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Analysis of Mindset in Course-Based Undergraduate Research Experiences for Mechanical Engineering

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Abstract

Course-based Undergraduate Research Experiences (CUREs) have recently grown in popularity in engineering disciplines as they provide a high impact practice for students. This study examines a series of CUREs and directed research experiences in a small mechanical engineering program. The research team developed a validated survey that was taken by students near the beginning of their research experience and near the end of the process to gauge their level of mindset growth from the research experience. This survey may be used to determine if statistically significant shifts in students' entrepreneurial-mindsets (EM) are attained while participating in Course-based Undergraduate Research Experiences (CUREs).

We tracked a specific mechanical engineering research course offered multiple times at one institution and compared the findings to the larger group of students at the institution participating in similar research experiences. Before the research experience, students felt most confident in critically evaluating credibility of information. After the research experience, students had higher confidence in all EM measures. Our ultimate goal with this research is to find out if CUREs are useful in promoting further learning and retention in the engineering field of study.

Introduction

In 2020 the University of Washington Tacoma (UWT) started a new mechanical engineering program to support high regional demand for additional engineering students. The program was designed with progressive thinking about high impact practices to support student experiences. In particular, the program faculty pushed hard to create meaningful undergraduate research experiences for students in the program.

Many prior studies have demonstrated the power of course-based undergraduate research experiences (CUREs) as a way to support students in retention [1–3]. CUREs are considered a high impact practice, as they create a direct mentoring relationship between a student and a faculty member. One challenge of undergraduate research is the time required to mentor individual students. CUREs provide a way for one faculty member to mentor multiple students while supporting faculty workload equity due to class loading.

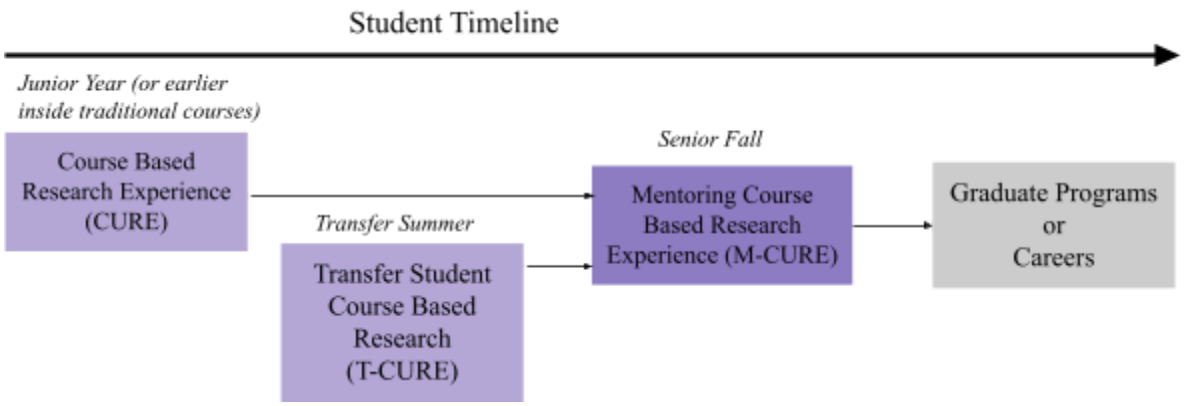

Figure 1. Overview of the scaffolded research experience designed for undergraduate students. Adapted from prior papers about T-CURE and M-CURE experiences [4,5].

For a smaller program launching near the end of the COVID-19 pandemic, introducing CUREs was a great way to support students in finding community in the new program as shown in Figure 1. Several faculty created CURE courses that provided research experiences in more traditional engineering classes. Others created CUREs that provided an experience in summer that was focused on supporting transfer students [4]. In the fall of senior year, students who had an interest in graduate programs were also encouraged to take an M-CURE that focused on writing peer reviewed papers and transition to graduate programs [3,5].

The last element of the CURE experiences was tied to development of an entrepreneurial mindset (EM). EM for this project is defined as a set of attitudes, dispositions, habits, and behaviors that shape a unique approach to problem-solving, innovation, and value creation. In the context of research, we are focused on helping students connect research with value creation. We have defined a research mindset as a broader idea that includes many facets of an entrepreneurial mindset. These factors in turn are connected to the idea of student-centered research [6].

All of the CUREs in the program included a focus on helping students develop an entrepreneurial mindset, often through guided reflection prompts and concept mapping. To assess the impacts of CUREs applied within the UWT mechanical engineering program more systematically, we asked the following research questions:

1. How do UWT mechanical engineering students participating in CUREs experiences differ from research students at other institutions?
2. How have CURE courses in the mechanical engineering program supported entrepreneurial mindset development and research identity formation for students?

The first research question is intended to help us better understand if our CURE offerings are creating experiences for students that are representative of the UWT student population. The second question is aligned with a large effort to develop research and entrepreneurial mindset in the UWT student population.

Background

A CURE has been defined as a research experience that is included in an undergraduate class with the goal of providing an authentic research journey to students [7]. CUREs have been studied extensively in science fields, including biology and chemistry. As a result, mentored undergraduate research in science and engineering is well recognized as a high impact practice in higher education [8]. One of the key benefits of undergraduate research is that underrepresented students who are mentored demonstrate higher levels of engagement, academic confidence, and performance [9]. Female and undergraduate students of color in STEM are more likely to pursue graduate degrees when they are mentored by faculty in research [10–13].

A scaffolded approach with research experiences embedded in the curriculum over multiple years (Figure 1) can be particularly powerful, as more experienced undergraduate researchers develop skills and a deeper sense of research identity [14]. A summary of other recent studies focused on STEM identity for students is in Table 1.

Prybutok et al. [15] found that mechanical engineering students had a stronger physics identity compared to civil engineering students in upper division courses. Godwin et al. [16] determined that students who have been in engineering for longer feel more confident. Patrick et al. [17] found that interest in engineering was the best determination for persistence and identity in engineering. Hughes et al. [18] connected retention to internships and community in engineering.

Table 1. Summary of prior surveys on STEM research identity.

Authors	Date	Focus Group	Identity Focus	Assessment
Prybutok et al. [15]	2016	Undergraduate Engineering Students	Physics Identity	Surveys
Godwin et al. [16]	2017	Undergraduate Engineering Students	STEM Identity	Surveys
Patrick et al. [17]	2018	Undergraduate Engineering Students	STEM Identity	Surveys
Hughes et al. [18]	2019	Undergraduate Engineering Students who listed Engineering as their major in Freshman Year	STEM Identity	Secondary analysis of existing national survey datasets
Dillon et al. [4]	2024	Mechanical Engineers	Research Identity	Identity artifacts and surveys
This Study	**2025**	**Mechanical Engineering Students enrolled in CUREs**	**Research Identity and EM**	**Survey data**

The work of Dillon et al. [4] was the most closely aligned with this project. In the study, transfer students were exposed to a CURE in the summer before transfer to a four year institution with the goal of community building and increasing research and STEM identity during the course. The current study expands on this work by looking at student survey data on research identity across the mechanical engineering curriculum as students participated in CUREs.

Methods

CURE Course Design and Intervention

One of the important features of the CURE design process in the program was to focus on student-centered research experiences. Like student-centered teaching, this idea is that the research experience should be tailored to the needs of the students and focus on creating a rich student experience. This type of design focus may lead to richer experiences for students.

Most of the students participating in the study experienced CUREs in mechanical engineering as either a directed study course or a part of a more traditional course. Most of the experiences had several features in common that had been designed by the instructors to enhance student research identity and formation of an entrepreneurial mindset (EM).

1. Students completed weekly journal prompts designed to help them reflect on their research projects in the broader context and benefits for society. Many of the journal prompts were based on the Kern Entrepreneurial Engineering Network's (KEEN) Student Outcomes (KSOs) developed by faculty at Ohio Northern University [19]. Several of the reflection questions are connected to stakeholders.
2. Students participated in an activity based on the Question Formulation Technique (QFT) that they used to generate a list of research questions. The QFT method has been used by prior researchers to help students practice generating questions [20–22]. Each student in the CURE was then assigned a specific research question to focus on.
3. Students were asked to generate a concept map focused on the research project stakeholders. The prompt was focused on how the research project would create value for stakeholders. This method has been used widely as a tool to help students develop EM and to directly assess EM [23–27].

Some of the CUREs included activities for building research identity specifically, like sharing research artifacts [4].

Other common features included working alone or in small groups on a specific research task. The research experiences were designed to be authentic, focused on helping faculty collect data or test new ideas. Whenever possible, the research projects also had a tie to the community or existing regional partnerships since this type of collaboration has been shown to help students from underrepresented groups connect with careers. The research experiences were also very carefully scaffolded so students were tackling very small pieces of a larger research project.

Survey Design

A pre-post survey was created to evaluate shifts in student learning and evaluate research identify outcomes when engaging in a CURE. The survey was designed as part of a larger study based on the Kern Entrepreneurial Engineering Network's (KEEN) Student Outcomes (KSOs) developed by faculty at Ohio Northern University [19]. The survey questions related to the KSOs had students provide their perceptions of their ability to perform various types of research tasks on a five-point Likert score between 1-very poor and 5 - very good. The elements focused on research identity were adapted in part from prior work by Pietri et al. [28], where students are asked to indicate their level of engagement in various aspects of the research project. The survey was validated using 115 student responses from three different academic institutions. Survey validation included the evaluation of question reliability and strength of correlation to the research domains using confirmatory factor analysis. Details of the survey development and validation are provided by Walters et al. [29].

The survey was distributed to all students participating in CUREs at different institutions. The institutions were all part of a collaborative grant project with faculty trained on CUREs. Each CURE had different instructors and projects as developed by the individual faculty members. Near the beginning of the research module, students were asked to complete a pre-survey questionnaire. At the end of the course or research module, the students were asked to complete a post-survey about their research experience. The survey was designed to determine if changes had occurred in their perceptions of their research identity. The survey questions we analyzed are included in Appendix 1.

To mask student identities, each student generated a unique code and included it in both the pre and post survey. To analyze the survey data, we merged the data for pre and post surveys based on the unique student identifiers. The number of fully completed pre and post survey data is a significantly lower number of surveys (less than 10%) due to students that failed to complete either the pre or post survey, or did not include a unique identifier in the survey.

To analyze the data, we used the statistical software R [30]. The data was downloaded from a qualtrics survey and imported into R. The data was cleaned to ensure results were complete, which included removing incomplete submissions. Initially the results were visualized by institution and demographic data to identify trends.

To understand the student self-perceptions of research, we analyzed the pre and post survey data. This task required us to compare the pre and post survey data using the unique identifier provided by each student. Since many students did not complete both the pre and post surveys with a valid unique identifier, this became a much smaller data set. The pre and post data set was compared using a standard delta calculation (Δ).

$$\Delta = pre\ value - post\ value \quad (1)$$

Results

The total pre and post set includes 254 surveys from 6 institutions. After filtering, the results included 70 surveys completed by mechanical engineering students at the University of Washington Tacoma. The surveys were filtered by course number prefixes, TME represents the courses for this institution and program. 25 surveys were completed that included both pre and post survey results. This subset was important since the type of CUREs in the program are implementing a specific type of structure.

The student demographics for the mechanical engineering students are shown in Figures 2-3. In general, the proportions of students who have done research with faculty as first generation students is a bit higher than those that are not. This trend is consistent with the recent emphasis on CUREs in the program.

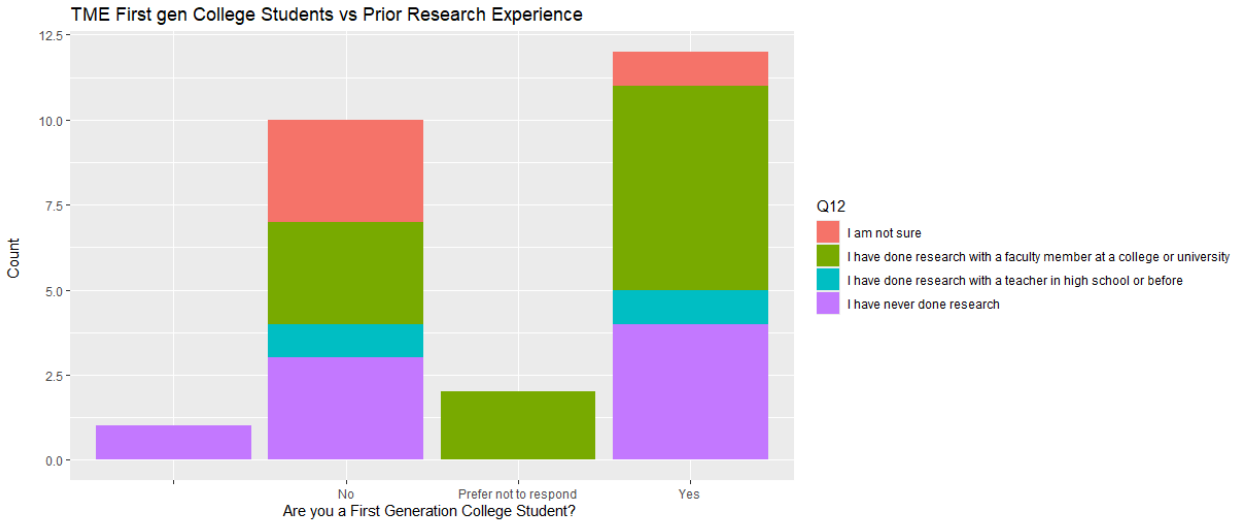

Figure 2. Student demographics for the research students in the program, first generation status. Total responses (n=25).

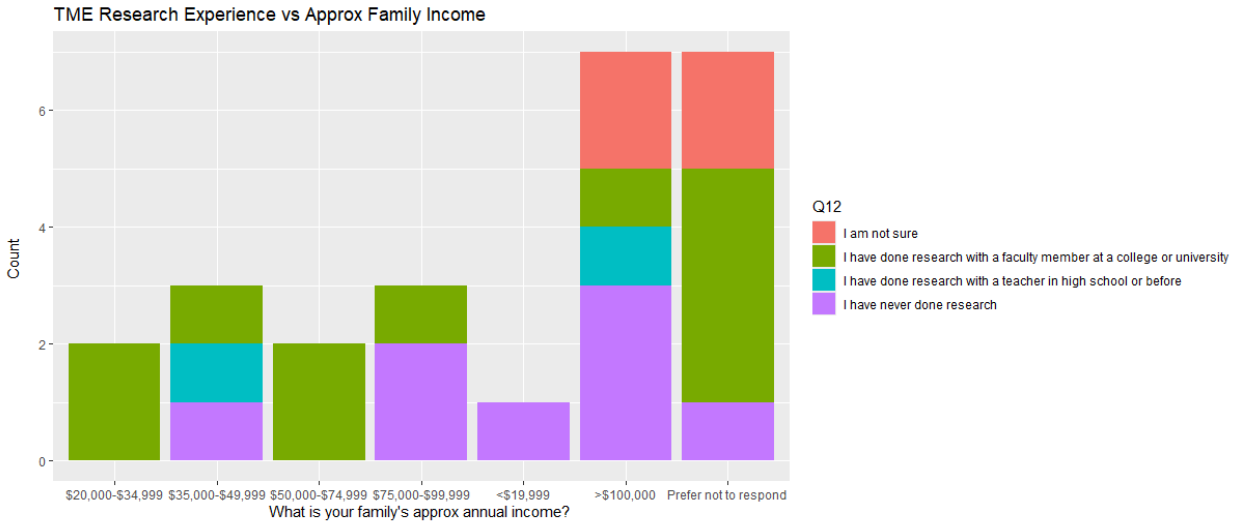

Figure 3. Student family annual income and prior research experience (n=25).

The student pre and post experience responses are shown in Figure 4, 5, and 6 for both TME students (blue) and the larger sample of students (red). In general the trend for TME students is consistent with the larger study population. TME students did have stronger pre-survey confidence for working with others and their ability to modify research focus to meet the needs of stakeholders. After completing the CURE experience the distribution of student confidence in all the objective areas shifted toward very good.

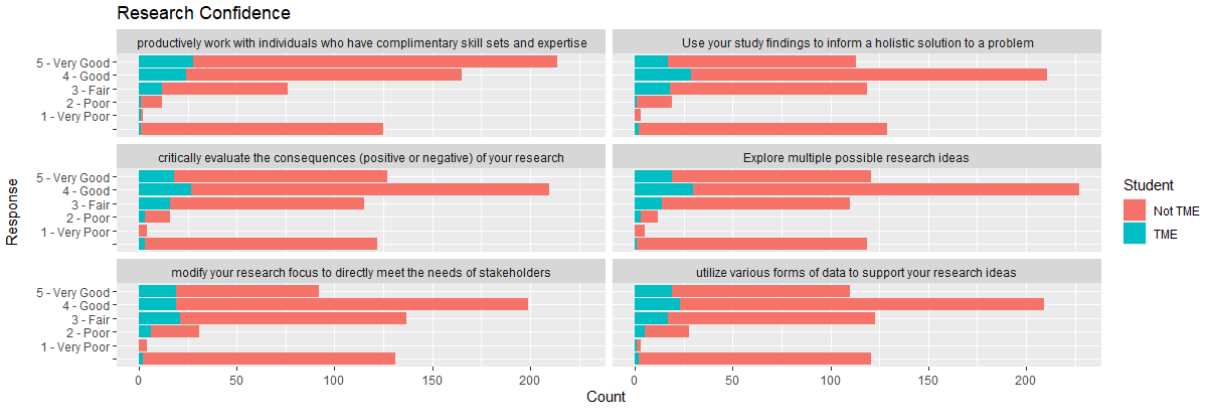

Fig. 4a

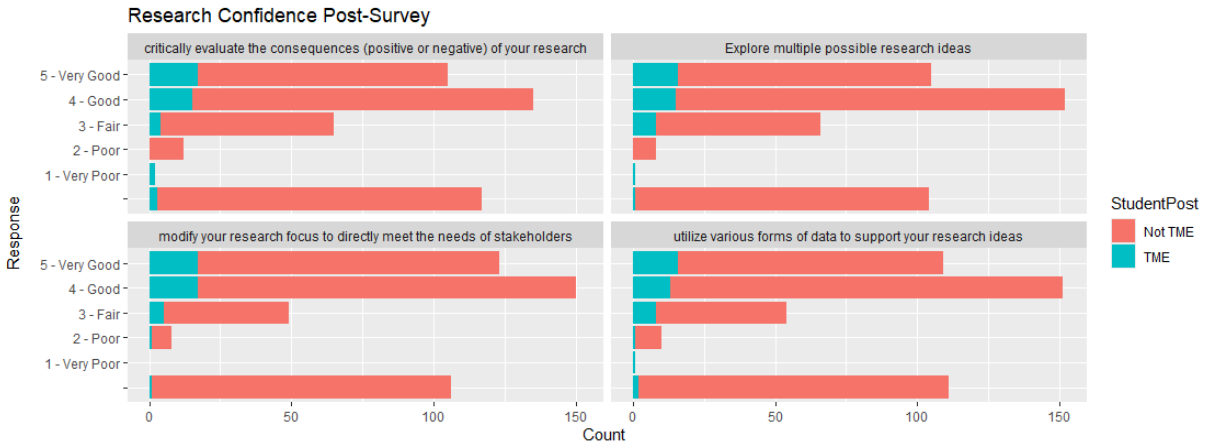

Fig. 4b

Figure 4. Student responses to research and EM survey questions before the CURE (a) and after the CURE (b).

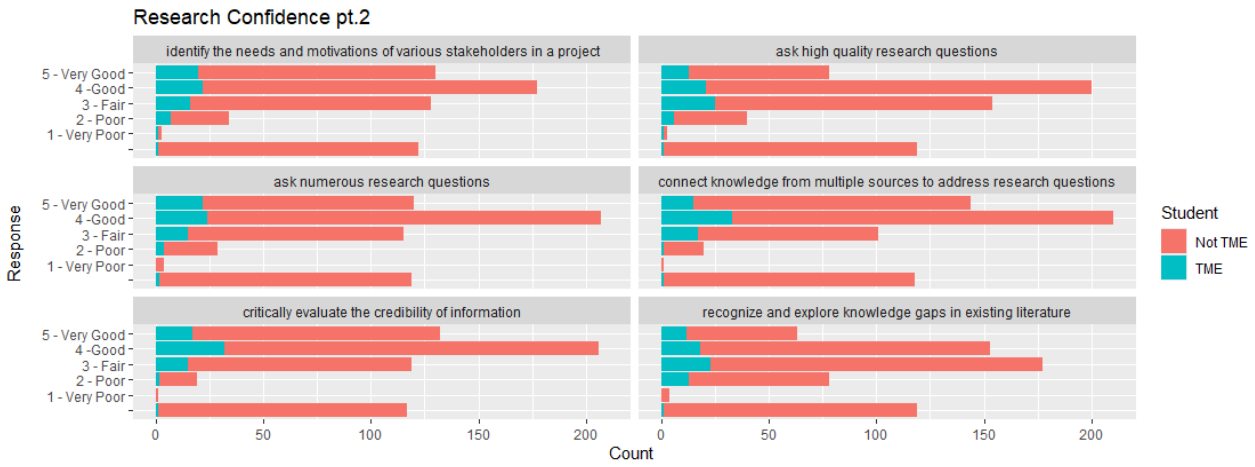

Fig. 5a

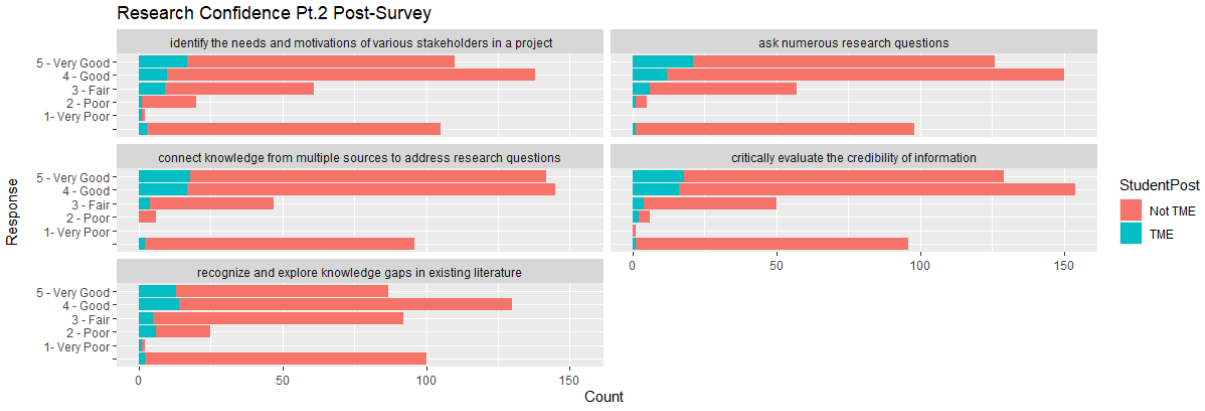

Fig. 5b

Figure 5. Student responses to research and EM survey questions before the CURE (a) and after the CURE (b).

One of the questions asked on the post survey was "Overall, do you think that participating in research was valuable for your learning? Please Explain." The following are student comments from the post survey answering this question. The overall trend of the responses was positive, and it was evident that the students regarded the research as being valuable in some way to their learning.
A sample of student comments in the post survey have been included below:

- This has been a very valuable experience. I got to work with the engineering design process hands on and see what it is like to brainstorm designs from just a vague idea/goal. I also got to have enough exposure to literature that I am much more comfortable with reading it, interpreting it, and pulling out the key points. I am also got experience with working as a team to accomplish the same goal and saw how everyone's input and research was considered and implemented. It was a very positive team environment that I feel very good about at the end of the course.

- This research was invaluable for me. I learned so much and found new value in things that I never have before. Such as writing papers based on literature, saw the importance of numerical modeling first hand, and learned how to interact with the broader scientific community on platforms like LinkedIn.
- yea, I learned how to filter out information on resources, get what is more important to me. I also learned how to express my ideas/thoughts in a scientific way.
- I do think it was. I would like to pursue work in research and having this experience both exposes me to my future career but also gives me the experience to show others my capabilities.

For many of the post CURE experiences, the shift (increase in confidence) was more dramatic for TME students than the larger student survey population. This is particularly true for asking research questions and connecting knowledge. These trends may be due in part to the EM activities included in the course structures for many of the TME CUREs. Future work will consider the larger data set to better understand this trend.

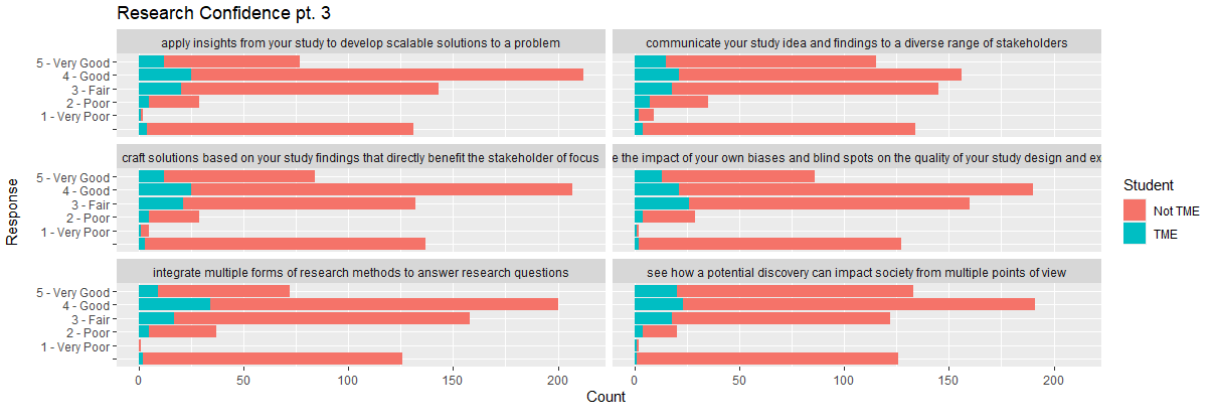

Fig. 6a

Figure 6. Student responses to research and EM survey questions before the CURE (a). Students did not answer these questions on the Post-Survey

An example of the type of distribution of the delta values (pre minus post survey) is shown in Figure 7. For the much smaller data set of students that completed both the pre and post survey for TME courses the results are shown in Table 2. For all the average (mean) measured responses, the students reported an increase in the Δ. The highest average gains were reported for modifying the research focus to directly meet the needs of stakeholders. This makes sense because all the TME courses had a strong focus on understanding stakeholders in both the reflection prompts and the concept map required for the projects in all the CUREs.

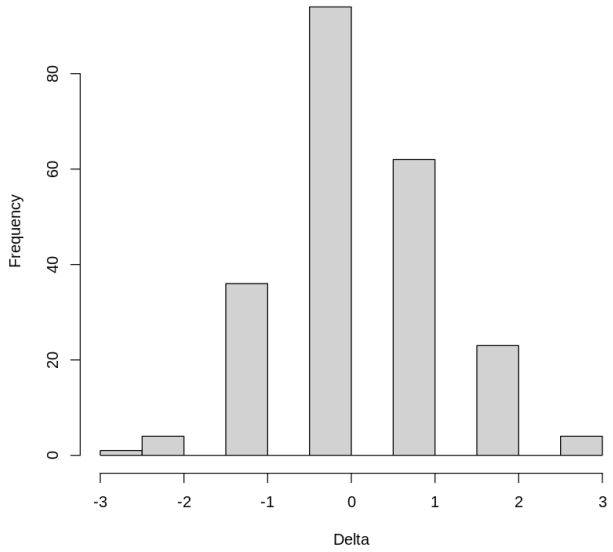

Figure 7. Example histogram of change (Δ) in student self-reported ability for question 1 part five "Identify the needs and motivations of various stakeholders in a project"

The other two high factors included exploring knowledge gaps in existing literature and utilizing data to support research. Smaller gains occurred in the other factors tied to research mindset. The lowest gain was reported for exploring multiple possible research ideas. This makes sense since the CURE structure for the TME program did not typically include student generated research topics, although they practiced generating research questions aligned with a specific topic.

Conclusions

After analysis of the CURE data for the mechanical engineering program we return to our research questions.

RQ1: How do UWT mechanical engineering students participating in CUREs experiences differ from research students at other institutions?

Student demographics were similar for TME students and other institutions based on comparison with the larger student population. The sample size for the TME students is small enough that only a few statistically significant conclusions are appropriate at this time. Analysis of the larger full data set is planned for future work.

In general, TME mechanical engineering students had slightly higher gains in key areas like connecting their work to stakeholders and connecting knowledge. These trends are likely correlated to the EM activities included in the course structures for many of the TME CUREs. Specifically the QFT method and the concept mapping activities may have led to higher student confidence in these areas. This is an indication that faculty should consider similar activities in their CURE course development.

Table 2. Summary of change (Δ) in student self-reported ability to do specific tasks as part of the CURE. The delta (Δ) in student self-reported ability was calculated for each student, then the average (mean) for that set was determined along with the standard deviation.

Question	Number of Responses	Pre-Survey Mean	Post-Survey Mean	Δ Mean [Standard Deviation]	T-test P-Value
Ask Numerous Research Questions	235	3.93	4.18	0.25 [1.04]	0.0008*
Critically evaluate the credibility of information	236	4.03	4.23	0.19 [0.87]	0.003701*
Recognize and explore knowledge gaps in existing literature	235	3.45	3.82	0.41 [1.02]	8.717e-06*
Connect knowledge from multiple sources to address research questions	238	4.07	4.26	0.21 [0.88]	0.01175*
Identify the needs and motivations of various stakeholders in a project	229	3.90	4.12	0.25 [1.04]	0.00947*
Explore multiple possible research ideas	229	4.02	4.09	0.09 [0.93]	0.4184
Modify your research focus to directly meet the needs of stakeholders	222	3.78	4.22	0.46 [1.01]	4.926e-09*
Critically evaluate the consequences (positive or negative) of your research	224	3.98	4.09	0.14 [1.01]	0.1211
Utilize various forms of data to support your research ideas	224	3.87	4.16	0.33 [1.01]	6.911e-05*

* Statistically significant for a 95% threshold

RQ2: How have CURE courses in the mechanical engineering program supported entrepreneurial mindset development and research identity formation for students?

The CURE courses in the mechanical engineering program have been an important way to develop EM in students. In particular, utilizing student-focused research methods has supported students in the program and increasing confidence in EM focused objectives. Students participating in the CUREs in the TME program reported small average gains (Δ) in every facet of the research mindset surveyed (Table 2). This indicates the CURE program is having consistent positive impacts on student mindset in the program. The development of CUREs will continue in the program in an effort to support this type of improvement over time. Collecting additional data will help further clarify trends.

For a new program the implementation of CUREs that focus on mindset development and growth has been transformative for students. Many of the students' anecdotal responses in the survey indicate that the experience was very helpful.

Acknowledgments

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Appendix 1 - Survey Questions Analyzed

Using the scale of 1 - Very Poor to 5 - Very Good, please rate your ability to do the following research activities:

- ask numerous research questions (1-5 scale)
- critically evaluate the credibility of information(1-5 scale)
- recognize and explore knowledge gaps in existing literature (1-5 scale)
- connect knowledge from multiple sources to address research questions (1-5 scale)
- identify the needs and motivations of various stakeholders in a project (1-5 scale)

Please explain how you engaged with the literature and with stakeholders to develop the focus and activities of your research project.

Using the scale of 1 - Very Poor to 5 - Very Good, please rate **your ability** to do the following research activities:

- ask high quality research questions (1-5 scale)
- explore multiple possible research ideas (1-5 scale)
- modify your research focus to directly meet the needs of stakeholders(1-5 scale)
- critically evaluate the consequences (positive or negative) of your research(1-5 scale)

Please explain how you arrived at your final set of research hypotheses and/or research questions for your research project.

Using the scale of 1 - Very Poor to 5 - Very Good, please rate **your ability** to do the following research activities:

- utilize various forms of data to support your research ideas(1-5 scale)
- productively work with individuals who have complimentary skill sets and expertise (1-5 scale)
- Use your study findings to inform a holistic solution to a problem(1-5 scale)

Please provide an example for how you adapted your data collection strategies most effectively develop a solution to the research problem.

Using the scale of 1 - Very Poor to 5 - Very Good, please rate **your ability** to do the following research activities:

- evaluate the impact of your own biases and blind spots on the quality of your study design and execution(1-5 scale)
- integrate multiple forms of research methods to answer research questions(1-5 scale)
- apply insights from your study to develop scalable solutions to a problem(1-5 scale)

Please provide an example for how you navigated the various forms of bias that exist when conducting research.

Using the scale of 1 - Very Poor to 5 - Very Good, please rate **your ability** to do the following research activities:

- see how a potential discovery can impact society from multiple points of view(1-5 scale)
- apply insights from your study to develop scalable solutions to a problem(1-5 scale)
- communicate your study idea and findings to a diverse range of stakeholders(1-5 scale)
- craft solutions based on your study findings that directly benefit the stakeholder of focus(1-5 scale)

Please provide an example for how you communicated the findings from your research.