2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #37066

Student Comprehension of and Growth in Creating Value with an Entrepreneurial Mindset

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Introduction

(Full Research Paper). Much of the history of engineering education has revolved around math and science so deeply that students expect they must excel at both if pursuing engineering as a career [1]. However, at the onset of the century, the National Academy of Engineering published a study stressing the need to prepare for the future of engineering and called for a transformation to our engineering education landscape [2]. While math and science are vital to understanding and applying foundational concepts in engineering, the field has grown beyond this limited definition and requires engineers become involved with design activities to adequately identify problems and create solutions [3], [4]. An element of empathy and considering human welfare has also become critical to ensure solutions being developed not only support end users but also address the problem as identified by end users [2], [5]. Moreover, beyond applying the technical knowledge gained in the coursework, the American Society for Engineering Education (ASEE) highlighted that graduating engineering students must know how to "work as part of teams, communicate well, and understand the economic, social, environment, and international context of their professional activities" [6, p.1]. Stemming from this point is the need to instill societal perspectives into graduating engineering students so they holistically understand the impact of their products locally and globally [7].

With the scope of engineering expanding past the application of math and science, we must prepare engineering students to carry out their work with these responsibilities in mind. One way to do so is implementation of the Entrepreneurial Mindset (EM) which cultivates the significance of curiosity, making connections, and creating value. An EM promotes information gathering, inter-topic connection making, and constant valuation of an engineer's product or service and the ways in which it supports society. While an EM appears business venture-centered at first glance, its support and application in the engineering classroom has been growing due to its relevance to the role engineers play today [8], [9]. For example, corporations have been calling on higher institutions to graduate more global engineers that are prepared to work in our increasingly global society [10]. A characteristic that describes global engineers is their ability to translate engineering work to a business context which can be done with an EM.
The Kern Entrepreneurial Engineering Network (KEEN) is here to meet this need. KEEN is a partnership of engineering faculty across the nation dedicated to integrating the EM into engineering coursework [11]. Within KEEN, an EM is achieved through Entrepreneurial Minded Learning (EML) and applies what are known as the 3Cs: Curiosity, Connections, and Creating Value. Since joining KEEN in 2017, The Ohio State University College of Engineering has integrated EML into the standard and honors course sequences of its First-Year Engineering Program (FYEP) to better prepare students to identify problems and develop solutions as practicing engineers.

Background

Upon joining the network, our initial EML implementation efforts focused on restructuring the design-build project of our standard course sequence in the FYEP by centering it around the 3Cs.

This began by visiting other KEEN institutions to understand how EML is implemented in their first-year engineering courses [12]–[14]. Following these visits, various concepts from the 3Cs were explicitly added to the course curriculum to ensure students were becoming familiar with the 3Cs and actively applying them in their project work.

As it currently stands, the standard course sequence consists of two courses where the second course (ENGR 1182) is designed to provide students with the knowledge of engineering fundamentals. This course is divided into two segments: (1) Graphics and (2) Design Project. The graphics segment focuses on computer-aided design and the design project is team-based and open-ended. The design-project segment was re-designed using an EM learning framework in 2019 [15] to move from a design project with clearly defined criteria and final objectives to student-defined problems and a strong emphasis on user-centered design. It currently serves as a semester-long project where students go through the engineering design process via three structured phases: problem identification, conceptual design, and detailed design. In the problem identification phase, students first identify a target user group and perform primary and secondary research to identify users' pains. From that understanding of the user, students identify a problem and create their own set of design requirements based on user needs in the conceptual design phase. Students generate their own strategy for prototype testing in the final detailed design phase and are encouraged to constantly consider the value their proposed solution has for all stakeholders, including the end users on which the problem identification was originally based. As the design project is very open-ended, students pursue many topics and consequently, the scope of resulting projects is large.

As the years progressed, EML was also integrated into the curriculum for the FYEP honors course sequences and capstone courses. We standardized the EML coursework implemented in the standard course sequence so that it could readily apply to these other courses. This involved the development of direct and indirect assessments for each of the 3Cs [16]. With this development, we modified our learning objectives to meet our EML goals and created rubrics to measure student performance with each assessment type [17]. As it currently stands, the honors course sequence also consists of two courses where the second course (ENGR 1282) is designed to provide students with the knowledge of engineering fundamentals as well. Much like ENGR 1182, ENGR 1282 is divided into two segments: (1) Graphics and (2) Design project where the design project is primarily how the two tracks differ. In ENGR 1282, the design project is a semester-long project and group-based, yet students are tasked with a rigid project scenario and problem statement for which to design their solution. Note the design project elaborated upon here is not the traditional project given in ENGR 1282. Rather, it was developed for the purposes of meeting course requirements while being in an online environment due to the COVID-19 pandemic. In this design project, students are part of a research and development team contracted out by a local escape room business to design and develop a new themed escape room. For this project, clearly defined criteria and final objectives are set for the students before they began working. Examples of such criteria included predetermined end users, electrical/mechanical components that must be integrated into the escape room design, and floor plans to build.
In this work, we assess student performance with the Creating Value Direct Assessment [18] in both the standard and honors course sequences of our FYEP at the beginning (see Figure 1) of the Appendix for the first assessment) and end (see Figure 2 of the Appendix for the second assessment) of the 2021 spring semester. The deployment of the assessment before content

coverage supplied students an example scenario to identify points of value creation while the deployment at the end of the academic year required students to identify a scenario based on their semester-long design project. Upon collection of completed assessments from the students, two reviewers trained with the Creating Value Direct Assessment rubric [18] (see Figure 3 of the Appendix) evaluated student responses and scores were used for pre/post analysis within and between course sequences. We computed descriptive statistics and conducted significance testing for all four datasets to determine the effectiveness of our EML coursework on first-year engineering students' ability to create value.

Methods

The Creating Value Direct Assessment was deployed at the beginning of the 2021 spring semester in both course sequences of our FYEP. This assessment is geared towards measuring students' ability to identify the various kinds of value a solution can create for the stakeholder groups they identify. As shown in Figure 1 and Figure 2, the assessment supplies students a table to provide the stakeholders, value categories, and value created for each stakeholder/value category combination. KEEN recognizes three types of value categories (economic, social, and environmental) as ones engineers should consider in their work [19]. Students received sub-scores for each of these three variables and total scores based on their sum (see the "Features" column of the rubric in Figure 3). In the pre-assessment (Figure 1), an example scenario is provided at the top of the assessment (communication platforms for team-based projects) while in the post-assessment (Figure 2), there is an area for students to identify a scenario that relates to their semester-long design projects.

Students received the assessment via our learning management system, Canvas, as a blank Excel sheet and once completed, students saved and submitted their work via a Qualtrics survey. At the end of the academic year, students received the same blank Excel sheet to identify stakeholders, value categories, and value created, but they were prompted to identify a scenario related to their semester-long design projects first rather than obtain one from the teaching team. To complete the assessment, students filled in their example scenario, stakeholders, value categories and the corresponding value created for each stakeholder and submitted their work via Qualtrics.
Upon receiving all responses for both course sequences, two graders on the research team randomly selected ten completed assessments to grade via the Creating Value Rubric (see Figure 3) to establish inter-rater reliability (IRR). Note 0.70 is deemed an adequate IRR for group comparisons and served as the minimum IRR we strived to achieve [20]. Upon grading these pilot assessments, the graders convened to discuss any discrepancies in their grading and repeated the process until achieving an IRR of at least 0.70. Once meeting this threshold, 50 pre and 50 paired post assessments for each course (standard and honors) were pulled, de-identified, and divided among the graders to assess. Assigned scores for each category were stored in a separate Excel sheet and used for data analysis. When scoring stakeholders provided with the rubric, full points were awarded to students that supplied at least three different stakeholder types, two points for two stakeholder types and so on. In terms of value categories, points were awarded if those listed were economic, social, or environmental, with each category earning one point for a maximum of three. Lastly, full points were awarded if the grader agreed with the value created for each stakeholder/value category pairing. Points were deducted if value items

were copied across groups, if the grader disagreed with multiple value items provided, or if the grader could identify value items for particular groups that were not identified by the student. With all assessments scored, we computed descriptive statistics for each of the four datasets (pre-standard course, post-standard course, pre-honors course, post-honors course) and conducted statistical tests to determine any differences within our datasets. significance testing, we analyzed for any pre/post differences within and across course types via these statistical tests and conducted tests for normality via the Shapiro-Wilk Test and Q-Q plots. These normality tests were used to establish if parametric or nonparametric testing was appropriate. Nonparametric tests were used given normality testing indicated non-normal data for each variable (stakeholders, value categories, value created) in all four datasets. Thus, we applied the Wilcoxon Signed Rank Test for pre/post significance testing within courses and the Mann-Whitney U Test for pre/post significance testing across courses. An α value of 0.10 and a null hypothesis of no significant change from pre to post was used for all statistical tests.

Results

We found the mean scores for stakeholders, value categories, and value created items provided by students in the standard course to exceed those provided by students in the honors course (see Table 1). However, the standard deviation for each variable among the standard course was slightly larger than those of the honors course, indicating a wider range of scores for students in the standard course.

Table 1: Descriptive statistics of creating value scores (pre-academic semester)

Course Type	**Stakeholders** ***M(SD)***	**Value Categories** ***M(SD)***	**Value Items** ***M(SD)***	**Total** ***M(SD)***	**Inter-Rater Reliability (IRR)**
Standard	2.53 (0.809)	1.51 (0.543)	1.90 (0.755)	5.94 (1.57)	0.91
Honors	2.27 (0.717)	1.21 (0.498)	1.85 (0.668)	5.33 (1.22)	0.85

In the post-datasets (see Table 2), the mean score for value categories was greater for the standard course while those for the stakeholders and value items created were greater for the honors course. Moreover, the net increase in the mean for the latter variables was greater for the honors course than the standards course. Recall the grading scheme for identified stakeholders. Considering this, the mean stakeholders in the honors course pre-dataset (2.27±0.717) indicates the honors students were more likely to provide two stakeholder types and over the course of the year and learned to identify at least three types (post-mean of 2.77±0.425) which depicts considerable growth in this skill. Similarly, the increase in stakeholder/value category pairings from 1.85±0.668 to 2.06±0.752 suggests net growth in honors students over the semester.

Table 2: Descriptive statistics of creating value scores (post-academic semester)

Course Type	**Stakeholders** ***M(SD)***	**Value Categories** ***M(SD)***	**Value Items** ***M(SD)***	**Total** ***M(SD)***	**Inter-Rater Reliability (IRR)**
Standard	2.73 (0.635)	1.71 (0.701)	2.04 (0.662)	6.47 (1.61)	0.91

Honors	2.77 (0.425)	1.33 (0.550)	2.06 (0.752)	6.15 (1.14)	0.86

The standard deviations for stakeholders and value categories scores were larger for the standard course in the post-assessment, indicating more variability here than in the honors course once again.

Wilcoxon Signed Rank tests corroborate our observations taken from the descriptive statistics. Ultimately, the change in students' scores for two variables were significantly different in each course type (see Table 3).

Table 3: Wilcoxon signed rank test p-values (pre/post)

Course Type	Stakeholders	Value Categories	Value Items	Total
Standard	0.061*	0.073*	0.181	0.023*
Honors	0.001*	0.181	0.040*	0.001*

** Significant at α = 0.10*

The significant change seen in stakeholders scores for both courses indicate the element of our coursework that teaches students to consider all end users/end user groups is effective in helping our students to do just that. However, it is important to note the magnitude of change exhibited by the students in the honors course is greater than that of the students in the standard course where the honors course saw a 1.20 increase in mean stakeholder scores while that of the standard course saw a 1.08 increase. This indicates the course content students receive regarding stakeholder identification is effective in both course sequences but may be more so in the honors course than the standard course. In terms of the other changes seen, students in the standard course exhibited a second significant change in their value categories scores while those in the honors course exhibited theirs in value items. The former couples with the larger standard deviations found in Tables 1 and 2 and begins to illustrate a trend for this course. Lastly, the significant change seen in value items provided by the honors students is supported by the change seen in the mean for this variable (see Table 1 and Table 2) and indicates the course content that covers value identification in the honors course is effective for these students as well.

After identifying significant score differences within course types, we moved towards analyzing for differences across courses to ultimately determine where creating value concepts are delivered, understood, and applied more readily by students. With a null hypothesis of no difference between course types, we rejected the null hypothesis three times and identify those differences as significant (see Table 4).

Table 4: Mann-Whitney U test p-values (across course types)

Pre/Post	Stakeholders	Value Categories	Value Items	Total
Pre	0.019*	0.004*	0.664	0.006*
Post	0.795	0.005*	0.793	0.165

** Significant at α = 0.10*

The statistically different value categories scores in pre and post datasets (Table 4) combined with the greater means found for the standard course (Table 1 and Table 2) and the significant change found via Table 3 collectively show increased performance of students in the standard course regarding value category identification. The final significant difference found was for stakeholder scores between the pre-datasets. These findings couple with the larger jump in the score for mean stakeholders of the honors course (1.22 times greater from pre to post for the honors course and 1.08 times greater for the standard course) and the significant difference between pre/post datasets of this course (see Table 3) to convey identification of more stakeholder groups by honors students.

Discussion

With a recognized need to teach students to identify when, where, and how value is created in various scenarios, we sought out to develop a direct assessment of this skill and apply this within the standard and honors course of our FYEP. We created two similar versions of this tool: one for deployment at the start of an academic semester and one at the end where the former supplies students with a scenario and the latter asks students to identify value related to their semester-long design project. A corresponding rubric to assess student performance was also created and established standards for students to (ideally) reach. The scores assessed to students based on this rubric were then used for our analysis and yielded several findings. We found that students in the standard course exhibited greater mean scores and a wider spread in the pre-assessment, a greater mean score for value categories in the post-assessment, a wider spread of scores in stakeholders and value categories in the post-assessment, and a significant change from pre- to post-assessment in stakeholder and value category identification. Students in the honors course exhibited a significant change from pre- to post-assessment in value item identification, greater mean stakeholder and value item scores in the post-assessment and a greater net growth in these scores. In addition, a significant difference exists between stakeholder and value category pre-scores across course types and a significant difference exists between value category post-scores across course types. These findings have broader implications of how content coverage impacts student understanding and performance of this concept.

The first of these findings with broader implications is student ability to identify value categories in the standard course. As previously noted, these students maintained a higher mean score for value categories, a larger spread of scores obtained, and significant increase from pre to post within the course and when compared to the honors course. The larger mean scores computed for value categories among the standard course students indicates these students successfully identify the value categories KEEN recognizes in its EML. Here, we provide several examples of adequate and inadequate answers as scored by the research team to better situate the types of value categories students provided; Students that listed adequate economic value categories typically referenced the financial gain product developers had and inadequate value categories included time, enjoyment, and professional development.

In addition, we believe the wider spread exhibited by the standard course students does not immediately indicate poorer performance. Recall the three categories KEEN recognizes students should consider as they identify value creation: economic, social, and environmental value. Considering this, we see a larger standard deviation in both pre/post datasets for students in the standard course, which may be due to broader thinking with respect to types of value categories. In other words, we see a divergence in thought from the expected KEEN value categories and a more expansive generative session when identifying them for this population. We attribute the ability of students in the standard course to score significantly higher than those in the honors course to the different course curriculums where students in the standards course, as previously elaborated upon, complete a semester-long and open-ended design project. With this course structure and content in mind, we identify the open-ended aspect of the semester-long design project as the primary reason students identified more value categories and consistently scored higher in that portion of the rubric than students in the honors course. In other words, the course structure and content appear to have an effect on student comprehension of value categories and their ability to think broadly and generate them as needed.

While we expect that the structure and content of ENGR 1182 contributed to the generation of value categories by students in the standard course, we believe the structure and content of the honors course may have attributed to their performance and serves as our second primary finding. As previously noted, students in the honors course exhibited greater post-scores in all rubric categories except for value categories, a greater net increase in scores from pre to post in all rubric categories except for value categories, a smaller spread for each rubric category, and significant changes in their ability to identify stakeholders and the value created for them. Recall the rigidity of this semester-long design project in which clearly defined criteria and final objectives are provided to students prior to beginning their work. Although the ENGR 1282 semester-long design project was more constrained, we suspect it still offered students several benefits. By having pre-determined end users to design for, we expect that students had more time to become situated with their needs and consider them deeply. We believe this allowed students to firmly grasp the concepts behind stakeholders, the importance and ability of designing for their needs, and ultimately contributed to the jump seen in both stakeholder and value item sub-scores honors students exhibited from the pre- to post-data. Since the project was more defined and rigid in terms of scope, we suspect students had more time in the semester to design and develop their escape room solutions for their end users which allowed them to become closely acquainted with the processes that proceed problem identification and framing. Overall, we identify the rigidity of the course structure, the defined criteria, and pre-defined problem statement to provide students more time to master stakeholder identification and the value creation items for each stakeholder.

Conclusion

In this work, we set out to document the Creating Value Direct Assessment where student comprehension of and ability to Create Value, a component of the three C's integral to EML, is assessed. This tool was deployed in the FYEP standard and honors course sequences at the beginning and end of the spring 2021 semester to track student growth in their ability to create value after learning about it and executing it themselves for semester-long design projects. Student responses to the direct assessment were assessed via a rubric with three categories: stakeholders identified, value categories identified, and value items generated for each stakeholder based on the value category being observed.

Overall, students in both the standard and honors course sequences exhibited a net increase in mean scores for each rubric category, indicating course content geared towards the creating value component of EML successfully taught students how to identify stakeholders, value categories related to the problem at hand, and the subsequent value created for each stakeholder. We also found student performance to depend on the design project they completed. Specifically, students in the standard course sequence identified more value categories in both the pre- and post-assessments, exhibited a greater net increase in mean value categories scores earned, and saw a significant change in their ability to identify value categories. We attribute these results to the open-ended design project where every phase of engineering design process requires students to think broadly. Spending much of the semester thinking critically for this project trained students in expansive ideation and transferred to their performance in the post-Creating Value Direct Assessment deployed. Meanwhile, students in the honors course sequence exhibited greater mean scores for the stakeholder and value items rubric categories in the post-assessment, a greater net increase in mean stakeholder and value item scores earned, and a significant change in their ability to identify both stakeholders and value items. We attribute these results to the rigid design project where various components of the engineering design process, such as the problem statement and targeted end users, were already identified prior to working on this project. By having some components of the project predetermined for students, there was more time to work closely on other components of the project such as end users' needs. This transferred to their performance on the post-Creating Value Direct Assessment, namely, their ability to identify stakeholders involved in a project scenario and the value engineers can create for them.

While our findings show student ability to create value depends on how they are exposed to the concept and practice it, we do not argue one method is "better" than the other. Rather, we highlight the ways in which the structure of these courses and their semester-long design projects affects student ability to create value in different ways. Engineering educators can decide which facet(s) of creating value they would like to highlight with their students and have them practice more. In addition, while we used the Creating Value Direct Assessment as a summative assessment in this work, we anticipate it can be used as a formative assessment by educators, especially if they are focusing in on aspects of creating value, such as value item generation, and want to track student growth of this skill more closely. Overall, we find the Creating Value Direct Assessment to offer much value to educators as they track student ability to create value and to students as they learn the vital components of value creation and practice the ability themselves.

Acknowledgements

We would like to acknowledge and thank Meg West of the Kern Family Foundation and Rachel Kajfez [18] for their foundational work and original creation of the Creating Value Direct Assessment and KEEN for their funding of this project in our First-Year Engineering Program.

Appendix

Scenario:
You are on an engineering team and you need to communicate project details with all members of the team. Brainstorm communication applications or services you are familiar with that could be used to accomplish this task. After brainstorming, choose one application or service you would recommend to your team.

Brainstorm					

Recommendation

Instructions:
You must convince your team of the value of your identified communication application or service. To do this, please complete the following tasks. Identify value categories and place them in gray boxes. Identify stakeholders relevant to the product/process/service and place them in red boxes. For each value category and stakeholder pair, identify the value(s) the product/process/service creates for each stakeholder. See the following example.

Example:

	Value Categories	
Stakeholders	Economic	
Application owner		

	Value Categories								
Stakeholders									

Figure 1: Deployed creating value direct assessment (pre-assessment)

Instructions:

You and your team have developed a solution to an identified opportunity. Please provide a brief summary of the identified opportunity and the solution your team has developed in the boxes below.

Identified Opportunity

Solution

Instructions:

You must convince your teaching team of the value of your solution. To do this, please complete the following tasks. Identify value categories and place them in gray boxes. Identify stakeholders relevant to your identified opportunity and solution, place them in red boxes. For each value category and stakeholder pair, identify the value(s) your solution creates for each stakeholder. See the following example.

Example:

	Value Categories	
Stakeholders	Economic	
Application owner	Profits from download cost	

	Value Categories								
Stakeholders									

Figure 2: Deployed creating value direct assessment (post-assessment)

Feature	Accomplished (3)	Emerging (2)	Developing (1)	Inadequate (0)	EMLO
Identification of stakeholders	Multiple stakeholders of chosen communication platform identified with a diverse perspective. (EX: engineering team members, engineering project client, and owner of platform depict a diverse perspective representing views both inside and outside of the team)	Multiple stakeholders of chosen communication platform identified without a diverse perspective. (EX: engineering team member #1 and engineering team member #2 depict a lack of diverse perspective because they are members of the same team)	Few (1 to 2) stakeholders of chosen communication platform identified without a diverse perspective. (EX: engineering team member #1 and engineering team member #2 depict a lack of diverse perspective because they are members of the same team)	No original stakeholders identified (i.e., only example provided).	5c.Describe the features of an identified opportunity.
Identification of value categories	At least the main three value types (social, economic, and environmental) are represented in value categories identified. (EX: society and general population both represent a social value)	Only two of the main three value types (social, economic, and environmental) are represented in value categories identified. (EX: society and general population both represent a social value)	Only one of the main three value types (social, economic, and environmental) are represented in value categories identified. (EX: society and general population both represent a social value)	No value categories were identified.	4c.Identify social values, economic values, and environmental values in common business practices.
Identification of values within each category for each stakeholder	Value(s) identified within each category fully relate the values to the given stakeholder and the proposed communication platform.	Value(s) identified within each category partially relate the values to the given stakeholder and the proposed communication platform.	Value(s) identified within each category does not relate the values to the given stakeholder and the proposed communication platform or the table is incomplete.	Value(s) not provided.	4b.Discuss social values, economic values, and environmental values in relation to a proposed solution to a problem.

Figure 3: Rubric developed to score creating value direct assessments

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