

Enhancing Research and Mentoring Skills in Engineering Education through a Mentoring Triad Model

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Abstract—This innovative practice study submitted in the “Competencies Development” category is a multi-methods case study that aims to examine the impact of a unique Mentoring Triad Model on enhancing research skills in undergraduate students, mentoring skills in graduate students, and professional growth in faculty mentors. The Mentoring Triad consists of an undergraduate student, graduate student, and faculty member collaborating on a semester-long research project within the context of a large Midwestern research university. Data was collected from each participant through surveys, interviews, observations, and document analysis. Results indicate the Mentoring Triad Model facilitated significant growth in research skills, psychosocial development, and professional competencies for all participants. The undergraduate student developed research abilities, intercultural competence, communication skills, collaboration, and self-regulation. The graduate student enhanced their mentoring, research, empathy, project management, adaptability, and collaboration skills. The faculty mentor refined their team management, mentoring, time management, openness to feedback, and collaborative capacities. Findings support the Mentoring Triad as an effective model for integrating research and multi-level mentorship to advance the holistic development of aspiring researchers and professionals in higher education, with implications for replication across disciplines and institutions.

Index Terms—Intercultural competence, Mentoring, Project based learning, Research Program, Reflection

I. INTRODUCTION

Mentorship and research skills are essential components of higher education, especially in engineering disciplines. The increasing demand for interdisciplinary expertise and research competency has led to the development of innovative research mentorship models. This study examines the impact of a unique research mentorship framework known as the Mentoring Triad Model, which pairs an undergraduate student, a graduate student, and a faculty mentor. The aim is to enhance the research skills of undergraduates, mentoring skills of graduate students, and professional growth of faculty mentors.

II. BACKGROUND

A. Research Programs

Undergraduate research programs (URPs) provide opportunities for students to immerse themselves in research activities,

enhancing critical thinking, problem-solving, and communication skills [1], [2]. These programs are particularly effective in STEM fields, where students can bridge theoretical knowledge with practical application [3], [4]. Through active participation in research projects, students develop a deeper understanding of their disciplines, gain confidence, and establish valuable mentor-mentee relationships [5], [6].

However, URPs face significant challenges due to faculty time constraints and the difficulty in providing high-quality mentorship for every student [7]. As faculty members balance teaching, research, and administrative responsibilities, finding enough time for effective individualized mentorship becomes increasingly challenging [8]. In response, graduate students are often recruited as near-peer mentors [2], which helps ease faculty workload and provides graduate mentors with opportunities to develop their own leadership and teaching skills [9].

B. Importance of Research Mentorship

Mentorship is critical for students across academic levels. At the undergraduate level, effective mentorship ensures that students receive guidance in understanding the research process, overcoming challenges, and navigating academic expectations [10]. For graduate students, mentorship experiences are vital for cultivating their ability to guide others, manage research projects, and contribute to scientific literature [11]. However, traditional mentoring models sometimes fall short of creating comprehensive support structures, often leading to unmet expectations and frustration [12].

Effective mentorship programs emphasize regular communication, constructive feedback, and mutual learning [13]. By fostering collaboration and openness, mentors can provide valuable insights while developing their own leadership styles [14]. Approaches like the Mentoring Triad Model offer a solution to the limitations of traditional models by creating a hierarchical yet collaborative environment where all participants can contribute meaningfully and learn together.

C. Purpose of the Study

The purpose of this study is to explore the experiences of the Mentoring Triad Model participants in developing research skills among undergraduate students, mentoring skills in graduate students, and professional growth for faculty mentors. The study aims to answer the following research questions:

- 1) How does participation in the Mentoring Triad Model impact the research skills development of undergraduate students?
- 2) In what ways does serving as a mentor in the triad model contribute to the mentoring skill development of graduate students?
- 3) How does the triad model influence the professional growth and mentorship practices of faculty mentors?

By addressing these questions, the study seeks to offer valuable insights into the design of scalable, effective mentorship programs that can enhance educational outcomes across various academic disciplines.

III. CONCEPTUAL FRAMEWORK

A. Mentoring Triad Model

The Mentoring Triad Model is designed to facilitate a comprehensive educational experience by integrating both undergraduate research and graduate mentoring within a collaborative framework. This model is structured around a triad consisting of an undergraduate student, a graduate student (typically at the PhD level), and a faculty member. Each participant in the triad assumes specific roles and responsibilities that contribute to the educational objectives and personal development of all members involved.

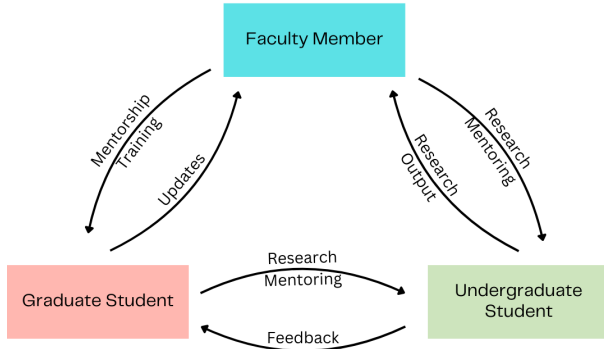


Fig. 1. The Mentoring Triad Model Diagram

B. Roles and Responsibilities

The roles and responsibilities within the triad are delineated to enhance the learning and development of each member effectively. Table 1 summarizes these roles and tasks.

In the Mentoring Triad Model, participants engage in meaningful tasks tailored to their specific developmental needs and roles, ensuring a comprehensive learning experience through direct involvement in a real-world research project. For the undergraduate student, engagement involves directly working on research tasks that form the backbone of the project. This

TABLE I
ROLES AND RESPONSIBILITIES WITHIN THE MENTORING TRIAD MODEL

Participant	Roles	Responsibilities and Tasks
Undergraduate Student	Learner, Collaborator	Engage in research tasks, learn research methodologies, participate in project planning, and present findings.
Graduate Student	Mentor, Researcher	Mentor the undergraduate student, manage parts of the research project, develop and refine mentoring skills, and contribute to research output.
Faculty Member	Senior Mentor, Supervisor	Oversee the entire project, provide guidance and mentorship to the graduate student, ensure the research meets academic standards, and foster a supportive learning environment.

includes designing experiments, collecting data, analyzing results, and contributing to writing manuscripts. Such tasks not only bolster their research skills but also immerse them in the practical challenges and intellectual demands of academic inquiry. The undergraduate's role is hands-on and formative, designed to stimulate curiosity and foster a deep understanding of the subject matter.

The graduate student, in their role as a mentor, engages in the dual tasks of guiding the undergraduate student and learning the nuances of effective mentorship—an apprenticeship in leadership and teaching within academia. This involves not just overseeing the undergraduate's work from a technical standpoint but also providing support, feedback, and encouragement. The graduate student's tasks extend to managing portions of the project, ensuring deadlines are met and objectives are achieved. This dual focus on mentoring and managing a research project enhances their own skills in leadership, communication, and project oversight, preparing them for future roles as independent researchers and educators.

Lastly, the faculty member, serving as the senior mentor and supervisor, engages in providing overarching guidance and support to both the graduate and undergraduate students. This role involves more than just administrative oversight; it encompasses the fostering of an academic environment conducive to growth and discovery. The faculty member's tasks include refining the project's direction, securing resources, and ensuring ethical standards are maintained. Additionally, they model advanced research practices and mentorship strategies, offering feedback and insights that help shape the graduate student's approach to mentoring and the undergraduate's research trajectory.

Through these tailored roles, each member of the triad actively contributes to and benefits from the research project. This structured yet dynamic interaction not only drives the project forward but also ensures that each participant develops both individually and in concert with their team members.

C. Theoretical Foundations

The theoretical foundation of the Mentoring Triad Model is rooted in collaborative and constructivist pedagogies, emphasizing project-based learning. Collaborative pedagogy supports the model by advocating for mutual learning experiences and shared knowledge creation among all participants [15]. This approach facilitates an environment where undergraduate and graduate students can learn from each other and from the faculty mentor, thus enhancing the educational experience.

Constructivist pedagogy, particularly in its application to project-based learning, is integral to the model. It posits that learners construct knowledge most effectively through active engagement in meaningful tasks [16]. In the context of the Mentoring Triad Model, each participant is actively involved in a real-world research project that requires critical thinking, problem-solving, and innovation. This hands-on approach not only helps consolidate theoretical knowledge but also enhances practical skills crucial for professional success in academia and beyond.

Through the implementation of this model, the study aims to test the effectiveness of a structured yet flexible framework for enhancing research skills in undergraduate students and mentoring skills in graduate students, while also contributing to the professional development of faculty members. This approach hopes to offer significant insights into the benefits and challenges of such an integrated mentorship system, providing a scalable model for similar educational settings.

IV. METHODS

A. Research Design

This study employed a multi-methods case study design to explore the experiences of participants in a mentoring triad model. Case study research is a widely used approach in educational research [17], [18], as it allows for an in-depth examination of a phenomenon within its real-world context [19]. This design was chosen for its flexibility and ability to provide rich, detailed insights into the experiences of the mentoring triad participants. The phenomenon under study is the mentorship program and the unit of analysis is the participants of the mentoring triad: a faculty mentor, a graduate student mentee, and an undergraduate student mentee.

To ensure the trustworthiness and credibility of the findings, the study employed a triangulation of data sources [20]. Multiple data collection methods, both qualitative and quantitative, were used: including surveys, interviews, observations, and document analysis. This approach allowed for the corroboration of findings across different data sources and provided a more comprehensive understanding of the case.

B. Context and Participants

This study examined a semester-long mentoring program that implemented the mentoring triad model within a large midwestern research university. The mentoring program was designed to foster research skill development in the undergraduate mentee, mentoring skill development in the graduate mentee, and professional growth for the faculty mentor as

well as establish an effective model of mentorship that can be replicated across various academic disciplines and professional fields. The mentoring triad consisted of three key participants: a faculty mentor, a graduate student mentee, and an undergraduate student mentee. Each participant had specific roles and responsibilities within the triad.

The mentoring triad collaborated on a research project that aimed to assess the impact of a structured study abroad initiative on the intercultural competence of STEM students. This project aligned with the faculty mentor's research interests and provided an opportunity for the graduate and undergraduate mentees to develop their research skills while also gaining knowledge of integrating intercultural competence through structured interventions and curriculum design.

The participants were selected based on their interest in the mentoring program and their commitment to the research project. The faculty mentor was chosen based on their expertise and experience in STEM education and intercultural competence. The graduate mentee was selected based on their strong academic background, industry experience, and potential for growth as a mentor and researcher. The undergraduate mentee was chosen based on their demonstrated interest in research and their willingness to learn and contribute to the project.

Throughout the mentoring program, the triad members engaged in regular weekly meetings, research activities, and skill development sessions. They followed a structured approach, utilizing project management tools such as Gantt charts and agile methodologies to ensure the timely completion of research tasks and deliverables.

C. Data Collection and Analysis

Data were collected from each participant using various methods to capture their experiences and growth throughout the mentoring triad project. Table 2 summarizes the data sources for each participant: The pre-post survey [21] was ad-

TABLE II
DATA SOURCES FOR THE STUDY

Participant	Data Sources
Undergraduate Student	Sprint retrospectives, Exit Interview, Pre-post research skills efficacy survey, Research Posters, Research Presentations, Mentor observations, Reviewer feedback from Poster Session, Research Manuscript and revisions
Graduate Student	Sprint retrospectives, Exit Interview, Project plan, Faculty Mentor Observations
Faculty Member	Sprint retrospectives, Exit Interview, Mentorship plan

ministered to the undergraduate student to assess their research skills efficacy before and after participating in the mentoring triad. The survey results were analyzed using descriptive statistics and compared pre and post scores to determine significant changes.

Sprint retrospectives were conducted with all participants at the end of each project sprint (i.e., every four weeks). These

retrospectives provided valuable insights into the participants' experiences, challenges, and successes throughout the project. The retrospective questions were designed to elicit reflective responses and facilitate discussion among the triad members.

Semi-structured interviews were conducted with each participant at the conclusion of the project. The interview questions focused on the participants' overall experiences, skill development, and perceptions of the mentoring triad model. Interviews were audio-recorded, transcribed verbatim, and analyzed using thematic analysis [22]. The analysis involved iterative coding, categorization, and theme development to identify patterns and key findings across the cases.

Other data sources, such as the undergraduate student's posters, presentations, and manuscript revisions, were examined to assess their research skill development and growth over time. Mentor observations and reviewer feedback from the poster session provided additional insights into the undergraduate's progress and areas for improvement. The project plan and mentorship plan served as valuable data sources for understanding the graduate student's and faculty mentor's approaches to mentoring, project management, and skill development. These documents were analyzed alongside the interview and retrospective data to provide a comprehensive understanding of each case.

V. RESULTS

A. Case 1 - Undergraduate Student

Case 1 focuses on the experiences of an undergraduate, a senior majoring in electrical engineering with a strong interest in research but limited prior experience. Through the mentoring program, he had the opportunity to work closely with a graduate student and faculty mentor on a research project investigating the impact of structured study abroad on the intercultural competence of STEM students.

Throughout the project, the undergraduate student developed a wide range of skills, such as (a) **Research Skills:** The student gained hands-on experience in conducting a literature review, performing qualitative analysis, and contributing to the development of research manuscript and poster. The student's growth is evident in the results of the pre-post research skills efficacy survey. Before the mentoring program, the student rated their abilities in various research tasks as low to moderate (1-3 on a 5-point scale). However, after completing the program, their ratings increased to 4-5 across all areas, indicating a significant improvement in their research skills and confidence. (b) **Intercultural Competence.** Engaging with the intercultural research topic helped the student develop a deeper appreciation for cultural diversity and the importance of empathy. He noted, *"Through my interactions with my mentors, both from unique backgrounds and had different perspectives, I learned how to navigate and appreciate different cultures. These personal connections helped me see the world through multiple lenses, which I feel would be very useful in life."* (c) **Communication Skills:** The student's communication skills, both verbal and written, improved significantly through regular interactions with their

mentors, working on research outputs, and presenting at research conferences. He shared, *"I became more an active listener and can articulate my thoughts clearly...I learnt how best poster real estate can be used in an effective manner...My presentation skills have also improved."* (d) **Openness and Adaptability:** The dynamic nature of the project required the student to be open to feedback and willing to step outside their comfort zone. He embraced this challenge, stating, *"I am no longer threatened from any unforeseen circumstance but takes that it as an opportunity to learn and grow in life."* (e) **Collaboration:** Working closely with their graduate student and faculty mentors, the undergraduate student learned the value of teamwork and leveraging diverse perspectives, reflecting, *"I felt that by leveraging our collective strength, we achieved our goal in planned time frame."* (f) **Time management, self-regulation, and metacognition:** As they engaged in various research tasks, the student became more aware of their own learning processes and the strategies needed to optimize their performance, noting, *"I felt thematic analysis was very time consuming and I need to do better planning so that I can balance out my time between this research and my college assignment and TA job"*. This reflection demonstrates the student's growing ability to monitor their own learning and adapt their approach to meet the demands of multiple responsibilities. While balancing the demands of the research project with a full course load was initially challenging, the student learned to prioritize tasks and manage their time effectively. *"Through trial and error, I discovered the strategy of prioritization, and effective planning. This helped me in maximizing my productivity and maintaining a healthy work-life balance,"* he reflected.

The undergraduate student's experiences highlight the transformative power of the mentoring triad model by providing a supportive environment that fostered the student's holistic development and prepared them for future research endeavors.

B. Case 2 - Graduate Student

Case 2 is a second-year PhD student in Technology with an educational background that spans Computer Science, Organizational Leadership, Intercultural Studies, and Business Analytics. Before rejoining academia for PhD, the student garnered five years of industry experience as a project manager, which endowed them with a robust foundation in overseeing projects and leading diverse teams. This diverse academic and professional background uniquely positioned them to bridge the gap between theoretical research and practical application within the mentoring triad.

In the project, the graduate student assumed a pivotal role in managing the day-to-day activities, which involved creating and monitoring the project plan. Their responsibilities extended to teaching the undergraduate student essential research skills, such as conducting a literature review and performing qualitative analysis. The graduate student also reviewed the undergraduate's work regularly, providing constructive feedback aimed at refining the research outputs. This continuous interaction not only facilitated the undergraduate's learning

process but also ensured the project adhered to its intended timeline and quality standards.

Throughout their involvement in the mentoring triad, the graduate student developed a multifaceted skill set. (a) **Mentoring and Coaching:** *"I was not sure if I can teach someone, but over time I felt more comfortable sharing knowledge and providing feedback,"* reflects the graduate student on their evolving mentoring skills. (b) **Research Skills:** Despite their prior experience, the project presented new challenges in research design and execution, enhancing their capability to manage complex research tasks as evidenced by in their reflection, *"I liked that my mentee had so many questions. It made me think hard about why we do what we do. I feel it helped me become a better researcher"*. (c) **Empathy:** Engaging closely with the undergraduate student allowed them to develop a deeper understanding and empathy towards the learning process, noting in the interview, *"Working so closely with someone new to qualitative research, I realized just how confusing and frustrating it can be at the start. It made me more patient and thoughtful in how I offer help. Kinda reminded me of my undergraduate research days"*. (d) **Project Management:** Their industry experience was invaluable, yet the academic setting introduced nuances that required adaptability and innovation in project management. They mentioned *"One thing I learnt is that everyone has their own process and pace of working. And busy schedules! Balancing the project work with our academic schedules was tricky. Keeping in constant communication, expressing any competing priorities helped us create transparency and stay on track."* (e) **Adaptability and Flexibility:** The dynamic nature of the project demanded continual adjustments to methods and expectations, encapsulated in their remark, *"Also, everyone had so many great ideas that we had ended up changing our project direction multiple times. This changed our project plan. We decided to present in a couple conferences at the last minute which also interfered with our plan. But I am glad it did, because in the end we achieved more than we originally expected."* (f) **Collaboration:** Working with both the faculty and undergraduate student honed their collaborative skills, with the graduate student observing, *"It was an interesting team dynamic. There were clear mentor-mentee relationships but we were also peers, working together on the research project. I had to complete my individual tasks while providing guidance and support to undergraduate student_i. At the time, I was also being assessed by mentor_j. She would tell me how well I did or if I should change something next time. Mentor_j and I would meet separately first, come up with a plan and then meet undergraduate student_i to get him onboard."*

This experience highlighted the intricate balance between teaching and learning within the triad, with the graduate student enhancing their own skills while contributing significantly to the development of the undergraduate's research capabilities.

C. Case 3 - Faculty Member

Case 3 discusses the role of the faculty mentor, a research scientist with over seven years of experience in STEM and engineering education research. Holding a PhD in STEM education and trained as an intercultural specialist, the faculty mentor combines expertise at the intersection of STEM disciplines and intercultural competence. Prior to academia, they held leadership roles in industry and managed large teams. The lead mentor plays a crucial role in guiding both graduate and undergraduate students.

In this project, the faculty mentor guided a PhD student and oversaw the mentoring style of the PhD student in mentoring the undergraduate student. Through this mentoring process, the faculty mentor also developed multiple skills, such as **Team Management**. They noted, *"As the lead mentor, my management style emphasizes empowerment of my mentees and providing strategical guidance. Through mentoring the PhD student and overseeing their mentorship of the UG student, I've developed vital skills in aligning my mentoring approaches and expectations across various levels. I also felt confident in giving more responsibility to the grad mentee, which helped establish trust in our mentoring relationship. This process has helped me ensure effective knowledge transfer. Developing these skills myself helped me to move ahead in my goal to cultivate a resilient, skilled, and collaborative team environment"*. The faculty mentor also enhanced their **Time Management** skills. During the interview, they mentioned that they felt relieved that the project was completed on time, during a particularly busy semester: *"It felt a sense of relief when we were able to complete the project within the timeframe. It was a very busy semester for all of us. We all were putting multiple hats on, I felt accomplished as I was strategic enough to craft the Gantt Chart well and put a clear timeline for all the deliverables. But really, thanks to the mentees they were committed too"*. **Openness** and a commitment to lifelong learning emerged as key values for the faculty mentor. They emphasized, *"I am always open to ideas, thoughts and proposals that my mentees have. I want to seek feedback on my mentoring styles. I sometimes challenge them to contradict and I like when they do that as I learn from that. I value openness as I believe I am a lifelong learner, even you learn so much from your mentees"*. This attitude towards mentee feedback reflects a humble approach to mentoring. Finally, the faculty mentor stressed the importance of **collaboration** in driving research success and personal growth. They shared, *"I love to collaborate and work. When I collaborate I never run out of ideas. For this project we had a team of three with three different levels of research experience, but we were continuously learning from one another. Collaboration also speeds up the work as you can divvy up the work and allocate roles."*

Overall, the experiences of the faculty mentor illustrate that learning is not constrained by age or experience and one can continually learn at every stage of life. From a mentoring perspective, it is vital to have a mentor who is receptive

to change and ideas, creating a space where mentees feel a sense of belonging and confidence to share their thoughts openly. This case highlights the profound impact effective mentoring can have, not just on the mentees' development but equally on the mentor's growth, emphasizing the importance of adaptability and continuous learning in the pursuit of excellence in any field.

VI. DISCUSSION AND IMPLICATIONS

The results of this case study provide valuable insights into the experiences and skill development of participants in the Mentoring Triad Model. Participants across all levels reported significant improvements in their ability to conduct and manage research. Undergraduates particularly benefited from hands-on experience, transitioning from novice to proficient in understanding and applying research methodologies. This aligns with Linn et al. [10], who emphasized the value of research experiences in deepening students' understanding of their field.

Furthermore, participants reported increased confidence, particularly graduate students who noted a heightened sense of self-efficacy in their mentoring and leadership abilities. This aligns with research by Thiry and Laursen [9] that emphasizes the reinforcing nature of mentoring on mentors' own learning and confidence. Interactions within the triad also significantly improved communication and collaboration skills, enabling participants to work effectively in teams, provide constructive feedback, and engage in meaningful academic discourse. This development is critical in engineering education to prepare students for the collaborative demands of complex real-world professional environments [23], [24].

Participants engaged in a project that involved assessing intercultural competence, which not only contributed to the project's goals but also enhanced their own sensitivity and understanding of cultural diversity. This is crucial in engineering education to develop engineers who are competent in navigating global and multicultural environments [25], [26]. Additionally, the participants developed professional skills such as project management, time management, and adaptability by learning to manage research tasks effectively, adhering to timelines, and adapting to changing project scopes and objectives. These professional skills are particularly valuable as they transcend academic settings, preparing participants for diverse career paths in both academia and industry. The integration of these professional skills within the academic mentorship framework provides a robust foundation for holistic development, echoing the broader educational objective of preparing students for multifaceted professional roles [27], [28].

The Mentoring Triad Model offers a significant advantage over traditional mentoring by fostering the development of the next generation of mentors through the training of graduate students while simultaneously benefiting undergraduate students. This model allows undergraduates to experience the dual benefit of near-peer learning from graduate students, who provide relatable guidance, and mentoring from experienced

faculty, who offer deep academic and professional insights. Moreover, the triad structure ensures a balanced workload between the faculty and graduate student mentors, providing more consistent support for the undergraduate; if one mentor is unavailable due to other commitments, the other can step in, ensuring continuous guidance. Additionally, this model encourages the development of strong interpersonal and leadership skills in graduate students, preparing them for future roles as independent mentors and researchers. This holistic approach not only enhances the learning experience for undergraduates but also cultivates the mentoring capabilities of graduate students, thereby contributing to a sustainable mentoring ecosystem within academic institutions.

These insights reveal the intricate dynamics within the Mentoring Triad Model, highlighting its capacity to address multiple educational objectives simultaneously. The model not only advances research and mentoring skills but also enriches participants' interpersonal competencies, making it a robust framework for holistic academic development. The findings support Vygotsky's [29] theory of social constructivism, which states that learning is inherently a social process. The Mentoring Triad Model serves as a real-world application of this theory, showing that knowledge is constructed through social interactions and mediated by more knowledgeable others within the educational setting [30]. Practically, this research highlights the effectiveness of mentorship models that integrate various levels of expertise and experience, suggesting that such models could be replicated across different disciplines and institutions. This could potentially alleviate faculty workload issues while providing graduate students with essential leadership and mentoring experience [31].

VII. CONCLUSION, LIMITATIONS. FUTURE WORK

In conclusion, this multi-methods case study examined the experiences of participants in a Mentoring Triad Model aimed at enhancing research skills, mentoring abilities, and professional development. The results indicate that the model fostered significant growth for the undergraduate student, graduate student, and faculty mentor across research, psychosocial, and professional domains. The findings support collaborative and constructivist pedagogies, extending research on the impacts of mentored undergraduate research experiences and multi-level mentoring models. The study offers a replicable model and best practices for structuring effective mentoring programs to facilitate participant development. However, the study has some limitations, including the small sample size and single institutional context. Future research should examine the implementation of the Mentoring Triad Model across diverse disciplines, institutions, and participant backgrounds. Longitudinal research could also explore the long-term impacts of participation on educational and career outcomes. Despite the limitations, this study provides valuable insights into the potential of multi-level mentoring models to enhance the development of aspiring researchers and professionals in higher education.

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