Undergraduate Research as a Tool for Building Entrepreneurial Mindset in Engineering Students

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Abstract

Entrepreneurial Mindset (EM) has become a widespread classroom practice in many universities in recent years. Our research project is focused on how EM may be infused into undergraduate research experiences for engineering students. For several years, we have offered a workshop to help faculty develop methods to build EM into research practice. This includes research in traditional lab groups and also building course-based undergraduate research experiences (CURE) into the curriculum. After the workshop, participants join a year-long coaching process with a faculty mentor to develop and execute their projects with students.

In this paper, we report on the key elements of the workshop design and insights from past participants across multiple years. We surveyed all past participants of the workshops, and respondents indicated that they had received several benefits from the workshop experience including better planning and organization of research experiences for undergraduates. Faculty reported significant benefits to the students such as more attending graduate school but also to their own research practices including building a capacity for more readily identifying the value of their work.

We hope that future faculty interested in EM and undergraduate research will see the possibilities of bringing the two together in their work. We believe infusing an EM with undergraduate research in a variety of contexts will help our students continue to tackle the complex problems facing society.

Introduction

Many engineering faculty members believe that undergraduate students are not able to contribute meaningfully to research projects - but this belief is flawed. Faculty might believe this because they have not scaffolded the research experience for students, or because they hold a fixed mindset about student potential. Shifting faculty perspectives about undergraduate research is an important first step in creating rich research opportunities for students. This work is important because undergraduate research is well established as an effective tool to support students in moving to graduate programs, in particular for underrepresented students [1]–[3]. Underrepresented students have reported that mindset and mentoring are important factors in succeeding in STEM fields [4], [5].

In 2019 our team developed a faculty development workshop focused on undergraduate research experiences in engineering and computer science. Our goal was to help faculty members to think about mentoring undergraduate students as an opportunity to help shape student mindsets. We believe that focusing on the research experience as a growth-oriented student experience leads to much richer outcomes than focusing purely on research productivity (e.g., papers published). However, we

acknowledge that excellent undergraduate research experiences often lead to peer-reviewed publications and help faculty career progression.

In partnership with the Kern Entrepreneurial Engineering Network (KEEN), a workshop has been held for four summers to help faculty integrate the entrepreneurial mindset (EM) into their work with research students. We are interested in exploring the impact of this work on participation and sharing our findings with the broader engineering community.

Research questions:

1. How can faculty use an EM to adjust their approach to research activities and student mentoring?
2. What structures/practices from the workshop help faculty adjust their approach to research to align with EM principles?

Background

Engineering faculty development has been studied for many years as a tool to create pedagogical changes in the classroom. Different approaches include workshops like the National Effective Teaching Institute (NETI) [6], virtual communities of practice [7], and longer-term interventions [8].

Prior authors have also studied faculty development as a tool for developing EM in faculty and students. Melton et al. proposed a design system thinking framework for faculty development workshops focused on EM [9]. Jackson et al. recently studied the motivation of faculty for attending workshops focused on EM [10]. Melton et al. explored how COVID-19 impacted faculty development for EM [11]. An extensive and growing body of work is focused on training students to practice EM [12]–[16].

A few authors have focused on specific faculty development workshops or programs, as shown in Table 1. Of these prior works, our project is the only one focused on student research structures and EM.

Table 1. Summary of prior literature focused on faculty development programs and EM.

Author	Date	Group Trained	Training Focus
Jordan et al. [17]	2016	Engineering Faculty	Workshop and grant program for EM
Mayled et al. [18]	2019	Engineering Capstone Instructors	Workshops, coaching and EM
Dillon et al. [19]	2020	Engineering Faculty	Coaching structures for EM
Present Work	**2023**	**STEM Faculty**	**Workshop focused on undergraduate research and EM**

Methods

Our workshop structure was designed around a few key ideas. First, we wanted to help faculty connect their research to other areas (like teaching and service) using tools like Course-Based Research Experiences (CUREs). Second, we hoped to help faculty organize and structure training of research students with scaffolding and a mindset focus, much like they might organize a course. Finally we wanted our participants to focus on creating partnerships and collaborations with students and faculty to provide accountability for their research process.

Research Workshop Design

We designed the workshop to follow the steps associated with a typical research project. In each section, we challenge participants to think about research as a way to enhance student mindset. We developed short presentations that were then followed by active learning worksheets in a printed field guide. Most of the active learning worksheets were designed to be easily adapted for use with research students back home.

Module 1. Connecting Research to Your Career. In this module we encourage participants to think about how they might connect research to other parts of their roles. In the activity, we ask participants to build a concept map that connects their research to service, classes, and other aspects of their work. An example of this type of concept map is shown in Figure 1. One goal of this module is to help faculty think about alignment of service and teaching with research.

Module 2. Structuring Undergraduate Research to Help Yourself. Building on the concept map of Module 1, we ask faculty to brainstorm specific activities that engage undergraduate research students in a way to create value for their own research, teaching, and service activities. Examples might be to engage summer undergraduate research students in the generation of preliminary research data for new research ideas, development of K-12 or other education and outreach program materials, or even development of an effective teaching laboratory or maker space at their institution. Participants are tasked with drafting an implementation plan of three to five URE activities that create value for themselves including student tasks, logistics, time estimate, and requirements for student success. Participants are encouraged to implement these activities and consider how others, if planned strategically, may create a value-generator towards their long-term professional goals.

Module 3. Recruiting, Selecting, and Motivating Students. Construction of high-quality and diverse research groups hinges on well-designed and executed recruitment and selection plans that motivate students at the program onset. In this module, participants learn about the variety of different undergraduate research activities that they might wish to engage students in by “taxonomy” (apprenticeship style, course-based, community-based, wrap around experiences, bridge programs, etc.) and how recruitment objectives such as capacity for commitment and level of experience may differ among the different program types. They also learn about how broadening participation in their research can create exceptional value for their program.

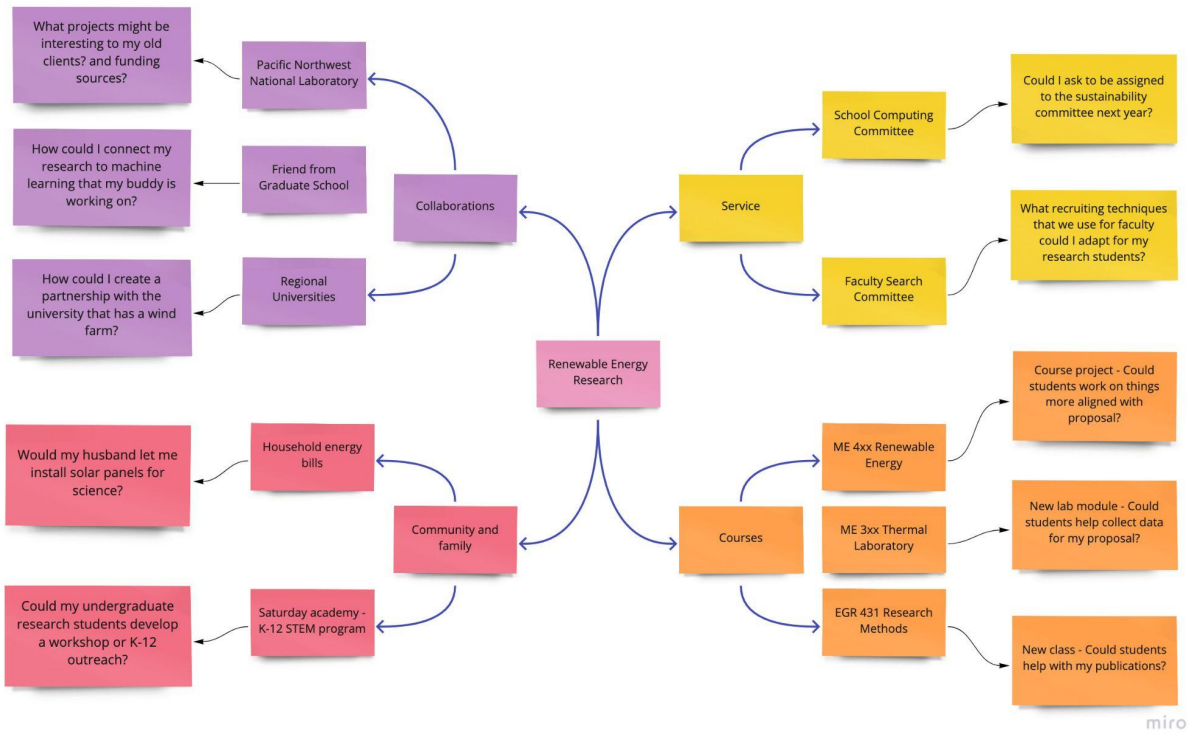

Figure 1. Example of a concept map showing how a faculty member might connect research with service, courses, and collaborations. This example is the type of map generated by participants during a workshop activity, but they are encouraged to use a similar mapping activity with their students.

Students of diverse backgrounds have different needs and communications styles that can affect their initial interest or confidence to apply for undergraduate research experiences. Participants learn about evidence-based recruitment strategies from first engagement through structuring of advertisements that faculty can implement to improve curiosity of students towards their research program, make connections between their own personal and professional interests to the research program, remove barriers, improve confidence, and therefore assist in recruiting a diverse pool of students for participation in their UREs [20], [21]. Participants also learn about implicit bias, how it may unintentionally affect not only their selections for their research program but also their students' perceptions of them, and evidence-based steps to reduce implicit bias in the selection of undergraduate research students [20], [22]–[29].

The module culminates with a fun activity to develop an elevator pitch, a brief research spiel, that sparks curiosity in the research program, makes connections to personal and professional student interests, and reflects the value it will create for student recruits while boosting confidence to apply for research program participation. Program participants develop and practice their elevator pitches in a group activity. They discuss how goals and strategies differ for the different taxonomies of research programs within their groups, and how the pitch might differ if revised instead for a grant program manager for which they were seeking funding. Lastly, participants are challenged with having their undergraduate research students develop elevator pitches of their own to describe their research.

Module 4. Sparking Curiosity. Curiosity is a central human motivation that is related to human success and achievement. It is not only one of three key predictors of academic achievement, but is also related to job performance, creative problem solving, and personal well-being [30]–[37]. According to psychological research, curiosity in people cannot simply be described on a single dimension from incurious to very curious; humans have different ways of experiencing and expressing curiosity that affect how they represent information in their minds and their motivations to seek new information and experiences, discover, learn, and grow [38], [39]. If we welcome and celebrate all types of curiosity, we can not only help students learn, but also contribute to their personal well-being in life.

Curiosity comes in different forms, and that affects what students are interested in and what that interest looks like. In this module, participants learn about the five dimensions of curiosity that are expressed to various degrees in the four basic types of curious people [38], [39]. They learn how different types of curious people are motivated to approach or avoid new experiences and information for a variety of reasons measurable on the five dimensional scale (i.e., joy for exploration, a need to know, stress/risk tolerance, level of social curiosity, and attraction to or avoidance of thrill/adventure seeking behaviors). With this awareness, participants learn how to identify the four different types of curious students and strategies that cultivate positive aspects of curiosity, shift avoidance behaviors, and encourage and motivate students towards research and discovery (e.g., modeling and encouraging academic risk taking, normalizing fear and anxiety, providing challenging group project / research options, linking boring stuff with things students want to know, and letting curiosity drive goal setting and growth) [40]. Participants are asked to develop and share an activity designed to cultivate curiosity in students based on the physical or digital spaces they will spend time in frequently (e.g., laboratory, study space, online platform, etc.), and how they can modify the activity to address each type of curious student.

Module 5. Mentoring Students. Faculty often have no formal plan for mentoring undergraduate research students. Intentional determination of skills and interests of incoming students, followed by creation of a mentoring plan based on best practices and instilling the 3 C's (curiosity, connections, and creating value) helps fuel curiosity, engagement, and motivation for research students. It helps create an environment where a diverse cohort of students with varied career goals (which may or may not include graduate school or a faculty position) can thrive and succeed. It also ensures that students grow their research skill sets and professional identity over their time in the research group.

The evidence-based approaches that this session leads faculty through focus on establishing clear expectations, making the steps of the research project (and the student's roles) explicit, teaching students resilience, incorporating a process for routine checks for understanding, creating a plan that fosters increasing student researcher independence over time, and making sure each student has a professional development plan with clear goals, benchmarks, and outcomes. Thinking carefully about how to use upper level students as peer mentors, developing a research contract and communications plan, surveying departing students to gain insight on how to improve the process, being proactive about assessing student understanding, and making sure students have networking and presentation opportunities that showcase their work are also effective best practices.

Module 6. Outreach and Broader Impacts. The goal of this module is to help faculty develop more effective and robust outreach and broader impacts activities for their research program. Many faculty have

little to no expertise in these areas, so creating activities on their own is generally not effective or innovative, does not utilize evidence-based practices, and does not present a strong case for proposal or paper reviews. Helping faculty think about ways to connect with existing and impactful outreach and broadening participation activities on their own campus/region, developed and managed by experts in these areas, creates a much stronger broader impact plan with meaningful outcomes. In addition, framing research in terms of the National Academy of Engineering Grand Challenges [41] or UN Sustainable Development Goals, for example, strengthens their ability to communicate their work to a variety of lay audiences and more effectively recruit and engage undergraduate (and graduate) research students. Lastly, framing research in terms of the 3C's (curiosity, connections, and creating value) and the Grand Challenges/Sustainable Development Goals goes hand-in-hand.

Faculty are encouraged to think about how their research relates to broader societal issues like those identified in the Grand Challenges, Sustainable Development Goals, etc. Examples of outcomes could include full participation of historically underrepresented groups, improved STEM education and educator development, increased public scientific literacy and engagement with STEM, development of a more globally competitive workforce, increased partnerships with industry, and enhanced infrastructure for education and research. Next, reaching out to K12 outreach experts on their own campus in their college or the college of education (who may run camps, museums, science fairs, competitions, group tours, etc.) is a good way to find out what activities and programs already exist that they might connect with and utilize with their own students and research. Other possible connections include campus Grand Challenge Scholars Programs, professional engineering organizations and affinity groups like SWE, NSBE, SHPE, ASME, AIChE, IEEE, ASCE, etc. Possible Town and Gown activities with which faculty might connect include Girl and Boy Scouts, K12 STEM groups or teams (like FIRST Robotics), Farmer's Markets and Festivals, or Lecture Series.

Some of these programs may have training seminars for undergraduate student participants that can be helpful in training students how to talk about the research in terms relevant to lay audiences. By linking with existing activities, faculty can create more impactful outreach and broader impacts programs that do not require that they build something from scratch in an area where they have little expertise and few connections.

Module 7. Connecting Research with Curriculum and ABET. In this module we explore how faculty might adapt other classes in traditional engineering programs to include research. We discuss how you might structure a course-based research experience (CURE). We do an activity where we ask faculty to map specific research activities to ABET outcomes so they could argue for additional resources if needed to revamp a class. We also provide resources about the value of CUREs in engineering, a well established tool in other fields [1], [42]–[44].

Module 8. Publishing. In this module we provide some structures for faculty to adapt that make publishing with students easier. One popular example is using a CURE class focused on mentoring and publishing during the fall of the senior year. This class has been discussed in the literature [45], but we review the relevant structures. In this section of the workshop we ask the participants to complete an activity that uses storytelling to write an abstract. The activity is designed to be used with undergraduate research students near the beginning of the paper writing process.

Module 9. Timelines. As our last activity in the workshop we ask the participants to build a timeline for their next 1-5 years of research. We keep this open-ended, but give them space to think deeply about their own research agenda and when/how they may wish to make a shift. Again, we encourage them to ask undergraduate research students to perform a similar goal-focused activity as a way to set career goals. This activity has become one of the most useful aspects of the workshop, perhaps because we so rarely take time to formally plan and think about our research as faculty. Most of us are so wrapped up in daily details of teaching and researching that sometimes we only see the individual trees. Taking time to reflect is valuable for many faculty.

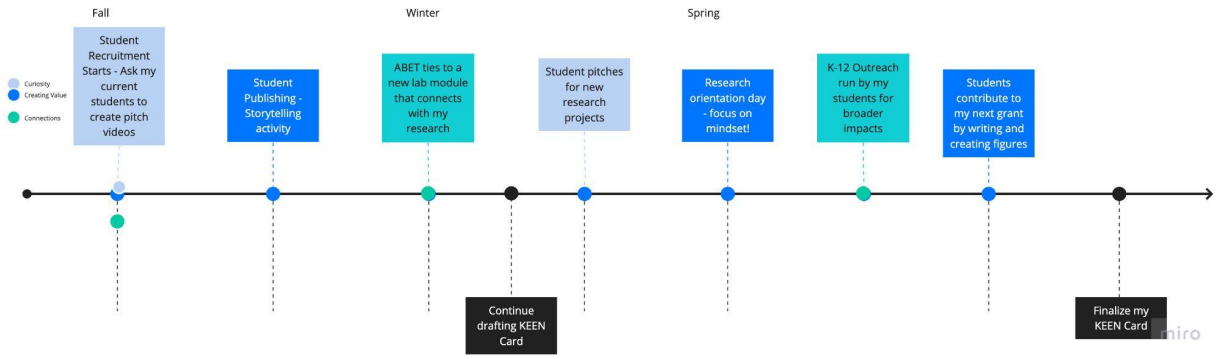

Figure 2. Example of a timeline activity for a participant in the workshop. Several of the activities identified tie directly to examples we cover in the workshop.

Post Workshop Coaching. After the conclusion of the formal workshop, the participants meet four times over the course of one year with a faculty coach/mentor to work on shifting one part of their research practice. Implementing this mentorship is an important final step that leads to improved outcomes for the participants. The coaching consists of three parts:

- Building community by cohorting participants during the workshop
- Meetings with coaches over the next year
- Call to action to share outputs with the community, which creates value

The first component is to cohort the participants based on probable shared experiences or interests (e.g., disciplines, school sizes, etc.) and then have these cohorts work together during the workshop to peer mentor as they invest themselves in these modules. Peer mentoring increases the depth of learning for many as different perspectives can inspire new approaches. After the workshop completes, coaches meet with the participants at least four times either individually or in small groups over the next year. This coaching is impactful because it helps maintain momentum, provide low-stakes accountability, and provides fresh viewpoints to ongoing projects. These meetings focus on assisting participants in narrowing their focus to achievable progress increments and creating valuable outcomes. One important component is to focus on assessment of the project as clear and high quality assessment goals tend to lead to valuable results. Finally, the coaches use these meetings to make a call to action for the broader engineering education community to share their work with others, both at their own institutions but also more widely.

Participant Survey

A survey, as shown below, was sent out to past participants from summer 2022, 2021, 2020, and 2019 workshops following approved IRB procedures. The survey focused on understanding the impact of the workshop on participants' research and engagement with student researchers (both undergraduate and graduate).

Likert Questions for the Learning Objectives (1-5 Strongly Disagree to Strongly Agree scale)
As a result of this workshop, I was be able to:
- Examine how an entrepreneurial mindset is vital to my own research activities
- Identify how directed research activities can be used to foster an entrepreneurial mindset for research students, or my own projects
- Design and test a variety of techniques for integrating disciplinary research in educational activities, both formally and informally, as well as curricular, co-curricular, and extra-curricular
- Examine how I might take advantage of my institution's structures and programs

Open Ended
- What actionable skills did you gain during the workshop?
- In what ways has your research improved as a result of the workshop?

Results

Survey Results

The survey was completed by 14 participants but only 10 completed the consent form. The total responses are approximately 23.7% of the total participants. Most of the respondents were from 2019 and 2022. This distribution makes sense because the 2019 workshop was the only in-person workshop, and the 2022 workshop was remote, but the most recent.

Survey responses for the Likert questions were mixed, but most respondents indicated that the workshop was most helpful for identifying how research activities could be used to foster EM and examining how to take advantage of institutional structures. The results are shown in Figure 3.

Open-ended comments had several useful insights about the experience from respondents:

- "I was able to look holistically at my research program and goals to better plan and organize it. I grew to value collaborations more, especially within my institution's programs and goals. I also learned to apply EM techniques to my research activities, especially focusing on the value creation from research. Finally, I learned to apply active learning to my research to improve engagement with both myself and my students."
- "I was able to repackage undergraduate research opportunities for students by better articulating the value of the project using EML."
- "My research is more organized and directed. I was also able to prioritize projects better within a larger plan (thanks to the timeline activity). My productivity increased due to a more effective management of efforts based on priorities."

- “truly starting with curiosities and frustrations students experience -- letting students lead the development of research questions, coaching them through a qualitative research process, letting them lead writing conference papers -- + 4 conference papers last year, hoping for same research output this year.”
- “A record number of students participating in undergraduate research with me went on to graduate school, in part because the new approach helped them feel more connected in community - both within the lab and the broader professional field.”

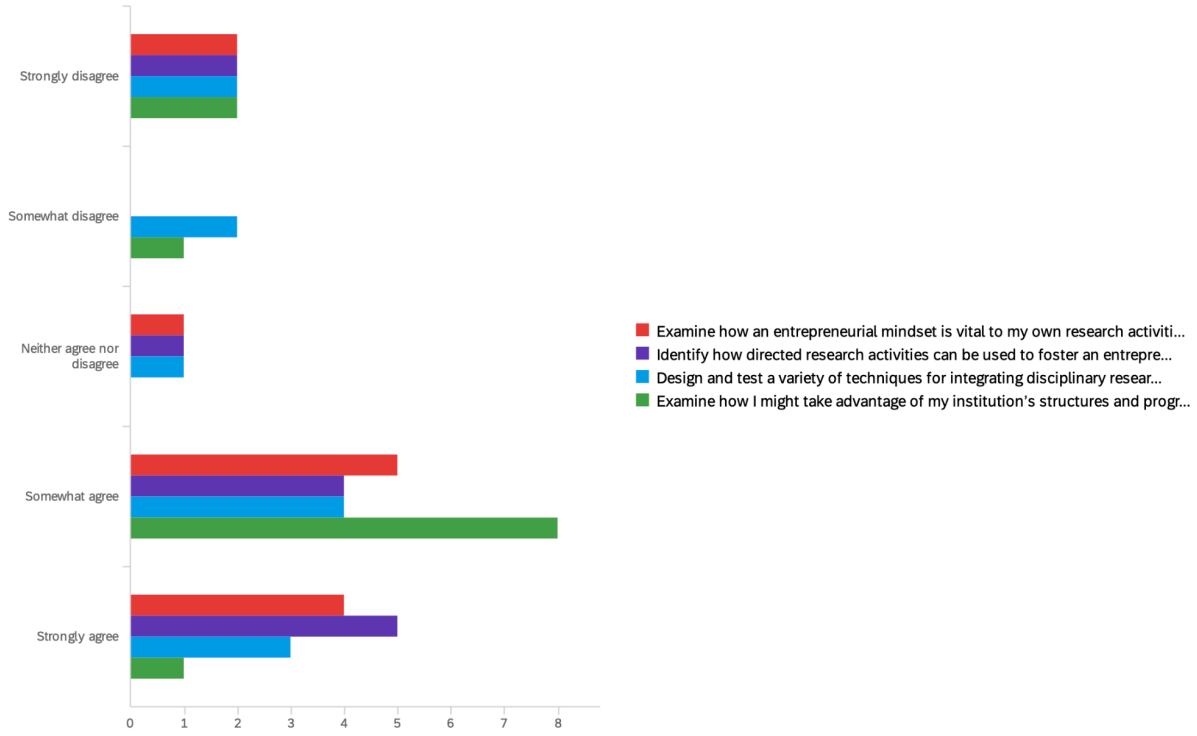

Figure 3. Summary of survey responses to each of the research outcomes.

Coaching and Facilitation Results

Participant vignettes - One participant shared with us the most important take-away from the workshop was learning to connect research to every part of your faculty job. Thinking about how to collect data using an undergraduate laboratory class over several years was a useful revelation. This participant also mentioned that they had started approaching service in a new way - useful as a way to network and create new research partnerships on campus rather than just a committee to attend.

Participant vignettes - Another participant had several negative experiences with research during graduate school. Attending this workshop allowed them to connect with new collaborators and create a new vision for what research might be - joyful! Using tools from the workshop, this experience led to several new research projects and seven peer reviewed papers since they attended the workshop in 2019. This

participant also felt that they were better able to focus on appropriate sized chunks of research to maintain a steady research program.

Themes from participants:

- Take small actions in your research team now. Build confidence in your work.
- Focus on student development. Treat your research like teaching - plan how you would like to develop your students.
- Focus on research that creates value. This focus helps maintain motivation and accountability.

Discussion

After four years of hosting a workshop focused on EM and research, we have developed a set of activities for faculty, which can be adapted for student researchers.

Research Question 1. How can faculty use an EM to adjust their approach to research activities and student mentoring?

Our workshop offers a range of methods to help faculty adjust their approach to research. Our survey and coaching indicates concept maps help students/faculty connect research to different aspects of their lives. Timelines and structure help students/faculty make a plan for creating value with research tasks and seems to offer significant benefits for participants. Focusing on student curiosity and agency helps increase the productivity of faculty research teams while supporting students and building community.

Research Question 2. What structures from a workshop on undergraduate research help faculty adjust their approach to research to align with EM principles?

The workshop key take-aways encourage faculty to think about research broadly. This might include working with teams to publish work that may create value in different ways than expected - like sharing a method, or supporting the career development of a student.

After our time facilitating and coaching many faculty members in this topic we offer the following approaches to aligning research with EM:

- Take one hour to plan your research! (alone or with your research students)
- Make time to connect your research with different aspects of your life that require your time and attention. Help your students do the same.
- Encourage and nurture the curiosity of your students - they can become drivers of the research process.
- Focus your efforts on research that creates value for humanity in some way, then take time to articulate that to your students and colleagues.

We plan to continue offering this workshop in the future and gather further feedback from our participants as they continue to make shifts in their own research structures. In the future, a mixed methods approach may help us better understand how faculty have adapted these tools for their students.

Acknowledgements

Funding for the EML and Student Research Workshop has been provided by the Kern Family Foundation. Dr. Doug Melton and Dr. Meg West provided thoughtful feedback about the workshop development over many years. Special thanks to all the participants who took time to take our survey and learn with us!

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