From Sink-or-Swim to Scaffolding: How Engineering Undergraduates Experience Faculty Mentoring

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Abstract

With this empirical full paper, we examine how a single case of undergraduate engineering students experience faculty mentoring within an engineering education research (EER) context. Undergraduate research is widely used to support persistence and broaden participation in engineering, yet little is known about how students interpret specific mentoring practices or how those practices produce developmental benefits. Guided by Self-Determination Theory and mentoring competencies from the Center for the Improvement of Mentored Experiences in Research (CIMER), we conducted an interpretive single-case study using semi-structured interviews with photo elicitation involving ten current and former undergraduate researchers mentored by the same faculty member at a large R1 Hispanic Serving Institution. We analyzed data using reflexive thematic analysis. Two themes captured variation in the enactment of evidence-based mentoring practices, from explicit to implicit. Students most readily recognized mentoring when it was visible and relational, particularly through scaffolded skill building, relationship building, empathy, and inclusive practices that supported belonging and confidence. In contrast, expectation setting, and autonomy support were often implicit and uneven, requiring students to infer goals and navigate decisions independently, leading some students toward empowerment and others toward overwhelm. Two additional themes captured benefits students described: a relational infrastructure and an opportunity infrastructure. Mentoring provided meaningful relationships, inclusion, legitimacy, identity development, personal and professional growth, material support, and access to professional engineering experiences and networks. Benefits were distributed across a broader mentoring ecosystem rather than originating solely from the faculty mentor. The EER context further contributed psychological safety and socially meaningful research topics that supported motivation and identity development, particularly for students who experience marginalization in traditional engineering spaces. Analyses show that mentoring effectiveness in this single case depended not only on mentor technical expertise and the presence of recommended practices but on how students interpreted them and how the mentor attuned practices to student readiness and work preferences. Overall, findings suggest undergraduate research mentoring in an EER context supports engineering persistence through best practices that are developmentally attuned, student-centered, and embedded within distributed mentoring ecosystems. Implications emphasize professional development that equips mentors to interpret student experiences and adapt their practices, departmental investment in layered mentoring networks that support students from multiple institutional actors, and recognition of EER contexts as promising sites for reflective, relational mentoring aligned with collectivist student values that may broaden participation in engineering.

Keywords: Engineering, undergraduate research, mentoring, persistence

Introduction

This empirical full paper advances research on persistence in engineering by examining how a single case of undergraduates mentored by one engineering faculty member experienced mentorship within an engineering education research (EER) context. Strengthening the engineering workforce is a national priority as engineers sustain critical societal systems such as infrastructure, health technologies, and national security. Yet entry requires completion of an accredited bachelor's degree, and roughly half of students who begin leave before graduating, limiting supply as workforce demands grow [1]–[3]. The challenge is compounded by persistent representation gaps relative to other fields [4].

Undergraduate research has become a central strategy for broadening participation in engineering, evolving from informal apprenticeships into structured educational practices [5]–[11]. Undergraduate research experiences (UREs) often provide students' first sustained exposure to research and scientific norms, supporting persistence [12]–[14], and are increasingly framed as equity-oriented interventions amid persistent disparities in STEM education and the workforce, particularly in engineering and computer science [15]–[20]. Although UREs expand access and opportunity for historically excluded students [7], [21]–[23], their effectiveness depends on the quality of faculty mentorship and its support of motivation through social psychological processes [24]–[29]. Despite widespread adoption of UREs, mentoring within UREs remains underexamined, particularly in EER contexts, even as retention challenges persist [30] and structured mentoring shows benefits [31]. Addressing this gap, we examine how undergraduates pursuing traditional engineering degrees but mentored in EER describe their mentor's use of contemporary mentoring practices and how those practices are beneficial.

We adopt the National Academies of Sciences, Engineering, and Medicine's (NASEM) definition of mentorship as an intentional, relational professional alliance supporting "personal and professional growth, development, and success of the relational partners through the provision of career and psychosocial support" [27, p. 186]. All participants received formal research mentorship, originating either through structured research programs or organically through classrooms or campus organizations. We operationalize contemporary mentoring using five evidence-based competencies recommended by the Center for the Improvement of Mentored Experiences in Research (CIMER) [32]: expectation setting, scaffolded skill building, relationship building, inclusive practices, and autonomy support. See Appendix A for a detailed comparison of traditional and contemporary mentoring practices.

Review of the literature

With this review, we trace the emergence of engineering education research as a mentoring context, the historical foundations of STEM mentoring, and the shift from inherited mentoring traditions toward evidence-based models centered on students' developmental and psychosocial needs. We conclude by outlining a conceptual framework that integrates Self-Determination Theory (SDT) with mentoring competencies advanced by CIMER.

Engineering education research as a mentoring context

Engineering education research emerged over the past twenty-five years as a distinct scholarly field responding to workforce needs and disparities in engineering [33]–[36]. Many classically trained engineering faculty now use EER as a site for undergraduate research, offering early access to authentic inquiry and structured mentorship [37]–[38]. Undergraduate participation in EER often involves qualitative and reflexive methods that invite students to examine lived experience, engineering identity, and belonging, particularly for students navigating marginalization in traditional engineering spaces [39].

Historical foundations and structural inequities in STEM mentoring

The benefits of UREs depend on mentoring quality. Early STEM mentoring models emphasized hierarchical, sink-or-swim independence and meritocratic assumptions rather than student development [40]–[43]. These models often reproduced norms aligned with White, male, middle class student profiles, privileging those with the cultural and social capital to navigate implicit expectations and independent work amid fewer competing demands such as employment or caregiving [44]–[50]. As Cassuto and Weisbuch argue, traditional mentoring is frequently an inherited system in which faculty replicate their own experiences, reinforcing privilege rather than rigor or ability [40]. In contrast, contemporary mentoring frameworks emphasize developmental support and practices that cultivate competence, belonging, and autonomy.

As student populations diversified, these inherited models exposed structural inequities that constrained access for women, first generation, racially minoritized, and nontraditional students [50]–[52], with many underrepresented undergraduates reporting exclusion from faculty labs and pressure out of programs [53]. These dynamics are particularly salient in engineering, where competitive cultures and low retention heighten the need for early, supportive mentoring [30], [54]–[55]. Although existing mentor training models draw on social psychological theory to promote student-centered practices, conventional approaches persist [56]–[61]. Faculty may undervalue professional development if they perceive their mentoring as already effective or if they interpret relational, contextual practices as lowering standards rather than broadening the field [52], [56], [62]–[64]. Without institutional incentives, mentoring remains preference driven and uneven, while departments that provide mentor training and recognition foster more intentional and responsive mentoring cultures [32], [56], [60]–[61], [65]–[67].

Research objectives and conceptual framework

To extend scholarship on undergraduate engineering mentorship, we conducted an interpretive exploration of the mentoring experiences of one case of EER students. We asked:

1) What do the accounts of a single case of undergraduates mentored by one engineering faculty member reveal about contemporary mentoring practices in engineering?
2) How do students describe the benefits they gain from mentoring practices?

Guided by calls to integrate social science theory into STEM education research [57], we developed an integrated conceptual framework for analysis grounded in Self-Determination Theory [68] and five CIMER mentoring competencies: expectation setting, scaffolded skill building, relationship building, inclusive and empathetic practices, and autonomy support [32]. We display the conceptual framework in Appendix B. Drawing on prior scholarship [69]–[70], the model positions mentoring as a developmental process that supports competence, relatedness, and autonomy and fosters persistence in engineering [7], [9], [25], [28], [71]. Though autonomy is frequently conflated with work independence, we adopt SDT's definition of autonomy as volition and self-endorsement or having meaningful choice over actions that matter [68].

Self-Determination Theory explains how environments that support belonging, competence building, and developmentally attuned autonomy enhance motivation [72]–[76]. CIMER operationalizes fulfillment of these needs through concrete mentoring practices including communication, expectation setting, scaffolded independence, role modeling, and professional development, with later programs incorporating ethics, wellbeing, work life integration, care and empathy, and culturally aware support and counterspaces that affirms historically underrepresented students [43], [52], [77]–[83]. Empirical studies largely corroborate this framework. Communication, encouragement, and structured expectations strengthen motivation [64], [84]–[85]. Competence and identity develop through scaffolded skill building and tools such as mentoring compacts and mentor maps that clarify expectations and build agency [27], [64], [92]–[93]. Culturally aware relational mentoring and proactive empathy foster belonging [25], [83], [89]–[91], while unequal access to faculty relationships undermines it [46], [86]–[88]. Autonomy emerges when mentors balance guidance with meaningful choice attuned to readiness [66], [72], [82], [94]. Because these practices may not emerge from experience alone, effective mentoring requires intentional learning and reflection [66], [95].

Methodology

We selected reflexive thematic analysis because our research questions required analytic interpretation of patterned meaning across students' accounts. This interpretive approach allowed us to prioritize depth from a small set of contextualized interviews. The single case served as an information-rich pilot where sustained lab mentoring enabled close examination of practices and student experiences. Consistent with our constructionist stance, RTA treats themes as subjective analytic constructions developed through reflexive engagement rather than objective discoveries [96]–[99]. Its flexibility supported our theoretically informed yet interpretive approach, allowing us to deductively use CIMER competencies to guide patterns of meaning for research question 1 (RQ1) while inductively constructing patterns for research question 2 (RQ2).

Sample and data generation

We used purposive and convenience recruitment consistent with RTA [100]–[102] to recruit undergraduates mentored for at least one academic term by a single engineering faculty member at a large R1 Hispanic Serving Institution in the U.S. South. Of 18 invited, 10 participated. Demographics are reported in aggregate to protect confidentiality. Participants were 40 percent female, 90 percent non-White, and 50 percent Black or African American, representing five ethnicities and four engineering disciplines; half were first generation college students. Mentoring was provided by a Black male tenure-track faculty member with over ten years of experience and a campus level award for Achievement in Undergraduate Research Mentoring. Mentoring duration ranged from three months to over two years. Two participants were undergraduates, two graduate students, and six employed full time, four in engineering.

We conducted semi-structured interviews incorporating photo elicitation in which participants submitted two photographs in advance representing their mentor's approach and how mentoring could have been more supportive. Protocol questions mapped to the conceptual framework are included in Appendix C. We asked students how they experienced mentoring practices and how practices supported persistence. Sample prompts included "Talk about the image that symbolizes your mentor's approach" and "Share a story about how your mentor built a relationship with you and how that supported you." Interviews via Microsoft Teams lasted 50 to 75 minutes, were recorded with consent, and transcribed.

Analytic approach

Consistent with RTA, we prioritized interpretive meaning making over reliability metrics or code frequency [97], [99]. Through six recursive phases of familiarization, coding, theme development, refinement, and narrative construction [96], we repeatedly read and annotated transcripts and organized patterns of meaning into evolving outlines. Coding was theoretically informed by mentoring literature but open to new insights. We iteratively refined, collapsed, or discarded codes as we reconsidered analytic patterns. Co-authors coded a subset of transcripts and engaged in reflexive dialogue to deepen interpretation, and we calibrated interpretations to ensure claims remained grounded in participants' accounts rather than prior familiarity [103].

We constructed themes as analytic interpretations rather than topic summaries and organized them in a working spreadsheet linking patterns of meaning and supporting excerpts.

Because RQ1 and RQ2 addressed distinct analytic concepts, we structured patterns differently across questions. For RQ1, use of contemporary practices, after interpretive construction of themes, we justified using CIMER competencies deductively as an organizing structure for patterns of meaning to illuminate where mentoring practices were visible to students. For RQ2, mentoring benefits, we retained an inductive analytic and organizing approach, preserving participants' in-vivo language to name patterns of meaning, such as "lit up" and "catching up with your uncle." Upon completion, participants reviewed representations of their accounts and offered clarifications. Report writing functioned as an additional analytic phase.

Quality and ethical considerations

Guided by Walther et al.'s qualitative research quality framework [104], we treated quality as an ongoing process of ensuring coherence and usefulness across theory, procedure, and interpretation. Patience supported rich construction of findings, including intentionally pausing after the first two interviews to engage the data and refine the protocol. Although not oriented toward consensus or replicability, our practices aligned with Lincoln and Guba's [105] trustworthiness principles. Prolonged engagement occurred through recursive reading, memoing, group reflection, and participant feedback on representations. We integrated extended, contextualized excerpts such as "He's not going to let you drown" to illuminate scaffolding directly into analytic claims. We also provide a table linking mentoring practices, excerpts, and developmental outcomes to demonstrate conceptual coherence. Consistent with the Reflexive Thematic Analysis Reporting Guidelines [99], we make our epistemological stance and positionality explicit, clarify that our aim is analytic insight rather than transferability, and acknowledge analytic and sampling limitations, including our decision not to link within-case variation to participant characteristics to preserve confidentiality.

Centering researcher reflexivity was critical in this approach to do justice to participants, audiences, and researchers [104], [100]. As the primary interviewer, the first author approached the study as a White woman trained in social work and higher education whose work focuses on mentoring, equity, student development, and policy. Positioned as an outsider to engineering but an insider to mentoring research and student support practice and drawing on recent experiences as a graduate mentee and nontraditional student, she was attuned to power dynamics, implicit expectations, and access to opportunity within mentoring relationships. Rather than bracketing these perspectives, we treated them as analytic resources, acknowledging that our analysis represents a situated interpretation rather than an objective account [96].

We prioritized ethical practice throughout the study. In our IRB protocol (#8081), we specified that the mentor would not participate in recruitment or interviews to support candid disclosure. Because some participants knew the first author, we emphasized informed consent, voluntary participation, and the right to withdraw without penalty. Interviews were conducted and transcribed outside the lab, findings reported in aggregate to protect confidentiality, and data stored securely with identifiers kept separate from transcripts and consent forms.

This single-case study has several limitations. Participants came from one institution and faculty mentor, narrowing perspectives, and purposive and convenience sampling may have introduced self-selection bias. Mentoring occurred across different periods (2018 to 2025) and contexts (i.e., summer programs, grant funded projects, and employment roles), which may have influenced experiences and recall. To preserve confidentiality, we did not connect within-case variation to student characteristics, limiting contextual insight, and the study includes only student perspectives. These pilot findings inform a planned multi-institution study of mentor and mentee pairs, designed to extend the mechanisms identified here across diverse contexts.

Analysis

We present a single case analysis of students' accounts of contemporary mentoring in an EER context. Photo elicitation images informed discussion and interpretation but were not analyzed as standalone data. We selectively shortened interview excerpts due to space limits.

Research Question 1

The analysis for RQ1 explores how undergraduate students' accounts illuminate contemporary mentoring practices enacted by one engineering faculty mentor. Students' narratives showed how they recognized, interpreted, and experienced mentoring in practice. Two themes capture these patterns: mentoring as visible, relational, enacted work and mentoring as inconsistently structured support requiring students to self-navigate.

Theme 1: Mentorship as visible, relational, enacted work

Students most clearly recognized mentoring when it was visible, relational, and tied to skill development and belonging. Students experienced such practices directly in everyday interactions rather than having to infer them. We constructed Theme 1 around tangible, relational forms of mentoring evident in students' accounts and organized these analytic patterns using three CIMER competencies: scaffolded skill building, relationship building that humanized the mentor, and inclusive and empathetic practices that signaled intentional equity.

Scaffolded skill building that made mentoring tangible. Students described scaffolded skill building as hands on, supportive, and intentional. The mentor broke unfamiliar research work into manageable steps through explanation, feedback, and resources, then reinforced learning through real tasks such as coding, writing, presenting, and group work. Independence increased gradually. One student explained, "Research was new to me. I really didn't know this academic world. [The mentor] kind of lets you dive into it, but there's still a guiding presence. He's not going to let you drown." Another described that the mentor gave "just enough so you can take a couple steps forward" before offering more guidance. Students valued that the mentor often observed their initial approaches before redirecting them, describing this as "let me see what you do and then I might nudge you in a different direction."

Relationship building that humanized the mentor. Students described relationship building as humanizing the mentor and strengthening engagement. A personable demeanor and layered interactions softened hierarchical boundaries, increased approachability, and fostered trust. While a few students framed the relationship as PI/student, they shared this reflected their preferences for professional boundaries rather than the mentor's relational abilities. Many others emphasized closeness, with one sharing, "He was a mentor, and personally, a really good friend." One student explained, "At the base level, our relationship, our friendship, sets the foundation for anything we do moving forward so I'm comfortable being my authentic self." Students described informal activities such as eating or running together as helping them "feel closer and not really much gap between student and faculty." One noted that even formal meetings included personal check-ins. Students also described the research group as a safe and supportive space built on the mentor's endorsement of collaboration and peer support.

Inclusion and empathy that signaled intentional equity. Students described inclusive and empathetic practices as central to equitable mentorship, experienced through racial and cultural representation, relevant research topics, and the mentor's use of positional power to reduce structural barriers. One participant noted, "He's a Black mentor. He's fully able to understand where I come from," while another described discussions of the 2023 Supreme Court decision on affirmative action as supportive rather than uncomfortable. Others experienced inclusion through research topics reflecting their own lives, including studies on underrepresented students and Black male engineering students. one sharing how a study on underrepresented students reflected “familial, confidence, and discipline issues” she had personally navigated. A student who did not identify as a Black male described inclusion through the mentor’s trust in assigning her a study on Black male engineering students, showing, “we all should be able to understand each other.” Students also emphasized advocacy in institutional spaces where they lacked power, explaining that “me as a student asking a faculty is different than a faculty asking a faculty.” One participant recalled being stranded at a conference hotel without a credit card and described the mentor’s intervention as unforgettable.

Theme 2: Mentorship as inconsistently structured support

Students described goal and expectation setting and autonomy support as less explicit than other mentoring practices. Rather than relying on formal tools or structured conversations, students often inferred expectations from cues or external structures such as conference submission guidelines. While this approach worked for some, others experienced overwhelm. We constructed Theme 2 around these accounts of implicit mentoring, organizing patterns around two CIMER competencies that appeared less consistently: expectation setting that lacked formalization and autonomy support that varied in its attunement to mentee preferences.

Implicit, situational structure requiring student interpretation. While some students found expectations clear, most reported loose organization, noting, “there weren’t really conversations about our research structure,” and some deferred to authority, admitting they would have said “everything’s fine” even when more structure was needed. The mentor often conveyed expectations through informal conversations, whiteboard planning, or external deadlines rather than explicit shared goals. Limited mentor time necessitated opportunistic rather than regularly scheduled meetings at times. Some recognized that they had “VIP access” to the mentor and that “not everybody could have that.” One reported clearer direction after working with a postdoctoral mentor who met more regularly, while another warned “at some point, the mentor will wear out” without broader support. Uncertainty also extended to goals and direction. One shared, “I’m very goal driven, so with the lack of that, it was very hard for me,” and another noted he often thought a project direction was clear “but to my detriment, it can be the complete opposite because it could seem very implied what direction [the mentor] wants to go.”

Uneven autonomy support reflecting variability in mentor attunement. Students experienced autonomy support as uneven and not uniformly beneficial. While assigned research topics were viewed as appropriate given their limited experience, they were granted substantial freedom in work structure. For some, autonomy in work felt empowering, with students noting that the mentor “did not micromanage” and allowed room to grow, while others found this freedom overwhelming. As one student reflected, “Too much freedom can lead you to a different path. Balance is great,” while another emphasized, “You need experience before you can really be on your own.” A third described, “There was a lot of freedom. The mentor would be like, ‘We want to be over there. Go ahead and do it. If you need help, let me know,’” adding that while it felt liberating, he would have preferred more support. Autonomy also extended to decisions about professional opportunities and future planning. Some students experienced and valued freedom to engage as much or as little in conferences, organizations, and career networking, while others wanted more intentional opportunities aligned with their goals. A few described subtle pressure toward graduate school or limited support for non-research career paths.

Research Question 2:

Next, we present the analysis for RQ2, capturing how students made sense of the benefits of mentorship. Accounts showed how mentoring supported undergraduates’ academic and life experiences by building safety, belonging, identity, access to resources, motivation, and opportunity. Two themes captured these patterns: mentorship as an infrastructure of relationships, and mentorship as an infrastructure of opportunity.

Theme 3: Mentorship as relational, inclusive infrastructure strengthening belonging

Mentorship functioned as a relational, inclusive infrastructure that created psychological safety, affirmed identity, and fostered belonging in engineering spaces. Students experienced mentoring as transformative when enacted through authenticity, respect, affirmation, and community connection. For some, these relational conditions were strengthened by shared racial, cultural, or experiential identities, making engineering feel possible and viable.

"Catching up with your uncle" as relational authenticity. Students articulated relational authenticity that made mentoring feel genuine and human. One explained that meetings began with personal check-ins, describing the interaction as "kind of like catching up with your uncle." Rather than adopting a purely authoritative role, the mentor engaged students through warmth, candor, and visible care. Students emphasized feeling seen, with one sharing that this was "one of the only places I felt like, as a 20-year-old, I was taken very seriously." Informal gestures and unprompted check-ins reinforced that the mentor cared about them.

"Never condescending" as dignity and respect. Students noted psychological safety and respect as emerging from the mentor's feedback style and follow through, emphasizing he was "never condescending," even when offering critique. Students also described being treated as legitimate contributors, with one noting that conversations began "as if you belong there," which increased confidence, particularly when working alongside graduate students. The mentor's consistent follow through on promises further reinforced trust.

"Seat at the table" as representational access. Students reported having a "seat at the table" as representational access that made participation in engineering spaces feel possible. For some, shared racial or cultural identity with the mentor served as essential support in environments where they otherwise felt isolated. Students described the mentor as a counterexample to deficit narratives about who belongs in engineering, with one noting that seeing a Black faculty member made them feel capable of completing an engineering degree. Representational access extended beyond campus into professional spaces, as traveling to conferences and presenting research where "there's not a lot of people that look like me" helped students envision themselves as future experts. One student reflected, "Just seeing, you know, experts in their field at these conferences, you sort of start to become that."

"Instilling hope" as belief in potential and future success. Students described mentorship as instilling hope by affirming their ability and encouraging once unimaginable futures. One described the essence of mentoring as "making you understand that you have the ability to do this." Hope emerged through the mentor's expressions of belief in their potential, providing critical boosts to "get their psyche back" after setbacks. One student explained, "He was so lively and positive that, like, you could be failing your class and still think you're doing okay." Students were encouraged to pursue opportunities they had written off, such as increasing their education level. A student described it as "putting the ball in your hands and telling you to go score," while another emphasized that the mentor had "the utmost confidence in my ability to succeed." These accounts show how mentorship cultivated hope and expanded possibilities.

"Connected" group belonging as feeling part of the team. Students portrayed the research group as a community of belonging where they felt connected through shared work and relationships. One stated, "It was a whole group, like a team," and another said she wasn't "just the undergrad." This environment reduced isolation and fostered confidence.

Theme 4: Mentorship as opportunity and motivation-building infrastructure

Mentorship operated as an infrastructure of opportunity that transformed proximity to faculty into access to power, legitimacy, resources, and future possibilities. Motivation emerged not simply as an internal trait but as an outcome of this infrastructure, shaped by material support, meaningful work, and the mentor's visible enthusiasm.

"Automatically you're good people" as borrowed legitimacy. Students understood mentorship as conferring borrowed legitimacy, where proximity to a highly regarded faculty member translated into credibility in institutional and professional spaces. Knowing the mentor meant others "automatically think, 'OK, you're good people,'" which reduced barriers. Several described intentionally staying close to the mentor because "any work that I produce with him will be good." One student was touched by "somebody at such an esteemed level kind of [seeing me] as his own personal project to make sprout more than what you're possibly thinking of."

"Opportunities poofed into my inbox" as social capital activation. Students described opportunities emerging through the mentor's proactive sharing of information, captured by one student's description that opportunities "just kind of poof into my inbox." Participants described access to scholarships, conferences, internships, and professional introductions that opened doors and shaped persistence. One recalled, "The provost's office would pop in, and he'd hand them my resume and be like, 'Help this kid get a job.'" Another noted that shared dinners with alumni "went a long way" in building relationships they expected to draw on later.

"Helping someone grow" role modeling character, values and life navigation. Students framed mentorship as role modeling for holistic growth in character, work ethic, and life skills. One student explained, "[The mentor] helped me understand, like, as a man, what was possible for me to get done, and how much I was underutilizing my capacity," while another described mentorship as "a visual kind of thing where you see that person's career path and lifestyle and you'd be like, wow, that's what I want actually for me." One participant described the mentor's attention to mental health as formative, recalling that after a "catastrophic event" they were "struggling pretty hard" and would not have pursued therapy due to "masculine boastfulness." The mentor modeled vulnerability by sharing, "I've used [therapy] before," and connected the student to campus resources. The participant said this intervention "kick started my belief of the importance of it," shaping help-seeking practices that extended beyond college.

"Exchange of knowledge" skills acquisition. Students described substantial skill development through an "exchange of knowledge," where hands on collaborative mentoring strengthened skills, confidence, professional identity, and research competence. Frequent presentations and conferences built professional skills extending beyond undergraduate research and shaping job attainment and long term confidence, with one participant noting, "Getting that engineering education knowledge, I've gained another 20 percent more of [professional skills] I can do better than other guys." Through scaffolded training, students learned to design studies, conduct literature reviews, analyze data, and navigate processes such as human subjects review in an environment where knowledge was shared rather than "hoarded." As one explained, "You feel like you're really learning…like you are now hooked up to the Internet for the first time."

"College isn't free" motivation from present and future material needs fulfilment. Students recounted motivation as emerging through paid research roles, scholarships, and flexible employment that reduced financial strain and made continued enrollment possible. As one student said, "Research was not even on my radar a little bit, but I know I did want a job." Financial support enabled focus on coursework and opened access to conferences and travel, while research experience and credentials positioned them competitively in the job market, allowing them to "rack up experience with things that may differentiate you."

"Lit up" motivation sparked by enthusiasm and positive relational energy. Students reported heightened motivation when mentoring connected them to communal work that mattered personally and socially, particularly research addressing underrepresentation. Although some initially joined for financial reasons, many developed a sense of purpose, viewing their work as contributing to helping "people who come after me have a better experience in the undergrad engineering program." They expressed a shared sense of "working towards something." This motivation was amplified by the mentor's visible joy, enthusiasm, and emotional investment in the work and the students. As one noted, "You aspire to be around somebody with that level of emotional capacity to care for people, and he exuberates that." Participants described his energy as contagious, sharing that "he got really lit up" when discussing research, and that "when people care about what they do, you want to also care."

Discussion

We discuss findings that both support and extend existing mentoring scholarship. To preserve confidentiality in this single-mentor case study, we do not link within-case variation to participant characteristics, but we intentionally retain contrasting experiences rather than presenting a single dominant story. We summarize the mechanisms linking mentoring practices, student experiences, and developmental outcomes derived from the analysis in Appendix D.

Students' experiences represented the three core SDT psychological needs, yet they identified the consistent use of three of five CIMER competencies. Relatedness emerged as foundational, with students identifying CIMER's relationship building and inclusive practices as central to persistence [46], [58], [84]–[85], [90]. Social cues of care strengthened connections, particularly for students navigating marginalization [46], [83], [87]–[88]. Proximity to a highly regarded mentor enhanced students' sense of legitimacy, with representational access countering deficit narratives around Black engineering students [64], [83], [85], [89].

The mentor most clearly supported competence through CIMER-recommended scaffolded skill-building: guided participation, feedback, and gradual responsibility [17], [27], [92], [95]. Yet students frequently reported uncertainty about project structure, expectations, and the broader arc of their work. Accounts indicated that competence may remain incomplete without CIMERs intentional expectation setting and communication tools [28], [81], [91], [93].

Students experienced autonomy support as variable and not uniformly beneficial, with many undergraduates prioritizing relatedness and competence and viewing limited autonomy as appropriate. These accounts were consistent with evidence that autonomy is less salient for engineering undergraduates than relatedness [85]. Accounts support developmental approaches to structure and autonomy that unfold through mentor attunement [25], [66], [72], [81]–[82].

Finally, accounts aligned with prior literature linking relatedness, competence, and autonomy to motivation [68], [72], [94], but other factors influenced motivation, extending this work by foregrounding material conditions, hope, and communal and future oriented goals as central drivers of undergraduate motivation in engineering. Students emphasized scholarships, paid research and conference participation, professional networks, prosocial research aims, and the mentor's visible enthusiasm and belief in their potential as key to sustained engagement.

Implications for research and practice

Accounts from this single case position undergraduate research mentoring in EER as a promising mechanism supporting engineering student persistence. Even when mentoring had limitations, students overwhelmingly described research mentoring experiences as transformative, carrying implications for mentors, departments, and the field.

At the mentor level, analyses highlight the importance of visible, relational practices, with students most readily identifying scaffolded skill building, opportunity sharing, warmth, inclusion, and approachability. Though engineering faculty may underestimate the role of emotional labor, relational practices were described as foundational. In contrast, autonomy and expectation setting were often unclear or uneven, suggesting these supports should be treated as developmental and intentionally attuned to students' needs. Mentors should consider that power dynamics may limit undergraduates' willingness to voice challenges or preferences. Also, rather than relying on narratives of innate brilliance or self-directed exceptionalism as indicators of engineering potential, mentors should consider adopting growth-oriented approaches that cultivate students' capacity through scaffolding, encouragement, and access to opportunity.

Implications for mentor training include incentivizing mentor professional development, particularly for experienced faculty who may perceive prior experience as sufficient preparation. Training should emphasize developmentally responsive support, explicit expectation setting for students who benefit from structure, and the role of relational practices in supporting belonging and persistence. Faculty may benefit from cross-disciplinary training from fields such as psychology to build empathy and relationship-based practices. Current CIMER training programs work with faculty, staff, postdocs, and graduate students, strengthening clarity of roles across the mentoring ecosystem. CIMER may consider extending this approach to include undergraduate mentees as active participants in mentoring practice. Finally, in addition to the five CIMER mentoring competencies we examined, students' accounts highlighted role modeling and career opportunity building as central components warranting greater emphasis.

At the departmental and institutional levels, analyses show undergraduate research mentoring provides critical advocacy, guidance, and opportunity supporting persistence in engineering. Departments can strengthen mentoring through structured onboarding, regularized research practices, and layered mentoring with graduate students and postdocs. Institutions should distribute mentoring responsibility through training and incentives such as teaching credit and service recognition, ensuring high quality mentoring does not fall disproportionately on a small subset of mentors. Because mentoring contributes to broadening participation, financial supports such as paid research roles should be treated as integral rather than ancillary.

For research, these analyses call for greater attention to how students interpret mentoring practices and how power, representation, and structure shape who benefits from mentoring. Future studies should examine whether these patterns extend to traditional undergraduate engineering research contexts. Scholars drawing on SDT may reconsider autonomy as a need that unfolds developmentally rather than as uniformly beneficial or equivalent to relatedness and competence. Studies on integrating CIMER competencies, EER, and ecosystem mentoring structures may support culture change in engineering and broaden the field.

Conclusions

Accounts from this single case suggest faculty research mentorship operates as an infrastructure of relationships, belonging, and opportunity that shapes persistence, identity, and access in engineering. Centering undergraduates' experiences shows mentoring is most meaningful when visible, relational, and enacted through concrete practices that reduce uncertainty, affirm belonging, and link present effort to future opportunity. Uneven expectation setting and autonomy support, however, highlight the limits of mentoring not developmentally attuned to undergraduate needs. Overall, students' experiences suggest undergraduate research mentoring may support broader participation in engineering and indicate the value of continued institutional attention to engineering education research programs.

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Appendix A

Traditional versus Contemporary Mentoring

Traditional Faculty Mentoring	Contemporary Faculty Mentoring
Guided by personal style, preference, or prior mentoring experiences	Guided by evidence, recommended practices, and professional development
Unstructured and informal	Structured and intentional
Implicit expectations	Explicit, transparent expectations & communication
Undefined goals and processes	Defined goals, structure, and developmental tools (i.e., individual development plans)
Single mentor dyad	Mentoring networks or constellations
Hierarchical, top-down	Collaborative and relational
Prioritizes independence through “figuring it out” alone	Scaffolds progression toward independent work combined with collaborative work
Assumes learning occurs through independent personal struggle	Distinguishes productive from unproductive struggle and guides mentees through unproductive struggle
Apprenticeship model with limited autonomy	Developmental model fostering student agency and ownership aligned to readiness
Authoritative and evaluative	Supportive, facilitative, mentor as partner or coach
Mentor-centered and prescriptive	Mentee-centered and responsive
Static, one-size-fits-all approach	Contextualized and adaptive
Focused on research output	Integrates psychosocial and career development
Transactional	Reflective, reciprocal, growth-oriented
Minimizes power, identity, systemic barriers	Attends to power, identity, intersectionality, and access barriers
Culturally neutral or unaware	Culturally responsive
Attributes problems to mentee deficit or mismatch	Responds to problems by adjusting mentoring approach
Lacks evaluation and accountability	Assessment-informed and continuously improved

Note. Taken from CIMER, 2025; Crisp & Cruz, 2009; Crisp et al., 2017; NASEM, 2019.

Appendix B

Conceptual Framework Mapping CIMER Mentoring Competencies to SDT

Note. CIMER stands for the Center for the Improvement of Mentored Experiences in Research, SDT stands for Self-Determination Theory, IDP stands for individual development plan

Appendix C

Sample Interview Questions Aligned With Conceptual Framework

RQ1: What do the accounts of a single case of undergraduate students mentored by one engineering faculty member reveal about contemporary mentoring practices in engineering?
RQ2: How do students describe the benefits they gain from mentoring practices?

Research Questions (RQs)	Interview Questions (IQs)	3 SDT components	3 of 5 CIMER competencies shown
RQ1	Tell me about a time when your mentor set and communicated expectations with you.	Competence	Expectation setting
RQ2	How did those approaches support you in the program?		
RQ1	Can you share a story about how your mentor built a relationship with you and built relationships within the research group?	Relatedness	Relationship building
RQ2	How did your mentor's approach to building a relationship support your persistence?		
RQ1	How did your mentor clarify how much autonomy you had in making research or degree-related decisions?	Autonomy	Autonomy support
RQ2	How was it helpful when your mentor supported your autonomy?		
Photovoice:			
RQ1	Tell me about the first image that symbolizes your mentor's approach to mentoring.	All	All
RQ1 & 2	Thinking about the second image, what does it show about something you wished could have been different with mentoring?	All	All

Note. Contact first author for complete interview protocol.

Appendix D

Linking Mentoring Practices and Developmental Outcomes

Mentoring Practice (RQ1)	Student Experience	Developmental Outcome (RQ2)
Infrastructure of Relationships		
SDT: Relatedness fulfillment for motivation		
CIMER*: Warm, trusting, humanized relationship	"Catching up with your uncle," authentic connection	Belonging and comfort in engineering spaces
CIMER*: Representation and inclusive interactions	"Seat at the table," feeling seen in engineering	Expanded access and belief in future possibilities
Respectful feedback and dignity	"Never condescending," all are legitimate contributors	Identity affirmation and persistence
Layered mentoring network (postdocs/peers/campus & broader connections)	"Connected" "It was a whole group, like a team."	Improved guidance, sense of belonging, and identity
Infrastructure of Opportunity		
SDT: Competence fulfillment for motivation		
CIMER*: Scaffolded skill building	"Not going to let you drown," gradual responsibility	Research competence and confidence
CIMER: Role modeling and encouragement	"Helping someone grow" and "Instilling hope"	Personal growth, academic guidance, and goal expansion
CIMER: Opportunity sharing	"Opportunities poofed into my inbox" and unhoarded "Exchange of knowledge"	Access to engineering experiences and professional networks
Closeness to esteemed faculty member	"Ok, you're good people" respect from others	Borrowed legitimacy
CIMER*: Expectation setting (Mentor: loose structure)	"The direction [of the work] could seem very implied"	Overwhelm for some
SDT: Autonomy fulfillment for motivation		
CIMER*: Autonomy support (Mentor: high autonomy without attunement)	For some: "Too much freedom" unhelpful For others: "Put the ball in my hands to go score"	Uneven desire and readiness for autonomy across students; empowering for some
Other Motivating Practices		
Paid research and material support	"College isn't free" reduced financial strain	Continued enrollment and engagement
Meaningful, prosocial research topics	"Working towards something" communal value	Purpose driven motivation
Enthusiasm, joy	Mentor "lit up" over research	Increased identity, motivation

Note. RQ is research question. SDT is Self-Determination Theory's human psychological needs, CIMER is Center for the Improvement of Mentored Experiences in Research mentoring competencies, *Pre-determined mentoring practices or competencies we asked about.