mentoring conversations.

Qualitative Assessment of Defining Legacy

The same PEI-MA Fellows from cohorts 1 and 2 who attended the three-day Leadership Conference wrote Legacy Statements about the impact they hoped to have, as previously described.

Five themes emerged and are listed in Table 1, along with their frequency counts. We found that PEI-MA Fellows prioritized *positively impacting communities of concern*, either by empowering specific communities or through community-based research. This aligns with their expressed desire to *inspire the next generation of scientists*, often specifically from underrepresented backgrounds. For some Fellows, that inspiration is in the classroom as they *change the face of the academy*. Fellows saw themselves *mentoring and leading with compassion* as professionals, faculty members, or academic leaders. Ultimately, these leadership positions will enable PEI-MA Fellows to *create inclusive, accessible opportunities* for future students.

Table 1. Legacy Statement Themes from Inductive Analysis

Themes	Count	Weighted Percentage	Included Terms
Positively impacting communities of concern	24	6.28%	Community, communities, empower, impact, broaden, broader, underrepresented, underserved, vulnerable.
Inspiring the next generation of scientists	23	6.02%	Student, students, generation, mentor, inspire, advocate, aspiring, mentor, role model.
Changing the face of the academy	16	4.19%	Academic, academy, academia, research, education, leadership, professor.
Mentoring and leading with compassion	12	3.14%	Compassion, compassionate, betterment, empathetic, humanity, nurturing, support.
Creating inclusive, accessible opportunities	11	2.88%	Opportunities, accessible, equitable, workforce, internships, meaningful.

Positively Impacting Communities of Concern

“Community” had the highest word count with 12 instances; it appeared in five different Legacy Statements. A word tree was created in NVivo 14 to show the context in which “community” appeared (see Figure 3). In one case, “community” specifically referred to fostering a positive culture for future graduate student communities. In the other four cases, “community” referred to broader or underserved communities. The term was often associated with empowering communities, as reflected in the Fellow’s background. Interestingly, some Fellows connected their research goals to work that would produce more positive outcomes for specific communities. Having a positive impact was not limited to people with similar backgrounds but was often related to broader communities and improving the lives of others.



Figure 3. Word Tree for “communities” from the NVivo word query.

“...I hope to empower these communities to advocate for themselves with policymakers and to continue conducting citizen science that reverses historical suppression.” – Cohort 2 Fellow

“My legacy will be to support the well-being of ... from resource-constrained communities by conducting community-based research and collaborating with this population to innovate socio-technical systems...” – Cohort 2 Fellow

Inspiring the Next Generation of Scientists

Inspiring and empowering future scientists was associated with mentoring and teaching. This included fostering a more representative workforce. The inspiration was explicitly framed as a “role model” only once. That sentiment was implicit in many of the Statements though. There was also an element of creating better environments and cultures for students who would become future academic leaders.

“...I want to leave a legacy emphasizing the importance of pouring into others, creating opportunities, and continuing to lift up those who come after you.” – Cohort 1 Fellow

“...To redefine leadership in academia as an act of service, ensuring that no graduate student walks their path alone and that community is the cornerstone of our collective success.” – Cohort 1 Fellow

Changing the Face of the Academy

This theme speaks the most directly to the research questions we posed about intergenerational mentoring inspiring future faculty members. There were both direct assertions of plans to become faculty members and more indirect ones where there was a clear desire to conduct research, but whether in academia or industry was unclear. The evaluation survey for the Leadership Conference covered time blocks rather than individual sessions. The Legacy Statement activity was evaluated alongside a “Navigating Your Career” session on day one. Fellows responded positively to whether their awareness of faculty career opportunities had increased (3.8 across both cohorts on a Likert scale, with 5 being strongly agree). Cohort 1 Fellows were slightly more amenable to the statement (3.9) than Cohort 2 Fellows (3.5). Fellows were more positive that the information provided would prepare them for potential faculty appointments and/or leadership opportunities in higher education (4.3). Since there were two sessions, the positive association cannot be attributed to either one individually. It would be interesting to follow up with the Fellows a few years after degree completion to see if their Legacy Statements are more explicitly about academic careers.

“My legacy will be to be a champion of minority success in engineering through being a leader and mentor to future generations of students, while being a professor and a future leader in higher education...” – Cohort 2 Fellow

“My legacy will be to create opportunity through technology, education, and community by connecting people to knowledge, building practical systems with integrity, and mentoring others with compassion, so that more individuals can thrive...” – Cohort 2 Fellow

Mentoring and Leading with Compassion

While mentoring and leadership were expected themes, focusing on compassion was not. Compassion is not a term traditionally linked with STEM graduate training. Yang and Gentry [55] see compassion as a proxy for social responsibility, yet they associate it with gender differences, noting that females tend to show more compassion. In our case, the gender identities of students who mentioned compassion were evenly split between male and female. There is an element of social responsibility in how compassion is presented in the Statements. It was often paired with the first two themes.

“My legacy will be to enhance ..., while developing the next generation of scientists by leading my research and service with compassion and curiosity.” – Cohort 2 Fellow

“...I hope to build a sustained culture of purpose, compassion, and growth that benefits not just individuals, but the broader community.” – Cohort 2 Fellow

“To create an inclusive and compassionate environment for minority students by providing mentorship and leadership so that students feel supported and can make a difference in their communities.” – Cohort 2 Fellow

Create Inclusive, Accessible Opportunities

We expected facilitating opportunities to be one of the main themes based on the conversation during the Legacy Statement activity. Throughout the Leadership Conference, the experience's impact was a common topic of discussion. This impact reaffirmed their dedication to creating similar opportunities for future students. Equally important is that, in nearly every case, these opportunities were specifically connected to inclusivity or accessibility. Access was based on the Fellows achieving enough status or influence to affect academic policy, not only providing opportunities for students but also fostering non-toxic spaces where students can thrive rather than just survive. One fellow even coined the term “Empathetic Discovery.”

“My legacy will be to create opportunity through technology, education, and community by connecting people to knowledge, building practical systems with integrity, and mentoring others with compassion, so that more individuals can thrive...” – Cohort 2 Fellow

“I am committed to a life of empathetic discovery, ensuring that my scientific contributions are rooted in generosity and the betterment of others. Beyond my own milestones, my greatest impact will be as an accessible mentor and educator, empowering the next generation of dreamers, regardless of their background, to see themselves I hope to be remembered not just for the heights I reached, but for the hands I held and the doors I opened for those following...” – Cohort 2 Fellow

Conclusions

The PEI-MA team developed programming to support the growth of leadership identity among two cohorts of PEI-MA Fellows. That programming was grounded in a holistic approach to student development, specifically designed to be culturally relevant, as previous research has shown to be more effective for students from historically marginalized groups [4], [39], [55]. The analysis produced three meaningful conclusions. First, mentor mapping as a structural

mentoring intervention can be effective. Second, creating legacy statements revealed a broader engineering academic identity than is usually assumed. Finally, the combination of these two activities fostered a more mature approach to mentoring literacy.

The longitudinal analysis of mentor maps shows that structured tools can facilitate significant evolution in mentor networks. The 100% growth rate in the “Academic Leader/Role Model” category of the mentor maps highlights the success of fostering intergenerational mentoring opportunities and addresses the two research sub-questions. The shift from mid-level staff to senior academic leaders as mentors demonstrates how PEI-MA enabled students to transcend institutional hierarchies and self-imposed barriers to senior leadership roles. The nature of mentors in PEI-MA and the interactions among Fellows built a cross-institutional support ecosystem. That ecosystem is not only hierarchical but, as importantly, lateral, including both identified mentors within PEI-MA Fellows and those from other campuses. This signaled an intentional filling of gaps, creating the maps that were brought on, helping Fellows transition from passive networking to strategic connection-building in key areas like “Sponsorship” and “Career Advice.”

The qualitative analysis of the legacy statements suggests that the activity helped graduate students envision themselves as future academic leaders, extending beyond their current professional identity as researchers-in-training. In the legacy statements, the frequency of terms related to three themes, “Positively impacting communities of concern,” “Inspiring the next generation,” and “Creating inclusive opportunities,” demonstrated a strong commitment to service often linked to graduate students from underserved backgrounds. Our analysis also revealed that this was connected with a deepening of Fellows’ dedication to leadership as faculty members committed to creating change, addressing sub-question 1. Notably, the emergence of “Mentoring and leading with compassion” as a theme suggests that the PEI-MA Fellows are actively working to redefine STEM academic leadership. The phrase “Empathetic discovery” is especially meaningful, as it extends that compassionate approach beyond leadership into research as well.

Considering both activities together, the Fellows are demonstrating a more mature level of mentorship literacy. The interactions with intergenerational leaders have impacted them. The discernment shown in the evolution of the mentor maps indicates how Fellows are becoming more thoughtful about the types of mentoring support they need and the kinds of people they need to provide it. Experiencing interactions with university presidents and other leaders has highlighted the value of their perspectives. The program effectively expanded professional and academic connections. There was a smaller increase in “Emotional Support” and “Accountability.” A targeted intervention focused on psychosocial support for graduate students may be necessary.

This ecosystem suggests that intentional, short-term intensive programs (like the three-day Leadership Conference) could yield long-term, functional professional relationships that survive long after the program ends, with 70% of participants foreseeing a continued role for these cross-institutional mentors. These findings offer a scalable model for creating diverse, inclusive, and supportive graduate student communities that operate beyond the constraints of a single campus, providing a blueprint for national-level graduate student professional development.

Limitations

The interpretation of these findings has certain limitations. For both activities, the sample size was small—11 for the mentor maps and 14 for the Legacy statements. While this was due to the size of the PEI-MA cohorts, it still limits the generalizability of this study. Qualitative studies can be effective if the sample is specific and the study has a narrow aim [52], [53], [54], both of which applied here. The main limitation was self-selection bias, which could have affected the results in a few ways. First, the study lacked a comparison group of non-participating students. This prevented us from definitively linking longitudinal growth in mentor networks solely to the program. It also limited our ability to attribute the themes from the legacy statements to PEI-MA programming. These themes may have been influenced by self-selection bias, as the graduate students who participated were likely predisposed to the themes that emerged [21], [39], [56]. Second, data collection was limited by a response rate of 69% (11 out of 16 Fellows completed the Mentor Map survey), which could have introduced self-selection bias. Despite these limitations, the specific appearance of program-affiliated actors—including PEI-MA staff, fellows, speakers, and assigned presidential mentors—in the second and third iterations of the mentor maps, along with terms reflecting the program's goals in the legacy statements, provides strong evidence that the PEI-MA program directly contributed to expanding participants' professional networks and broadening their perspectives on their identities.

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