Development of entrepreneurial mindset-driven training materials for undergraduate researchers

Dr. Maysam Nezafati, Georgia Institute of Technology

I am a lecturer in the department of biomedical engineering at Georgia institute of technology /Emory University. I have been working on educational research since 2016. My main focus is on problem based learning core courses. But specifically I work on

Dr. Irene Reizman, Rose-Hulman Institute of Technology

Irene M.B. Reizman is an Associate Professor in the Department of Chemical Engineering and the Alfred R. Schmidt Endowed Chair for Excellence in Teaching at the Rose-Hulman Institute of Technology. She holds a B.S.E. in Chemical Engineering from the University of Michigan and a Ph.D. in Chemical Engineering from the Massachusetts Institute of Technology. Her research interests include metabolic engineering, synthetic biology, and impacts of undergraduate research experiences on student learning.

Dr. Michelle Marincel Payne, Rose-Hulman Institute of Technology

Dr. Michelle Marincel Payne is an Associate Professor in the Civil and Environmental Engineering at Rose-Hulman Institute of Technology. She earned her Ph.D. in Environmental Engineering from the University of Illinois at Urbana-Champaign, her M.S. in Environmental Engineering from Missouri University of Science and Technology, and her B.S. in Nuclear Engineering from the University of Missouri-Rolla (same school, different name). At Rose-Hulman, Michelle is co-leading a project to infuse an entrepreneurial-mindset in undergraduate students' learning, and a project to improve teaming by teaching psychological safety in engineering education curricula. Michelle also mentors undergraduate researchers to investigate the removal of stormwater pollutants in engineered wetlands. Michelle was a 2018 ExCEEd Fellow, and was recognized as the 2019 ASCE Daniel V. Terrell Awardee.

Dr. Liping Liu, Lawrence Technological University

Liping Liu is an associate professor in the A. Leon Linton Department of Mechanical Engineering at Lawrence Technological University. She earned her Ph.D. degree in Mechanical Engineering from University of Illinois at Urbana-Champaign in 2011. Her resear

Development of entrepreneurial mindset-driven training materials for undergraduate researchers

Maysam Nezafati, Irene Reizman, Michelle Marincel Payne, Liping Liu

Abstract:

The importance of undergraduate research can be emphasized from two perspectives: first, it enhances students' engagement in learning, and second, it increases the productivity of research labs by employing undergraduate students as professional scholars. Many labs have difficulty implementing undergraduate research (UGR) programs despite the benefits. To address common challenges many institutions face with undergraduate research, we are developing a framework that emphasizes curiosity, connection, and value creation in research activities to foster an entrepreneurial mindset (EM) in undergraduate research. Using this framework, we aim to make research training more efficient, increase overall lab productivity, boost undergraduate research effectiveness, and motivate students.

Our project goals are to expose undergraduate students to research opportunities early, teach students about resilience skills so they can persist and be successful in their work, and support faculty in developing and providing meaningful research opportunities for undergraduate students. As part of this work, we also aim to better understand undergraduate students' motivations for being involved in research. To foster EM and achieve these goals, we designed a series of videos and faculty-led EM training workshops for students. These activities are scalable and transferable for undergraduate researchers and their mentors at different institutions.

The intent of these workshops is to enable students to become involved in research, and once involved, allow them to apply EM concepts to their research projects directly. Workshop topics include framing research questions with EM, building resilience in research, thriving in a research environment, developing a research pitch, using EM to drive effective data presentation, and focusing next steps in research to maximize research impact. Each workshop includes video content, a workbook, and a moderator guide, with workshops designed to be deployed either in-person or virtually facilitated by a workshop moderator.

In designing our interventions, we considered alignment with guidelines provided by the Council on Undergraduate Research (CUR), which include curating engaging and high-impact opportunities, creating a community of student scholars, peer mentoring, opportunities for early and sustained involvement, and program assessment [1].

To assess the impact of our workshop-based interventions on student research productivity and attitudes toward research, we developed a retrospective, post-experience survey and a one-year follow-up survey for students participating in the workshops. We initially distributed our post-experience survey to a baseline cohort of students who participated in UGR but did not complete the EM-focused workshops. To improve workshop content and better understand student motivations, we will collect the corresponding data from workshop participants in the future.

This paper describes our project goals, planned workshop content, and baseline survey results available on undergraduate student attitudes and motivations related to participating in research.

Eventually, by piloting workshops and collecting data collaboratively across five institutions that vary in size and culture, this project will deliver a flexible set of training modules and a menu of intervention options that other institutions may choose to modify and implement to improve undergraduate research experiences and outcomes.

Introduction:

Entrepreneurship has been an inseparable part of business programs' curriculum, but its embedding in engineering colleges or in interdisciplinary programs is fairly new. Considering real-life needs, the development of a professional skill set comprising proficiency in communication, business, creativity, leadership, and other attributes, is nearly or equally as important as the acquisition of technical skills by engineering students. By embedding entrepreneurship in engineering programs, students create personal, economic, and societal value. There is an overlap and logical fit between the outcomes of STEM programs and the skills emphasized in entrepreneurial programs [2].

Entrepreneurially-minded learning (EML) is an emergent pedagogy that emphasizes discovery, opportunity identification, and value creation. As a teaching method, it can be applied to all areas of study and has been developed by hundreds of faculty members at colleges and universities across the country [3], [4]. EML can also be infused to specific fields of engineering at any level from freshmen to capstone courses [5], [6]. EML relies on real-world experiences; opportunities to practice information literacy–accessing, analyzing, and synthesizing information; expert-to-novice mentoring in the learning process [7]; and value sensitive design which results in universal value creation [8]. Undergraduate research (UGR) naturally lends itself to realizing these important approaches to learning. This project is part of a larger effort to help undergraduate students develop an entrepreneurial mindset (EM) in research.

UGR experiences are a high-impact practice in undergraduate education, with studies indicating that UGR can help students clarify their career goals [9], identify as an engineer or scientist [10], and increase their resilience and ability to persist through failure [11]. Many universities offer UGR programs, but these can vary significantly in the levels of training and support that are offered to students and mentors. A report from the National Academies of Sciences, Engineering, and Medicine offered several recommendations for improving UGR opportunities in the STEM fields, including ensuring that mentors have appropriate professional development opportunities, leveraging resources such as off-campus networks or partnerships, and continually improving UGR experiences to improve student learning outcomes and success [12]. *The Characteristics of Excellence in Undergraduate Research* developed by the Council on Undergraduate Research also emphasizes the importance of professional development for mentors and research-supportive curricula and workshops for students [1].

While a high-impact practice, it may be challenging for faculty to prioritize involving UG students in research. This lack of involvement can be for various reasons, key ones being limitations on time for training students and lack of formal resources for mentorship training. These challenges may be especially true for apprenticeship-style UGR experiences or smaller programs and/or universities, where instruction in research skills and processes may primarily come from the research mentor. Some standardized curricula have been developed to train student researchers and mentors across STEM disciplines. The Center for the Improvement of Mentored Experiences in Research (CIMER) has published mentor training materials [13] as well *as* student training

materials [14] that can support summer programs or semester-long, introduction-to-research courses. Individual universities and research programs have also developed introductory courses, learning communities, or seminar series to build UGR skills [15], [16]. These resources provide a valuable starting point, but they are often tailored to a specific model of research (e.g. graduate students mentoring undergraduates in a large laboratory group), and smaller universities may have limited resources for a formal course in research.

Thus, we found a need for training materials that could be flexibly deployed across universities of various sizes, from large R1 universities to small primarily undergraduate institutions. Additionally, leveraging our partnership with the Kern Entrepreneurial Engineering Network (KEEN), our aim was to develop materials focused on helping students develop a mindset to support their success in research. With the tools of EM, students can understand how their research addresses an unmet need or opportunity, set goals for their contribution, and understand the potential societal impact of their work.

Project Goals:

Our team is focused on integrating EM into several aspects of UGR, from videos and activities that encourage students to become involved in UGR all the way through mentor development for faculty. Our multi-university team's strength comes from its diversity. Faculty from large research universities, Georgia Tech, the University of Illinois, and Baylor University, are collaborating with faculty from smaller schools, Lawrence Technological University and Rose-Hulman Institute of Technology, where the focus is primarily on undergraduate learning. At these five universities, we are piloting a variety of approaches to improving undergraduate research experiences. Our team is developing materials to support the following areas:

1. Activities to increase undergraduates' early exposure and awareness to research,
2. Workshops to facilitate a conversation around faculty mentoring needs and support, and
3. Workshops to improve and streamline research training for undergraduate students who are embarking upon or already involved in research.

This paper describes our team's efforts and plans to impact the latter opportunity: student research training from an entrepreneurial perspective. This paper describes our development of workshops tailored to students already participating in UGR, which provide them with guidance for leveraging EM in their own research projects. Addressing some of the gaps identified previously, these workshops are designed to be flexibly implemented in settings from primarily undergraduate institutions to R1 universities. They can be offered as stand-alone workshops, facilitated either in-person or online, and/or integrated into research-focused courses.

Intervention:

We identified six critical topics for supporting students in their UGR:

1. Framing Your Research Questions
2. Thriving in a Research Environment
3. Building Your Resilience in Research
4. Pitching Your Research
5. Visualizing Your Data

6. Maximizing the Impact of Your Research

These topics were identified by our team of faculty from all participating institutions based on existing needs and interest in their UGR programs. Learning objectives guided the development of materials related to these topics (Table 1).

Table 1. Learning objectives for undergraduate student research training workshops

Workshop	Learning Objectives
1. Framing Your Research Question	- Describe, at a high level, how the framework of the Entrepreneurial Mindset can be applied to research, emphasizing the connections between research opportunities, research plans, and research impact. - Use the technique of connecting broad statements to specific claims to help formulate a research question. - Use mind mapping to help identify open questions in your research project and collect information needed to understand your research opportunity. - Identify key stakeholders for your research project and describe the interests of those stakeholders.
2. Thriving in a Research Environment	- Describe the importance of using SMART goals to be able to answer your research question and make connections between your research and the interests of stakeholders. - Practice writing SMART goals for next steps in your research. - Prepare a goal-setting plan that includes frequency of reflection and a plan for accountability.
3. Building Your Resilience Research	- Explain your tendencies for how you respond to engaging with others during stressful situations: passive, aggressive, or assertive. - Describe empathic listening and its importance for achieving your goals and building relationships for maximum impact. - Through role-play, practice being assertive and using empathic listening skills.
4. Pitching Your Research	- Create a connection to start interest in the research. - Stimulate curiosity by developing interest in the audience. - Capitalize on opportunities. - Create a lasting connection with the audience.
5. Visualizing Your Data	- Understand the importance of identifying opportunities relevant to research and business goals from data collected and analyzed throughout the research process. - Evaluate the effectiveness of different types of data visualizations - Learn key data visualization principles and techniques behind creating effective and meaningful visualizations. - Demonstrate the ability to communicate insights from data visualization to stakeholders and using those insights to drive informed decisions. - Recognize ethical considerations relevant to data gathering and data

	visualization.
6. Maximizing the Impact of Your Research	- Describe the impact level of your research, including listing key results and identifying the groups most interested in those results. - List a variety of options for sharing undergraduate research, including both traditional academic venues (conferences, journal articles) as well as venues for reaching audiences outside of the academic context. - Identify the venues that might be most appropriate for sharing your work. - Prepare a dissemination plan for your research, including information on the intended audience and the message to be shared with each audience.

Methods:

Study Design

We designed two student self-assessment surveys to quantify the impact of our research training workshop on student research skills, research outcomes, motivation, and integration of EM in research. The first survey (post-survey) is intended to be taken immediately after the completion of the training workshops or after the completion of the research experience that integrates those workshops. The second survey (follow-up survey) will be distributed one year after the post-survey to assess whether students continued to do undergraduate research and also what types of deliverables or outcomes they generated from their research.

Our baseline (no intervention) group post-survey was distributed to 80 engineering or science students who participated in the academic year or summer research at three universities, ranging from a large R1 university to a small primarily undergraduate university. Our response rate for this initial survey was 26% (n = 21), though some individual questions had lower response rates, as reported in the figure captions. The follow-up survey will be distributed to the same set of students later this year. This data set will serve as a baseline for future comparison with results from students who do complete our research training workshops.

Assessment

The post-survey, based on a retrospective gains design, integrates subsets of questions from the Undergraduate Research Student Self-Assessment (URSSA) [17] and Intrinsic Motivation Inventory (IMI) [18], along with new questions designed by the research team to explore student growth in areas linked to EM (e.g. "Ability to explain the needs or motivations of various stakeholders"). The follow-up survey focuses on continuing student motivation as well as continued time on research, generation of research deliverables, and future plans. Post-survey / follow-up survey pairs are identified with a code so they can be linked to exploring the longer-term impacts of our interventions, such as greater student involvement in the preparation of conference presentations or journal articles. The post-survey responses can also be analyzed separately to look at more immediate impacts of the workshops and can serve as a larger pool for analysis if the response rates for a follow-up survey after one year are low. The key questions we aimed to address through our survey data collection are summarized in Table 2. Some of the research questions in Table 2 could be linked directly to categories of data collected on the standard

URSSA survey, while others were linked to demographic data collection or to the new EM-focused questions that our project team developed.

Table 2. Key questions used for the design of student self-assessment surveys

Do students who participate in EM-focused research training workshops during their research experience…
Stay involved in undergraduate research longer and/or spend more hours doing research?
Disseminate their research results more widely or frequently?
Incorporate aspects of EM into their motivation for research?
Show increased ability to relate the 3Cs as defined in the KEEN framework (curiosity, connections, creating value) to research?
Show increased gains in thinking and working like a scientist or engineer, as defined through relevant URSSA questions?
Show increased confidence and personal gains related to research, as defined through relevant URSSA questions?
Show positive changes in attitudes or behaviors related to research, as defined through relevant URSSA questions?

We expect that students will report changes in skill, motivation, and mindset after completing any research course or experience, with or without our workshops. Thus, in the first year of the project, we distributed the post-survey to students who completed research programs at participating universities but did not complete research training workshops developed in the current work. These students participated in research programs (summer, academic year) where we expect to use our research training workshops in the future.

Results and discussion:

Assessment

As baseline data, students reported gains in a number of important personal skills and mindsets after participating in undergraduate research (Figure 1). Respondents were asked to rank their gains in various abilities and skills over the course of their most recent research experience using a scale ranging from "no gains" to "great gain." Students report strong gains related to independent, self-guided work, with 76% of students reporting a great gain in "Ability to work independently" and 44% of students reporting a great gain in "Ability to take ownership of research on a topic of interest." This baseline data indicates many students already feel ownership and excitement about their research project and may not need additional EM tools to achieve that goal.

Our survey results also highlighted several areas where EM-focused workshops may be beneficial. For example, only 12% of respondents indicated a great gain in the "Ability to explain the needs

or motivations of various stakeholders" after their research experience. The smaller gain may be due in part to the fact that students are unsure of the definition of "stakeholder" in the context of research. This indicates an opportunity for using our training materials to help students identify stakeholders in their research along with the desired outcomes or impacts of their work. Several of our workshops touch on the role of stakeholders as students formulate their research questions, communicate their results, and identify the possible impacts of their research. Students also reported smaller gains in the "Ability to describe how a discovery could be scaled or sustained." EM-focused workshops may also help in this area by encouraging students to think about the unmet need or opportunity they are addressing through their research, which may be linked with factors like scale-up or sustainable implementation.
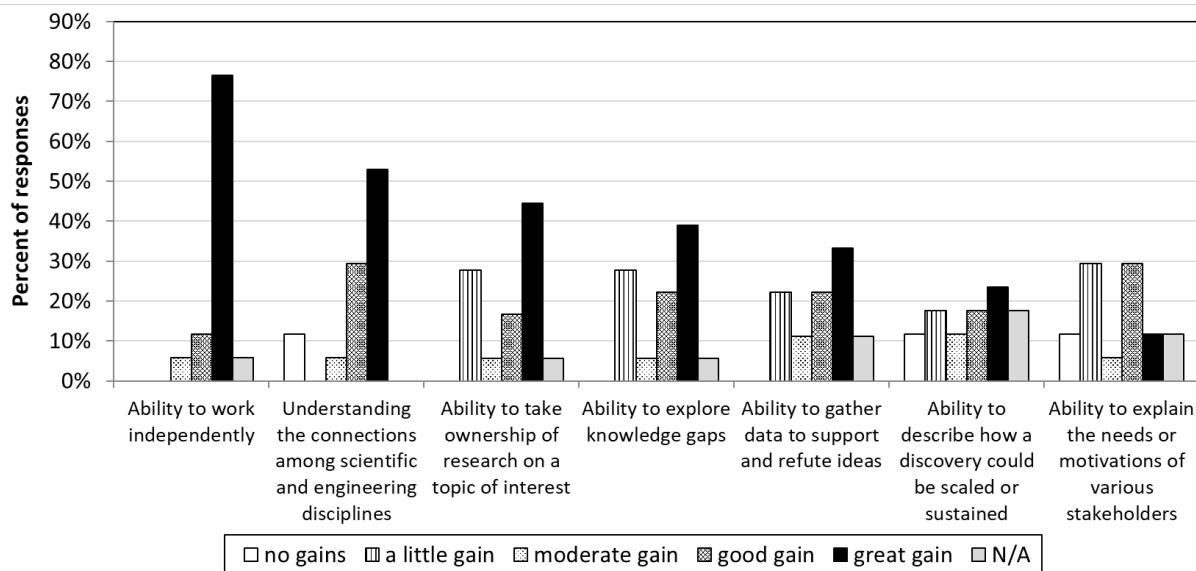

Figure 1. Student reported gains for the self-assessment survey question "How much did you GAIN in the following areas as a result of participating in undergraduate research?" (n = 18).

We also surveyed students regarding gains in general research skills like making oral presentations or writing scientific reports (Figure 2) to help develop ideas of where EM could be linked to those skills. While most students felt they made a great gain in documenting their work for future researchers, only a smaller percentage reported a great gain in making oral presentations or setting goals in their research. We plan to address goal setting through a workshop on SMART goals, linking goal setting to the desired impact of the research. Another workshop would allow students to practice their research pitch, helping provide students with the tools to recognize their audience and tailor presentations accordingly.
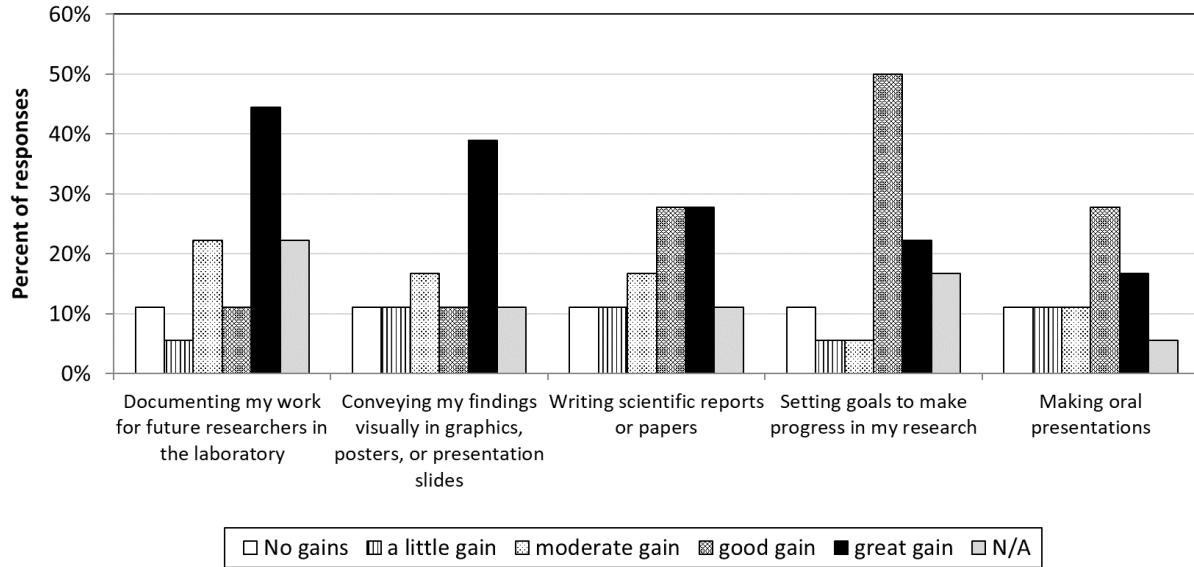
Figure 2. Student reported gains for the self-assessment survey question "How much did you GAIN in the following areas as a result of participating in undergraduate research?" (n = 18).

In terms of career preparation, while 100% of respondents agreed or strongly agreed that their research experience helped prepare them for graduate school, only 53% agreed or strongly agreed that it prepared them for entrepreneurial activities (Figure 3). While the framework of EM is not directly focused on the idea of starting businesses or ventures, workshops emphasizing this mindset could also be a tool to help students feel more prepared for a range of careers, encompassing graduate school, industry, and entrepreneurship.
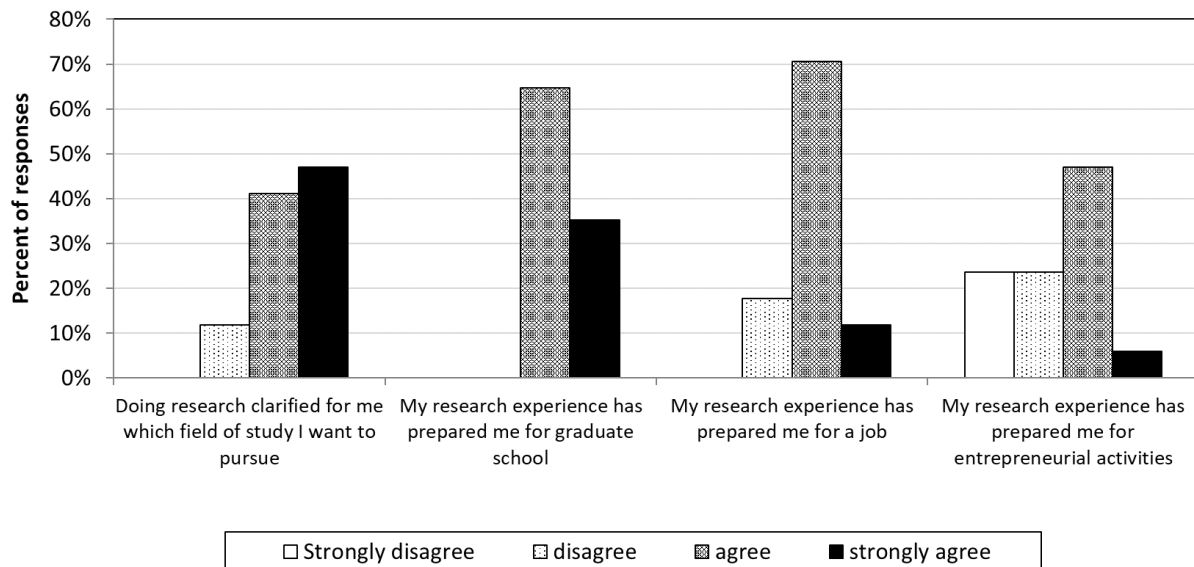

Figure 3. Student responses to self-assessment survey question "Rate how much you agree with the following statements:" (n = 17).

We also explored student motivations for undergraduate research, to help inform how our workshops could link with student goals in their research and support the development of intrinsic

motivation. We used the list of student motivations previously developed for the URSSA in our survey and asked students to rank their top three motivations. The motivation most frequently ranked first was "Gain hands-on experience in research." Other top motivations were "Explore my interest in science/engineering" and "Clarify which field I wanted to study." These motivations indicate students will value support in their professional development and the ability to link research to their academic and career goals. Thus, for workshops on topics such as research pitches, it may be valuable to emphasize to students the broad applicability of the workshop content across research, coursework, and industry careers.

Conclusion:

We created six workshops to provide research training and support undergraduate students in their research activities. According to our baseline data, our set of workshops has the potential to positively impact undergraduate students' contributions to research and perhaps their career trajectories as well. Specifically, students indicate the need to develop better stakeholder understanding and analysis, goal-setting, and pitching skills in the context of their research. They also demonstrate that they could benefit from research training from an EM perspective to help them see and prepare for a career in creative, entrepreneurial activities.

Allowing students to not only learn about but also to practice EM-focused activities in the context of their current, ongoing research, can encourage students to demonstrate the unmet need and opportunities they are addressing through their research. Supporting students and faculty in UGR experiences through an EM lens has the potential to unleash the innovation and agency of next-level undergraduate students, who may become graduate students, and who may become our next leaders in engineering.

Future work:

Our one-year follow-up survey will be distributed to this baseline cohort in the fall of 2023, which will complete our baseline data collection. We plan to roll out research training workshops to our first cohort of students in the summer of 2023. We will distribute the first round of post-survey assessments to that student group in fall 2023 and will begin to compare their responses to our baseline data set as presented here.

Based on feedback and our analysis of the impact of our EM-focused UGR activities, we will continue to update our materials which can be found at Engineering Unleashed: https://engineeringunleashed.com/card/3577.

Acknowledgments:

References:

[1] N. H. Hensel, "Characteristics of Excellence in Undergraduate Research.," 2012.

[2] S. E. Zappe, S. L. Cutler, and L. Gase, "A Systematic Review of the Impacts of Entrepreneurial Support Programs in Science, Technology, Engineering, and Math Fields," *Entrepreneurship Education and Pedagogy*, vol. 6, no. 1, pp. 3–31, 2023.

[3] A. Olson, D. Melton, and M. Johnson, "KEEN Top Resources: The basics of EM in a single card," *Engineering Unleashed*, Oct. 07, 2020.

[4] L. Bosman and S. Fernhaber, *Teaching the Entrepreneurial Mindset to Engineers*. Cham: Springer International Publishing, 2018. doi: 10.1007/978-3-319-61412-0.

[5] M. Nezafati, J. Le Doux, K. D. Pierre, and K. T. Shook, "WIP: Integration of Inclusive Mindset in a Middle-Year Biomedical Engineering Course: a Study Over Healthcare Disparities via Story-Driven Learning," in *ASEE Conferences*, Virtual Conference, Jul. 2021.

[6] M. Nezafati, M. Chua, and J. M. LeDoux, "Work in progress: A case study of integrating inclusive engineering skills into a middle-years biomedical engineering course via model-based reasoning," *ASEE Annual Conference and Exposition, Conference Proceedings*, vol. 2020-June. ASEE Conferences, Virtual On line , 2020. doi: 10.18260/1-2--35517.

[7] L. B. Bosman and M. Phillips, "Integrating the entrepreneurial mindset into the engineering classroom," *IEEE Transactions on Education*, vol. 65, no. 2, pp. 150–155, 2021.

[8] M. Nezafati, S. Schley, and J. M. Le Doux, "Responsible innovation in biomedical engineering: a value sensitive design intervention," in *Proceedings - Frontiers in Education Conference, FIE*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/FIE56618.2022.9962507.

[9] A. L. Zydney, J. S. Bennett, A. Shahid, and K. Bauer, "Faculty perspectives regarding the undergraduate research experience in science and engineering," *Journal of Engineering Education*, vol. 91, no. 3, pp. 291–297, 2002.

[10] A. Hunter, S. L. Laursen, and E. Seymour, "Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development," *Sci Educ*, vol. 91, no. 1, pp. 36–74, 2007.

[11] D. Lopatto, "Survey of undergraduate research experiences (SURE): First findings," *Cell Biol Educ*, vol. 3, no. 4, pp. 270–277, 2004.

[12] E. National Academies of Sciences and Medicine, "Undergraduate research experiences for STEM students: Successes, challenges, and opportunities," 2017.

[13] J. Handelsman, C. Pfund, S. M. Lauffer, and C. M. Pribbenow, "Entering mentoring," *Madison: The Wisconsin Program for Scientific Teaching*, 2005.

[14] N. Balster, C. Pfund, R. Rediske, and J. Branchaw, "Entering research: a course that creates community and structure for beginning undergraduate researchers in the STEM disciplines," *CBE—Life Sciences Education*, vol. 9, no. 2, pp. 108–118, 2010.

[15] C. Alvarado, J. Hummel, D. Mirza, R. Revelo, and L. Yan, "Scaling and Adapting a Program for Early Undergraduate Research in Computing," in *Proceedings of the 53rd ACM Technical Symposium on Computer Science Education-Volume 1*, 2022, pp. 50–56.

[16] K. R. Schneider, A. Bickel, and A. Morrison-Shetlar, "Planning and implementing a comprehensive student-centered research program for first-year STEM undergraduates," *J Coll Sci Teach*, vol. 44, no. 3, pp. 37–43, 2015.

[17] T. J. Weston and S. L. Laursen, "The undergraduate research student self-assessment (URSSA): Validation for use in program evaluation," *CBE—Life Sciences Education*, vol. 14, no. 3, p. ar33, 2015.

[18] R. M. Ryan and E. L. Deci, "Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions," *Contemp Educ Psychol*, vol. 25, no. 1, Jan. 2000, doi: 10.1006/ceps.1999.1020.