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WIP: Evaluating Entrepreneurially-minded Learning in Course-based Undergraduate Research Experiences

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Work in Progress: Evaluating Entrepreneurial-minded Learning in Course-based Undergraduate Research Experiences

Introduction

Engineering challenges are increasing in scope, scale, and complexity. Now, more than ever, future engineers must be equipped with the skills necessary to ensure solutions to these challenges are impactful and scalable across the various facets of society [1]. Scale and impact are the main epistemological tenets of entrepreneurially-minded learning (EML) [2], [3]. EML represents a specific kind of applied learning where one understands and connects a societal need with an engineering solution that leverages economic and market systems to make the solution scalable (KEEN source). The main aspects of innovative academic research align well with the goals and outputs of EML, namely the ability to clearly evaluate a need, study or innovate a solution to this need, and describe how the benefits of this solution might best be realized through policy, practice, or future research. Creating value is closely associated with the goals of most engineering research. Thus, engaging engineering students in meaningful undergraduate research experiences offers a way to promote students' EML. Additionally, undergraduate research has been shown to create beneficial shifts in student attitudes towards scientific research, resulting in increased retention in STEM fields [4], [5], [6].

In recent years, course-based undergraduate research experiences (CUREs) have been gaining popularity as a way to engage undergraduate students in authentic scientific inquiry on a large scale [7]. While CUREs have many similarities to traditional laboratory courses or course research projects, the work students do as part of a CURE is framed in a fundamentally different way. Research projects within CUREs ideally have direct and indirect impact on the broader scientific community and offer students the opportunity to share study findings with external stakeholders [8]. Consequently, CUREs represent an overlap between the triumvirate of student learning, stakeholder impact, and promotion of a faculty's research program.

In this work in progress (WIP) paper, we present preliminary findings from a study that seeks to explore the way CUREs and EM tools may support student development. The specific cool highlighted in this WIP is a survey tool for evaluating EML within CUREs. When completed, we believe that the insights provided by this research will be of significant value to faculty interested in promoting student learning through CUREs - especially those with high teaching loads.

The overarching research questions (RQ) this study seeks to address are the following:

- RQ1. In what ways do students in CUREs develop an entrepreneurial mindset?
- RQ2. What structures or practices help students develop EML through course-based research?

This WIP specifically focuses on RQ1 – the ways in which students EML appears to shift by engaging in CUREs – where future work will aim to address RQ2 once more student data is collected.

Background

CUREs have been applied to many different STEM topics, including biology [9], [10], ecology [11], [12], [13], chemistry [14], mathematics [15], [16], medicine [17] (Johnson et al 2021), and even music [18]. Largely, however, CUREs have been applied within the natural sciences and there is a lack of knowledge on the impact of CUREs on student learning in general and EML in particular.

The evaluation of EML in engineering education is well studied [19]. Evaluation techniques have ranged from the application of grading structures and rubrics attached to in-class assignments (e.g., Dancz et al. 2016; DiBerardino et al. 2018; Salib and Walisko 2014), to the application of index-based evaluation tools to evaluate various aspects of EML (e.g., Fulcher 2008; Harichandran et al. 2019; Saisana 2008). Other evaluation approaches have focused on pre-post surveys where EML was evaluated based on shifts in students' perception of entrepreneurial practices in engineering within a wide range of class projects, topics, workshops, and mentorship strategies (e.g., [26], [27], [28], [29], [30]. However, to our knowledge, no prior studies exist that explicitly evaluate growth or shifts in students' EML resulting from engaging in undergraduate research experiences in general or CUREs in particular.

The above-mentioned knowledge gaps motivated a three-year study that seeks to evaluate EML impacts and best practices from CURE application within engineering education. We contend that engaging engineering students in meaningful academic research experiences in the classroom potentially offers a way to promote EML within a broad range of engineering topics. Our research program seeks to test this hypothesis through the implementation and study of student EML for over 60 CUREs applied within multiple engineering and science disciplines across 15 US universities. The study in this WIP paper presents preliminary results from the first stage of this research centered on the creation and validation of a pre-post survey instrument for evaluating EML for students engaging in these CUREs.

The goal of the preliminary study presented was to evaluate if there appear to be statistically significant shifts in student EML through engaging in 12 studied CUREs. The next section provides an overview of the method employed for survey dissemination, validation, and interpretation, followed by a presentation and discussion of study findings and future research directions.

Study Design

The studied survey instrument was based on the extended Kern Entrepreneurial Engineering Network's (KEEN) Student Outcomes (KSOs) developed by faculty at Ohio Northern University [27]. The KSOs are categorized within the KEEN 3Cs of EML: curiosity, connections, and creating value. To specifically evaluate shifts in EML related to CURE research activities, the survey questions were tailored to the common steps or 'domains' of academic research which we categorized as: exploration, planning, execution, interpretation, and dissemination. The KSO-based survey had 18 questions asking students to rate their ability to perform various sub-activities within the exploration, planning, execution, interpretation, and dissemination research domains on a five-point likert scale (Table 1 below). A Qualtrics online survey was sent to students enrolled in these classes, taken before and after participating in any CURE-related activities. The 18-question survey asked students to rank their perceived ability to perform various research tasks related to the five research domains using the Likert scale: 1 - Very Poor, Poor, Fair, Good, or Very Good.

Survey validation included the evaluation of question reliability and strength of correlation to the research domains using confirmatory factor analysis. This evaluation included the analysis of 115 student responses who participated in 12 CUREs across three different academic institutions (University of Washington Tacoma, George Fox University, and George Washington University). The studied CUREs were applied within class topics including materials science, transportation engineering, structural engineering, biomechanics, nanotechnology, and physical hydrology.

Evaluation of survey question reliability and strength of correlation entailed analyzing the survey responses in three stages using SAS® OnDemand for Academics statistical software (SAS Institute Inc., 2021; SAS Institute Inc., 2017). The first stage used the PROC IMPORT procedure to import the data to SAS and to rescale the data where Very Good corresponded to 1 up to Very Good which corresponded to 5. In the second stage, since the data is polytomous, the PROC FREQ procedure with the option PLCORR was used to compute the Polychoric correlation coefficients. Lastly, the reliability of the survey was measured using the PROC CORR procedure with the option ALPH and PROC CALIS to compute the Cronbach's Alpha and to perform the factor analysis for evaluation of question load estimates, respectively. Evaluation of statistically significant shifts in students' EML between the pre and post survey responses was evaluated using a Wilcoxon Sign Rank Test. Evaluation of statistical significance was based on a P-value < 0.05. The data were also evaluated for normality using the Shapiro-Wilk and Kolmogorov-Smirnov tests.

Preliminary Findings & Future Directions

The confirmatory factor analysis revealed a high Cronbach Alpha Coefficients (>0.75) for four out of five of the research domains, with an acceptable score for the 'execution' research domain (0.66). High factor load estimates were also achieved for each survey question with an overall excellent Goodness of Fit Index (GFI, 0.978) indicating that the questions have good reliability and correlation with the associated research domains. Therefore, the survey instrument provides a robust tool to evaluate EML for CUREs. A summary of validation findings for each survey question can be found in Table 1.

Table 2: Factors Loadings and Cronbach Coefficient Alpha

Research Domain	**Question:** "Please rate your ability to do the following research activities…."	**Load Estimates**	**Cronbach Coefficient Alpha**
1 - Exploration	Q1-1: Ask numerous research questions	0.65604	0.779247
	Q1-2: Critically evaluate the credibility of information	0.78858	
	Q1-3: Recognize and explore knowledge gaps in existing literature	0.62087	
	Q1-4: Connect knowledge from multiple sources to address research questions	0.72859	
	Q1-5: Identify the needs and motivations of various stakeholders	0.60666	
2 - Planning	Q2-1: Ask high quality research questions	0.83831	0.773164
	Q2-2: Explore multiple possible research ideas	0.64387	
	Q2-3: Modify your research focus to directly meet the needs of stakeholders	0.65963	
	Q2-4: Critically evaluate the consequences (whether positive or negative) of your research	0.80376	
3 - Execution	Q3-1: Utilize various forms of data to support your research ideas	0.80167	0.748126
	Q3-2: Productively work with individuals who have complementary still sets and expertise	0.74745	
	Q3-3: Use your study findings to inform a holistic solution to a problem	0.73851	
4 - Interpretation	Q4-1: Evaluate the impact of your own biases and blind-spots on the quality of	0.5605	0.661988
	Q4-2: Integrate multiple forms of research methods to answer research questions	0.74491	
	Q4-3: Apply insights from your study to develop scalable solutions to a problem	0.7272	
5 - Dissemination	Q5-1: See how a potential discovery can impact society from multiple points of view (i.e., technological, societal, financial,	0.74151	0.762288
	Q5-2: Communicate your study idea and findings to a diverse range of stakeholders	0.58805	
	Q5-3: Craft solutions based on your study findings that directly benefit the stakeholders of focus	0.82415	

Table 3 below provides an assessment of statistically significant differences in EML between pre- and post-CURE student survey responses. The results show that in general students' perception of their ability to perform research activities grew across all five research domains, addressing RQ1. We controlled for differences in shifts across school types, of which we noticed no significant differences.

Some of the questions with the largest p-values (e.g. exploring gaps in the existing literature) are the ones that faculty reported spending more time on and/or may have been areas where students had previously had little to no exposure. Three survey questions yielding higher, yet still statistically significant p-values (0.01 to 0.05) included (Exploration): Q1-4: *Connect knowledge from multiple sources to address research questions,* Q1-5: *Identify the needs and motivations of various stakeholders*, and (Dissemination) Q5-1: *See how a potential discovery can impact society from multiple points of view (i.e., technological, societal, financial, environmental, etc.)*. Finally, one survey question did not reveal a statistically significant growth in perceived learning or ability related to the Execution domain: Q3-2: *Productively work with individuals who have complementary still sets and expertise.* This result could be because none of the EM-CURE projects in the study sample either directly focused on cross-disciplinary collaboration or engaged with researchers outside of the topic area of instruction. For example, a student team working to characterize tsunami debris loads only engaged with structural engineers and not with policy makers. This finding is important, as research that has true societal impact conceivably requires cross-disciplinary engagement and collaboration.

Overall, the study results are promising for the future application of the survey instrument to evaluate shifts in EML for students participating in CUREs, and more importantly, the way in which CUREs appear to promote gains in students' EML. However, the survey questions yielding low to no statistical significance point to focus areas for both study and practice as the research moves forward, related specifically to helping students meaningfully integrate stakeholder perspectives, and anticipated study impacts, in research design, along with ways to promote learning about the merits and utility of effective cross-disciplinary collaboration.

The future application of the survey instrument in more CURE classes will continue to evaluate if statistically significant shifts in students' EML are attained through engaging in CUREs, and the areas where this learning takes place. Additionally, by combining findings from the survey with a qualitative comparison of research activities employed within the CUREs through pre- and post-faculty member surveys, future work will aim to evaluate which CURE activities, timeframes, etc., led to the greatest gains in students' EML. In so doing, this work will provide evidence and best practices for the broader application of CUREs within engineering education.

Table 3: Evaluation of statistically significant differences in pre-post responses for each survey question using the Wilcoxon Sign Rank Test. We underline P-values that are not statistically significant.

Research Domain	**Question:** "Please rate your ability to do the following research activities…."	**Signed Rank**	**Shapiro-Wilk**	**Kolmogorov-Smirnov**
		P - Value	**Normality Tests**	
1 - Exploration	Q1-1: Ask numerous research questions	0.00025	<0.0001	<0.0100
	Q1-2: Critically evaluate the credibility of information	0.0063	<0.0001	<0.0100
	Q1-3: Recognize and explore knowledge gaps in existing literature	<.0001	<0.0001	<0.0100
	Q1-4: Connect knowledge from multiple sources to address research questions	0.0213	<0.0001	<0.0100
	Q1-5: Identify the needs and motivations of various	0.02015	<0.0001	<0.0100
2 - Planning	Q2-1: Ask high quality research questions	0.0003	<0.0001	<0.0100
	Q2-2: Explore multiple possible research ideas	0.00045	<0.0001	<0.0100
	Q2-3: Modify your research focus to directly meet the needs of stakeholders	<.0001	<0.0001	<0.0100
	Q2-4: Critically evaluate the consequences (whether positive or negative) of your research	0.0026	<0.0001	<0.0100
3 - Execution	Q3-1: Utilize various forms of data to support your research ideas	0.00015	<0.0001	<0.0100
	Q3-2: Productively work with individuals who have complementary still sets and expertise	**0.27565**	<0.0001	<0.0100
	Q3-3: Use your study findings to inform a holistic solution to a problem	0.0037	<0.0001	<0.0100
4 - Interpretation	Q4-1: Evaluate the impact of your own biases and blind-spots on the quality of your study design and execution	0.0054	<0.0001	<0.0100
	Q4-2: Integrate multiple forms of research methods to answer research questions	0.00375	<0.0001	<0.0100
	Q4-3: Apply insights from your study to develop scalable solutions to a problem	0.0005	<0.0001	<0.0100
5 - Dissemination	Q5-1: See how a potential discovery can impact society from multiple points of view (i.e., technological, societal, financial, environmental, etc.)	0.02775	<0.0001	<0.0100
	Q5-2: Communicate your study idea and findings to a diverse range of stakeholders	0.0064	<0.0001	<0.0100

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