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Application of Entrepreneurial Minded Learning Design Projects to Develop First-Year Engineering Students' Entrepreneurial Mindset*

ALEXANDRA JACKSON
Rowan University, Glassboro, NJ, USA. E-mail: jacksona4@students.rowan.edu

CHERYL A. BODNAR
Rowan University, Glassboro, NJ, USA. E-mail: bodnar@rowan.edu

SCOTT STREINER
University of Pittsburgh, Pittsburgh, PA. E-mail: SCS147@pitt.edu

KEVIN DAHM
Rowan University, Glassboro, NJ, USA. E-mail: dahm@rowan.edu

KAITLIN MALLOUK
Rowan University, Glassboro, NJ, USA. E-mail: mallouk@rowan.edu

BRUCE OESTREICH
Rowan University, Glassboro, NJ, USA. E-mail: oestreich@rowan.edu

The Entrepreneurial Mindset (EM) has become a widely studied topic in the field of engineering education, and is integral in student development and societal advancement. EM interventions into engineering curricula have been shown to positively encourage EM development; however, more research is needed to determine the longitudinal effects of these interventions. This study utilized an indirect assessment through survey responses and a direct assessment through grading rubrics to assess longitudinal outcomes in a first-year engineering program. The survey responses from the beginning and end of the academic year across two first year cohorts (n = 352 paired responses) indicated that students enter their engineering programs believing they already have a strong EM and leave their first year without much change. The direct assessment showed similar results, with both surveys and grading rubrics showing that students struggled the most with Ideation concepts. When analyzing these results in terms of the Kern Entrepreneurial Engineering Network (KEEN) 3Cs (Curiosity, Connections, and Creating Value), it was found that students performed the best in the aspects of projects that focus on Connections, and struggled the most with Creating Value. Overall, engineering students were shown to demonstrate minimal change in their EM over the course of their first-year, indicating the importance of EM integration into courses at all undergraduate levels as well as the significance of studying EM longitudinally. With these findings, educators and researchers can begin to modify first-year curriculum to help students with their ability to generate multiple potential solutions to problems. They can also work with their students to help them understand the value of their designs and the need for this focus as part of the design process.

Keywords: entrepreneurship; first year; project based learning; quantitative methods

1. Introduction

Development of an entrepreneurial mindset (EM) has recently become an accepted and encouraged student outcome within engineering programs [1]. EM education in engineering entices students to adapt to the roles that they will likely need to serve as society continues to change, involving not only technical skills, but also skills in business, management, communication, creativity, and leadership [2]. Integration of EM through projects and courses may help to alter the mindset of many engineering students and better prepare them for the future [3].

There have been a number of studies on the effects of integrating EM into engineering curricula [4–14]. These studies have shown that EM integration can have positive outcomes at any undergraduate level [14], with upper level undergraduates being more likely to apply EM as they are more advanced in their studies [15]. However, EM interventions have most often occurred in the early years of an undergraduate program, as it is important for students to develop an EM foundation before entering classes that require more hands on problem solving [16].

EM ideas have often been implemented through projects, with some programs having opted for semester-long projects [9, 11, 12], and others implementing multiple smaller projects throughout a course [4, 7, 17]. These projects have focused on problem solving [4], programming [10], and design [9, 11]. Besides projects, EM has also been integrated through extracurricular activities [6], films and videos [4], and in-class workshops [18].

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Mindset changes within the first year of undergraduate engineering are often addressed using survey answers from students after their participation in an EM based project [4, 7, 9, 11, 12, 17]. Although this method is beneficial for understanding the student perspective, most of these studies do not combine this in-direct form of assessment with any direct measures of EM development. Many of these studies also do not address the possible changes that may occur in EM over the course of a students' entire first year. This study seeks to answer the following research question; Does *students' entrepreneurial mindset change over the course of a first-year program?*, by using both in-direct (surveys) and direct (rubric-based) assessment strategies to measure if any change occurs in first-year engineering students' EM development through the participation in EM-inspired projects in a first-year design sequence.

2. Literature Review

2.1 Conceptualization of EM

Many studies that have focused on the evaluation of EM within engineering programs have adopted the Kern Entrepreneurial Engineering Network (KEEN)'s 3Cs; Curiosity, Connections, and Creating Value, as the framework for analyzing students' EM [8, 10, 11, 19–24]. KEEN itself was founded by the Kern Family Foundation in 2005 as a mechanism for bringing educators interested in fostering EM in their students together. The 3Cs were developed over a period of 10 years by KEEN with input from academic stakeholders as a way to conceptualize EM and standardize the language of KEEN partner institutions [25]. Although the KEEN 3Cs framework wasn't developed using traditional approaches often observed within engineering education, a framework study done by London et al. [26] showed literature support for the constructs. Curiosity involves the ability of engineers to use their desires to seek out answers, uncovering the information that will help solve large scale engineering issues in the future [8, 10, 20, 21, 27]. Students must also be able to make strong connections between their technical work and the world outside of the classroom. Making connections also involves outside the box thinking, relatability to faculty and other students, and risk assessment [8, 10, 20, 21, 27]. The final of the 3Cs, Creating Value, relates to students' ability to understand the value that their work brings to their customers, and looking at the big picture [8, 10, 20, 21, 27].

2.2 EM Interventions in First-Year Programs

First-year program EM interventions have often occurred within courses that incorporate design and problem solving [8, 9, 11, 17]. These interventions typically involve students being given a real world problem or "customer" that they had to design for, which encouraged entrepreneurially minded thinking and learning [7–9, 11, 12, 19, 20, 28]. In previous studies, the customer was a country or region in need of modern technology [8, 20], other engineering students [9, 12], the environment [12], or the general product market [19]. This project format has involved students working together in groups, being presented with smaller exercises, and being provided with benchmarks to guide project completion [9, 19]. Assessment of student EM development through end-of-project surveys has shown that the projects helped students develop communication skills, their understanding of the design process, and the importance of time management [9, 19]. Other project formats have also been successful, with some interventions having opted to incorporate multiple EM-focused projects over the course of one semester [4, 7, 17]. This multiple-project approach allowed students to experience multiple design challenges and obstacles, which resulted in them feeling more confident in the design process [17].

Although most EM interventions in the first-year have focused on design projects, some faculty have also incorporated different types of exercises to either help further their project or familiarize the students with the value of having an EM. Reid and Ferguson [4] introduced their students to EM with films and videos that highlight the importance of entrepreneurship. Some studies incorporated different lecture modules throughout the course and project to highlight important pieces of the design process [11, 12, 19, 21]. Others incorporated different types of skills such as CAD and programming [10, 17]. All of these types of interventions showed significant improvements in students' curiosity and creativity, whether it was through their high grades on projects [10], feedback through reflection [8], or survey responses from the students [11, 19].

EM has also been implemented into extracurricular activities and events. Yasuhara et al.'s [15] study suggests a correlation between student involvement in both engineering and non-engineering extracurricular activities and entrepreneurial attributes. Students were able to develop skills such as networking and community, two key entrepreneurial skills that are more difficult to strengthen in strictly course-based learning.

2.3 Assessment of Entrepreneurial Mindset Development in First Year Engineering

EM development within first year engineering students is commonly assessed on a project-to-project basis using surveys or questionnaires answered by the students [7, 9, 11, 12, 19]. These are most often presented after the completion of a project [9, 12, 19], and in some cases presented before and after a project to determine possible mindset changes [7, 11, 21]. In other studies, direct assessments such as project or course grades are used to measure changes in EM [20, 21]. A common thread is that most of the work that has been done on first-year EM development typically only involves the assessment of students using one measure (either in-direct or direct) and not the combination of both approaches. In the few instances where studies do consider both in-direct and direct assessment, they do not typically discuss if there exists any relationship between the in-direct and direct assessments performed [9, 19]. For example, Jensen and Schlegel [9] discuss student performance on project presentations and reports, but do not consider how students' grades may have contributed to their answers on the provided questionnaire.

There have been a few studies however, that have monitored students' EM development over the course of the entire first-year rather than just a single project [4, 17]. Reid and Ferguson's [4] study collected data from surveys using the Dweck mindset instrument to assess their EM before the introduction of EM concepts, then after a project involving EM, and then again at the end of their first year. This study found that engineering students tended to lean more towards a fixed mindset and away from an EM throughout the year, which was believed to have been caused by the students' courses such as calculus and physics that do not allow for much creativity [4, 17]. Riofrio's [17] study incorporated multiple EM projects across two semesters, surveying students on their perceived skills at the beginning and end. The surveys consisted of 17 statements focused on a student's abilities, in which students would rate their believed competence in that area on a scale from 1 to 4. The students who completed the EM projects were compared to a control group. Both groups showed an increase in entrepreneurial skills such as designing, prototyping, and teamwork throughout one year, but the group exposed to EM concepts showed net gains much higher than the control group [17]. While some of this increase might be attributable to students simply having more exposure to EM terminology, the results still suggest there is opportunity to improve students' EM through projects in the first year.

Although the prior studies discuss how curricula or projects integrating EM can lead to changes in students' EM over the first year of their engineering program [4, 17], more research is still needed in this area. One key point of observation is the reliance primarily on in-direct assessment strategies such as surveys that may not provide the full picture of how EM develops during a first-year program. This study seeks to address this gap in the research by studying whether first-year engineering students' EM changes as a function of participation in EM-based projects through both in-direct (surveys) and direct (rubric-based) assessments over the course of the entire first year.

3. Methodology

3.1 Study Design

First-year engineering students at a research university on the east coast participated in this study during academic years 2018–2019 and 2019–2020. The engineering curriculum includes an engineering design class in each semester. The design classes focus on developing introductory engineering skills such as applications of engineering, product development, engineering design, basic CAD and programming techniques, and statistics. Students participated in multiple EM-focused projects throughout their two semesters with an emphasis on hands-on design and problem solving. Although there were three projects conducted throughout the two courses that focused on encouraging the growth of EM in the students, this study will only focus on the two projects that all students completed, which are elaborated on in further detail below.

- <u>Product Archaeology/Sustainable Engineering (First Semester)</u>: This project concentrated on the life cycle of a product, encouraging students to understand the design process while thinking more broadly about the global, societal, economic, and environmental contexts of the product [29, 30]. Student teams focused on one of eight product categories: flashlights, speakers, shampoo, glue, mugs and cups, paper towels, diapers, and tennis balls. Teams of students followed the four phases of product archaeology, starting with research on the impacts of their product, then performing experiments on the product to determine its usefulness and ability to withstand certain conditions, and finally analyzing their results and drawing conclusions about their product. The end of project deliverables included both a final report and a presentation that encompassed their findings. The project, known as Product Archaeology in Fall 2017 and Fall 2018, had its title changed to Sustainable Engineering in Fall 2019 and its focus shifted from global, societal, economic, and environmental impacts to People, Planet, and Prosperity. The terminology related to archeological digs was also removed. This was done to emphasize the contexts related to sustainability, which has become a critical facet of how engineering is practiced. Despite the title change, the core components of the project that emphasized EM were left intact.

- Universal Design (Second Semester): Teams of students were instructed to create a child's toy that might be found in a Happy Meal, while following the seven principles of universal design: equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use [31]. Toys had to have at least two functions, and prototypes had to be created using CAD software and 3D printing. Once again, students were encouraged to reflect on their design decisions throughout the project. They also had the opportunity to take in customer feedback and focus on refining their initial idea into a functioning final product. The deliverables for this project also included a final report and video presentation.

3.2 Data Collection

Both in-direct assessment in the form of survey responses (n = 352 across two years), and direct assessments in the form of rubric-based project performance (n = 150 teams in the Product Archaeology/Sustainable Engineering projects across both years and n = 123 teams in the Universal Design project across both years), were collected from students over the 2018–2019 and 2019–2020 academic years. Proper human subjects' approval was obtained prior to data collection (IRB#Pro2018000048).

3.2.1 Student Entrepreneurial Mindset Assessment (ESEMA) Survey

The survey instrument used was the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) and the surveys were administered to the students at the beginning of the fall semester and at the end of the spring semester, respectively [22, 32]. The ESEMA focuses on six key attributes relating to EM: altruism, empathy, help seeking, ideation, interest, and open mindedness. The survey was developed by Brunhaver et al. [22] and has shown to exhibit evidence of validity and reliability. The survey instrument also links back to the 3Cs EM framework developed by the Kern Entrepreneurial Engineering Network (KEEN) as shown in Table 1. Each construct has at least three items, with the most number of items being Ideation with 11. More information on the attributes can be found in Table 1. Students answer each item on a scale from 1 to 5, with 1 meaning they strongly disagree with the statement, and 5 meaning they strongly identify with the statement. A complete copy of the survey instrument can be found in Appendix A-1. There were 175 paired responses obtained in 2018–19, and 177 paired responses obtained in 2019/20.

3.2.2 Rubric Development and Application

To facilitate direct assessment of student performance on the projects, a set of grading rubrics was devised for each project based upon the 3Cs EM framework developed by KEEN. The complete rubrics are shown in Appendix A-2 for the Sustainable Engineering project and A-3 for the Universal Design project. Each rubric was used to assess 8–10 aspects of written reports and/or oral presentations associated with the projects. These 8–10 aspects can be broadly divided into technical outcomes and effective communication outcomes. Each of the technical outcomes was regarded as an expression of one of the three Cs. For example, in the Universal

Table 1. Attributes of the ESEMA [22, 32]

Attribute	Definition	3Cs Correlation	Number of Items	Example
Altruism	Desire to make a positive impact, wanting to change the world for the better.	Creating Value	4	It is important to me to contribute to the good of society.
Empathy	Ability to feel for others, understanding of others' opinions and viewpoints.	Curiosity	3	I can easily tune into how someone else feels.
Help Seeking	Understanding when to ask for help, acceptance of needing help.	Connections	5	I am comfortable asking others for help.
Ideation	Interest in challenging accepted solutions, looking for new ways to solve problems.	Creating Value	11	I tend to work on problems that do not have clear solutions.
Interest	Wanting to know more about a variety of topics.	Curiosity	3	I participate in a variety of activities.
Open Mindedness	Looking for new ideas from others, accepting a variety of opinions.	Connections	8	I appreciate the value that people with different strengths bring to a team.

Design project, the four technical outcomes included in the rubric and their relationship with the 3Cs is as follows:

- *Scenario*: Evaluation of reports based on the students' understanding of the product and the customer, and how their understanding informs the design. This was considered an expression of Curiosity, as a successful team would further explore the interests of the customer, as well as the perceived need that the product is intended to fill.
- *Ideation and Design Process*: Evaluation based on team brainstorming efforts that led to their design decisions. It was noted that one of the failure modes in such a project is becoming enamored of a specific idea and pursuing it without considering alternatives. To carry out a disciplined design process that includes generating a list of possible approaches, critically evaluating the merits of each approach, and using objective criteria to make decisions, a student team is required to make meaningful Connections.
- *Product Prototype*: Evaluation based on the product produced and how the students described it. This aspect of the team's project was also mapped to Connections, as it brings together the "description of the prototype, how it was assembled, how it does and does not align with the original product criteria, and what was learned from the process".
- *Final Design and Recommendations*: Evaluation based on the final product design and how it was presented by the students, as well as what the students propose to be the method of manufacturing this product. The rubrics specify that an excellent report will present "a clear and complete final proposed design of the product that reflects a sound and thoughtful design process and is informed by lessons learned in the prototype stage. The proposed manufacturing method is based on a sound economic analysis and also addresses practical considerations", all of which was considered a reflection of a team's ability to Create Value.

The rubrics for technical outcomes had a dual role- they were used to evaluate the quality of the work submitted by the individual teams, and they were also used for a holistic assessment of the first year students' ability to express an EM.

Effective communication is an essential skill for engineering practice and developing communication skills was among the goals of these projects. Thus, even though good writing is not considered an expression of EM specifically, a rubric used for grading the reports also needed to reflect the quality of the writing. Consequently, rubrics were also developed for these outcomes related to effective communication:

- Organization.
- Clarity and Presentation.
- Abstract or Executive Summary.
- Figures, Tables and Graphics.

A similar mapping approach was completed for the Sustainable Engineering project, in which the technical outcomes were again developed and used as indicators of the 3Cs for each team's final report/presentation.

The rubrics were written such that for each outcome, a rater would assign a rating on a scale of 1–5, with 5 representing outstanding performance, 3 representing minimally acceptable performance, and 1 representing failing performance, or unacceptable. For example, the rubric ratings for Ideation and Design Process in the Universal Design project were given the following descriptions:

> 5: The report demonstrates a brainstorming process in which numerous ideas received serious consideration, and specific, logical criteria were used to choose between alternatives and make design decisions.
> 3: The report communicates a brainstorming process in which multiple ideas were considered and gives some rationale for design decisions, but some decisions have an unclear basis, and/or some relevant issues apparently didn't get considered.
> 1: The report gives little evidence of a brainstorming process or a design process. It is completely unclear how the team arrived at the final product design.

Although the ratings for 2 and 4 were not given detailed descriptions, they were understood as a blend between the criterion for 1 and 3 and 3 and 5 respectively. Ratings of 4 proved to be particularly common, as readers frequently determined that reports demonstrated a level of performance in between 3 and 5. This general structure for a rubric, with a 5-point scale and written descriptors acting as anchors for ratings of 1, 3 and 5, has been used previously at the authors' institution [33–34].

The data collected using the rubrics informed the assignment of grades to individual reports and presentations, though the specific weighting of each of the 8–10 individual elements in determining the final grade was left to the discretion of the instructor.

3.3 Data Analysis

In an effort to obtain a holistic view of students' EM development as part of their first-year experience, the students' survey answers and rubric results were analyzed.

3.3.1 *Survey Analysis*

Means were calculated for each participant within each construct, which were then used to calculate the overall mean for the construct at the start and end of each academic year as shown in Appendix A-4 and A-5 [35]. IBM SPSS 26 was used to perform paired t-tests on the fall and spring responses for each question and construct to determine if any statistically significant differences existed. The effect sizes using Glass' Delta, which is a way to measure statistical significance between two populations when their sample sizes are equivalent, but their standard deviations are different, were also calculated for each construct [36]. To measure the reliability of the data, Cronbach's alpha was calculated for each construct for the fall and spring data collection. Values obtained ranged from 0.768 to 0.950, indicating acceptable reliability [37].

3.3.2 *Rubric Analysis*

Because both rubrics used a standardized 1–5 scale, with 5 = outstanding and 1 = unacceptable, the aggregated numerical ratings can be readily interpreted as a demonstration of the cohort's performance in relation to the entrepreneurial mindset. Similarly to the survey analysis, student grades for their final reports were averaged for each section of the rubric for both projects. These were then compared to each of their mapped 3Cs to determine the overall EM of students upon the completion of their projects.

4. Results and Discussion

4.1 *ESEMA Survey Assessment*

The purpose of this study is to answer the question: *Does students' entrepreneurial mindset change over*

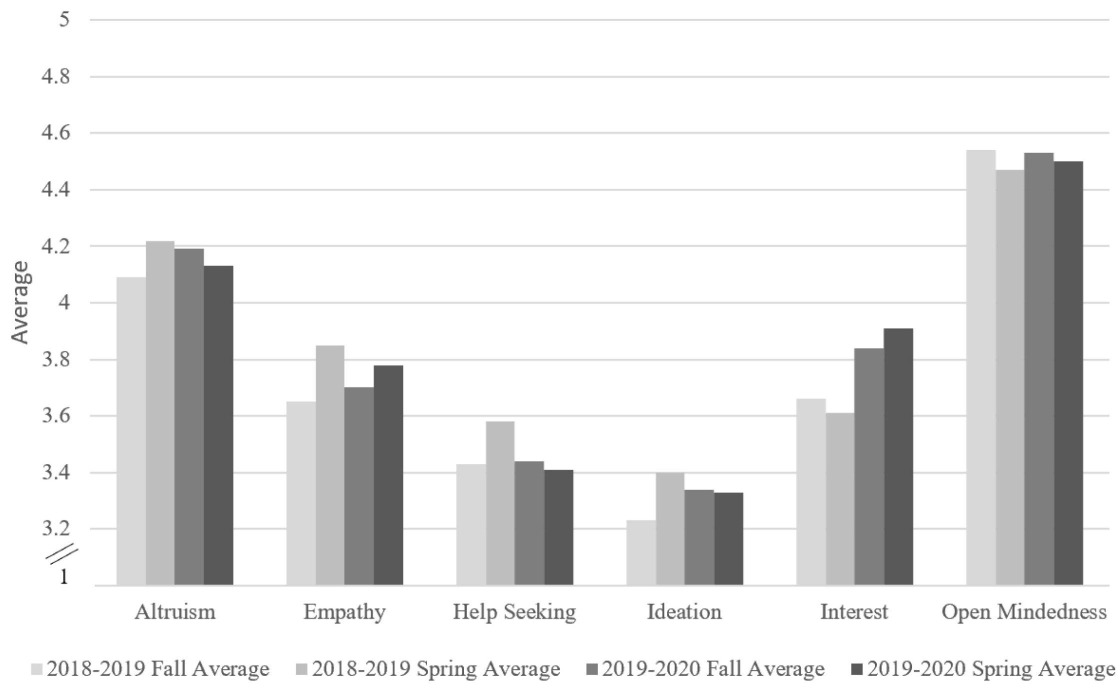

Fig. 1. ESEMA Survey Total Averages for each Construct.

Table 2. P-Scores and Glass' Delta Effect Sizes of ESEMA Constructs

	2018–2019		**2019–2020**	
	P-Score	**Effect Size (Glass' Delta)**	**P-Score**	**Effect Size (Glass' Delta)**
Altruism	0.006	0.152	0.223	0.076
Empathy	0.001	0.203	0.242	0.071
Help Seeking	0.007	0.145	0.551	0.030
Ideation	0.000	0.160	0.701	0.087
Interest	0.541	0.045	0.388	0.069
Open Mindedness	0.098	0.110	0.511	0.048

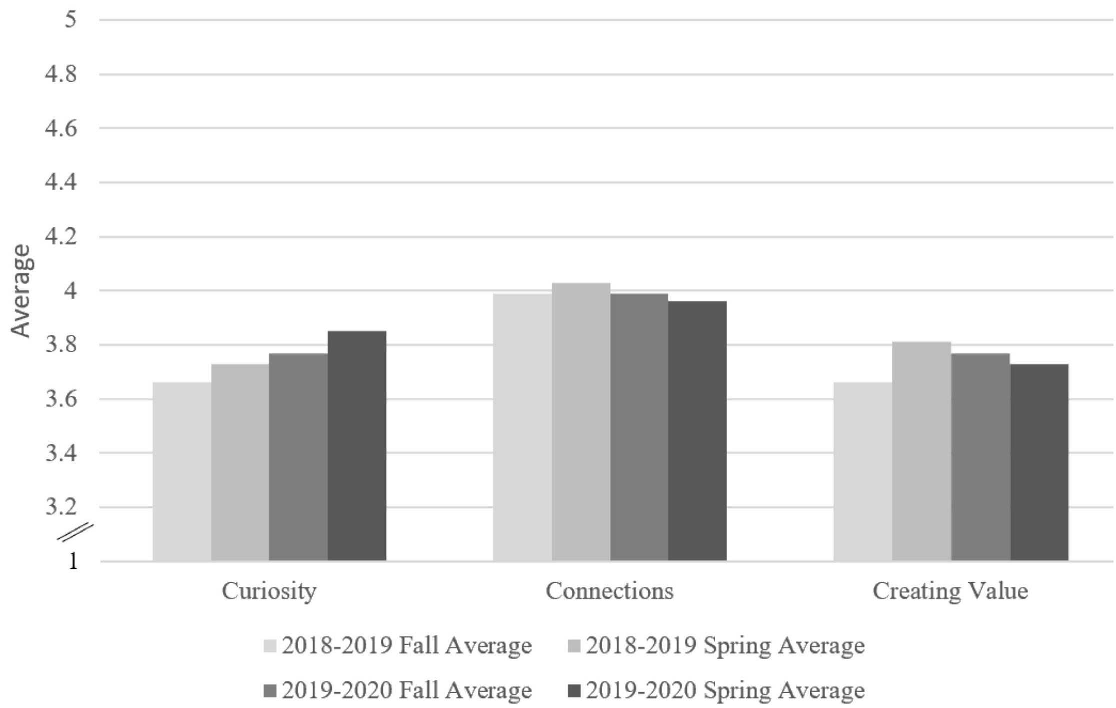

Fig. 2. ESEMA Totals in Terms of the 3Cs.

the course of a first year program? The averages of the ESEMA survey responses from the students across two years are presented in Fig. 1. The results of the statistical analysis are shown in Table 2.

As shown in Table 2, there was little change in students' entrepreneurial mindset over the course of their first-year program with only slight increases or decreases observed in constructs between fall and spring surveys. According to McLeod [38], effect sizes are considered large if they are over 0.8, therefore although we observed statistically significant changes in 2018/19 the effect of the intervention itself was small. There is no significant difference between the fall and spring data within the second year. Students across both years scored themselves similarly for each construct, with the highest average for both fall and spring surveys being Open Mindedness (4.54 and 4.47 in 2018/19 and 4.53 and 4.50 in 2019/20), followed by Altruism (4.09 and 4.22 in 2018/19 and 4.19 and 4.13 in 2019/20). College students have previously rated themselves highly in open mindedness and altruism related areas [37], as these are learned skills that are being stressed in EM curriculums through global awareness and designing for specific customers with various needs [19, 20, 22]. The Sustainability Project focused on People, Planet, and Prosperity, three concepts that encourage students to become environmentally aware, leading to altruism and open mindedness. The Universal Design project was aimed towards design for a specific customer, which also encouraged altruism and open mindedness in students. The lowest averages for both years for both the fall and spring surveys was Ideation (3.23 and 3.40 in 2018/19 and 3.34 and 3.33 in 2019/20). According to Daly et al. [40], ideation is difficult for inexperienced engineers and students, as they tend to focus on one main concept rather than generating ideas that would help fix the problem they are trying to solve.

In an effort to gain a broader understanding of students' entrepreneurial mindset development, these constructs were reframed in terms of the 3Cs EM framework, and averages for Curiosity, Connections, and Creating Value were found for each academic year as shown in Fig. 2.

Fig. 2 shows that students do not seem to show much change from the beginning to the end of their first-year program with regards to curiosity, connections, and creating value. Students scored themselves the highest in connections at all time points, which was likely influenced by their high values related to Open Mindedness. Since students tend to work in teams for projects focused on entrepreneurial mindset development, they are encouraged to develop solid communication skills with their teams, which can lead to open mindedness and help seeking behaviors [8]. Their higher ranking in Connections could also relate to Bernal et al.'s [7] study, in which they reported that students tend to rank themselves highly in skills related to technical

Table 3. Product Archaeology (Fall 2018)/Sustainable Engineering (Fall 2019) Rubric Results

	Fall 2018		Fall 2019	
	Average	**StDev**	**Average**	**StDev**
Curiosity (Research)	4.16	1.16	4.23	0.94
Curiosity (Sources)	4.36	1.08	4.03	1.06
Curiosity (Research Questions)	4.36	0.94	4.07	0.90
Connections (Technical Work)	4.60	0.82	4.40	0.91
Creating Value (Analysis)	4.15	1.23	3.82	1.04

Table 4. Universal Design Rubric Results

	Spring 2019		Spring 2020	
	Average	**StDev**	**Average**	**StDev**
Curiosity (Scenario)	4.22	0.86	4.31	0.92
Connections (Ideation and Design Process)	3.96	0.97	4.02	0.99
Connections (Prototype)	4.37	0.83	4.39	0.72
Creating Value (Final Design)	4.16	0.81	4.07	0.92

work [7], which is an aspect that studies often relate to making Connections [8, 23].

4.2 Rubric Grading Assessment

To further understand these self-reported differences in EM, we assessed students' direct development of EM based on their performance on two EM projects over the course of a first year program. Table 3 shows the rubric results from the Product Archaeology/Sustainable Engineering project, in which students performed the best in the Technical Work aspect, which was correlated to Connections.

As shown in Table 4, students who completed the Universal Design project struggle with the Ideation and Design Process portion of Connections, but excel in producing their prototype.

Both of the tables present similar results to the survey where students tended to perform highly in criteria relating to making Connections. Morano, Henson, and Cole [24] found that first year engineering students scored higher in Connections than either curiosity or creating value. They also found that students from the Sophomore and Senior levels scored significantly higher than first-year students in the Curiosity and Creating Value categories. This result was attributed to students having more EM interventions as they reach higher class levels.

However, it was observed that the Ideation and Design process was a struggle for students in both semesters of the Universal Design project. This is similar to the survey results, in which students rated themselves lower in Ideation than in any other construct. Bernal et al. [7] observed that students often struggle to make overall connections between lecture and earlier project experiences and its relevance to their design, something that is extremely important in the Ideation and Design Process. Students also spend a lot of time in the design process over analyzing the problem rather than actually coming up with ideas on how to solve it [40].

To better understand student performance in each of the 3Cs across both projects, an overall analysis of the 3Cs was performed for the rubrics across both years, as shown in Table 5. This analysis groups the Research, Sources, and Research Questions sections of the rubric from Sustainable Engineering with the Scenario section of Universal Design to form Curiosity. It then groups the Technical Work section from Sustainable Engineering with the Ideation and Design and Prototype processes from the Universal Design project to form Connections. Finally, the Analysis rubric section from Sustainable Engineering is grouped with the Final Design section from Universal Design to form Creating Value.

Table 5 demonstrates that Connections had the highest average for Product Archaeology / Sustain-

Table 5. 3Cs Rubrics Aggregated Data for Fall and Spring

	Product Archaeology/Sustainable Engineering (Fall 2018 & Fall 2019)		Universal Design (Spring 2019 & Spring 2020)	
	Average	**StDev**	**Average**	**StDev**
Curiosity	4.20	1.02	4.26	0.88
Connections	4.50	0.86	4.18	0.91
Creating Value	3.99	1.15	4.12	0.85

able Engineering, but Curiosity was the highest for Universal Design. As previously discussed, the Ideation and Design process that was included in the Universal Design process is where students struggled the most, and that brought down the overall average of this construct. Without the Ideation and Design section, Connections would have an average of 4.38, which would bring Connections up to the highest average. However, even with this modification, Connections is the only C in which Universal Design had a lower average than Product Archaeology / Sustainable Engineering. This could be attributed to Product Archaeology/Sustainable Engineering projects focusing on an existing product rather than students designing their own, which is an area where engineering students struggle [40]. In general, the higher Universal Design averages could link to the timing of the project, as this project was assigned within the second semester, so students would have already been exposed to one entire semester of EM focus.

These results also show that Creating Value has the lowest average across both projects. According to Bernal et al. [7], students may view the 3Cs as a sequence, in which one C is to be focused on at one time. The technical and experimental work can take a major focus in these early projects, which could lead to students performing better in Connections. Since Creating Value is often the final piece of the project, students spend less time focusing on these aspects, causing them not to succeed as strongly in this aspect. That being said, Creating Value did show a slight increase from Product Archaeology/ Sustainable Engineering to Universal Design (3.99 to 4.12). Bernal et al.'s [7] study showed that students had very positive outcomes in terms of Creating Value when they were presented with a specific customer to design for. In the Universal Design project, the students were told to design a toy that could be used by children, so they would have been able to understand an actual impact that the project might make on a real customer.

While the rubrics developed as part of this research are specific to the EM projects employed at the authors' university, the results demonstrate how the 3C EM framework can be applied when designing project rubrics to better understand students' EM development. Specifically, the rubric analysis helps identify the areas where students excel on projects in regards to EM and where improvement or further instruction is needed.

Overall, students seemed to show little change in EM development over their first year as shown by both the survey and rubric results. This result is supported by other work in the literature that found students didn't show change in EM development during their first-year because many of their courses are not EM based or incorporate few projects that promote creativity [4]. Literature has shown that students tend to change their overall perceptions of the entrepreneurship field the more that they are exposed to EM interventions [41], so considering most students' only experience with EM has taken place within this first-year design course, it may not be enough to encourage significant development at this stage.

5. Limitations

Three limitations of this work should be taken into consideration. The post data for the 2019–2020 year was taken during the COVID-19 pandemic, in which students were completing their semester online. This may have affected their ESEMA survey responses, causing their perception of their EM to decrease. Additionally, the results were obtained from only a single university context. As such, they would be influenced by the institutional environment and types of projects that were included as part of the first-year program. Finally, there was no process to establish interrater reliability on the rubric grading for the projects, though the faculty members running the project are familiar with the projects and their associated learning outcomes. Nevertheless, future work will include a more systematic process to ensure reliable assessment of the rubrics across the faculty team.

6. Conclusion

The engineering student entrepreneurial mindset is often encouraged by implementing projects that focus on the 3Cs: Curiosity, Connections, and Creating Value. This study's direct and in-direct assessments of EM have indicated various strengths and weaknesses. Students tend to excel in making Connections through their technical and experimental projects, working in a team, and presenting design ideas. Students also succeed when presented with opportunities that require them to be open minded and reflect on how they would be able to impact society. However, students struggled with ideation and the physical design process, as engineering students have a tendency to overanalyze and struggle to see the overall need for the design. Students also struggled more with Creating Value than the other two Cs discussed. It was determined that students may not be focusing as strongly on Creating Value, as it is often associated with the final piece of the project, in which students are more rushed to finish. However, they seemed to have done well in this category when provided with an actual customer who would be impacted by their work.

Even with these results focused on the 3Cs, there was not found to be significant changes in engineering student EM development across the first year of their program. Considering the limited time spent on EM interventions, it is expected that these students will be more likely to show changes in EM development after interventions occurring over longer time periods. For this reason, it is important that students be provided with continual exposure to EM throughout their coursework. This can include integrating EM into capstone engineering courses, general engineering courses, and creating projects revolving around EM concepts throughout the entirety of the undergraduate curriculum. As a future research study, it would be beneficial to explore how these students progress in EM development throughout their degree program to determine if changes to EM over longer periods of time correlate to the number of EM interventions.

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APPENDIX

Table A-1: The ESEMA Scale (reproduced with permission [32])

Never or only rarely true of me	Sometimes true of me	True of me about half the time	Frequently true of me	Always or almost always true of me
1	2	3	4	5

As you answer the following questions, think about your past experiences. Please respond to each question by indicating how true each of the following statements are to you.

Factor and Item Number	Statements
Altruism	
Item 1	I am driven to do things that improve the lives of others
Item 2	I care about solving problems important to society
Item 3	It is important to me to contribute to the good of society
Item 4	I believe it is important I do things that fix problems in the world
Empathy	
Item 1	Other people tell me I am good at understanding their feelings
Item 2	I can easily tune into how someone else feels
Item 3	I am good at predicting how someone will feel

Help Seeking	
Item 1	I ask for help when I need it
Item 2	I am comfortable asking others for help
Item 3	If I am struggling on a task, I ask for help
Item 4	I seek outside support when I am stuck
Item 5	I know when I need to ask for help
Ideation	
Item 1	I tend to work on problems that do not have clear solutions
Item 2	I typically develop new ideas by improving existing solutions
Item 3	I would rather work with what is unfamiliar than what is familiar
Item 4	I like to think of wild and crazy ideas
Item 5	I prefer tasks that are not well-defined
Item 6	I like to reimagine existing ideas
Item 7	Other people tell me I am good at thinking outside the box
Item 8	I am likely to change directions on a project even after putting forth a lot of effort
Item 9	I tend to embrace change
Item 10	I prefer to challenge adopted solutions rather than blindly accept them
Item 11	I like to think about ways to improve accepted solutions
Interest	
Item 1	I tend to get involved in a variety of activities
Item 2	I participate in a wide range of activities
Item 3	I enjoy being involved in a variety of activities
Open Mindedness	
Item 1	I recognize that people with different backgrounds from my own might have better ideas than I do
Item 2	I am willing to compromise if another idea seems better than my own
Item 3	I recognize the importance of others fields even if I don't know much about them
Item 4	I am willing to learn from others who have different areas of expertise
Item 5	I appreciate the value that different kinds of knowledge can bring to a project
Item 6	I am willing to update my plans in response to new information
Item 7	I appreciate the value that individuals with different strengths bring to a team
Item 8	I am willing to consider an idea put forth by someone with a different background than my own

Table A-2: Rubric for Sustainable Engineering Final Reports

Category	Mapped 3C	5 (Excellent)	3 (Acceptable)	1 (Unacceptable)
Organization	n/a	Report is extremely well organized. Every section has a descriptive heading and a clear and explicitly stated purpose. Cross-referencing to figures and appendices is used effectively wherever it is needed.	Report is divided into reasonable sections but some material may be repeated or oddly placed. Cross- referencing to figures/ appendices is generally used but sometimes missing or haphazard.	The report shows little or no organization. Reader has to expend unreasonable effort to figure out what is going on.
Clarity and Presentation	n/a	Report is written with great clarity and is easy to read and understand. Report is concise and free of grammatical and spelling errors.	Report conveys information adequately, but is at times unclear, wordy and/or unfocused. The number of instances of grammar and/or spelling errors is noticeable but not outrageous.	The report fails to convey information clearly. It has so many problems with ambiguous phrasings, lack of focus, grammar, and/or spelling, that the reader can't follow it.
Abstract/Executive Summary	n/a	Summary stands on its own and provides a compelling overview that includes statement of objectives, provides quantitative results, and summarizes conclusions and recommendations.	Summary is generally adequate but misses some pertinent information.	Summary doesn't address fundamental questions about project, such as objectives, approaches, conclusions and recommendations.

Figures, Tables, Graphics	n/a	Illustrations, figures and tables are clear and informative, well positioned within report, and captioned in sufficient detail to stand on their own.	All needed illustrations, figures, and tables are present and contain useful information, but sometimes lack clarity and/ or aren't well described in the captions.	Illustrations, figures and tables are missing or incomprehensible. Captions are missing or haphazard.
Historical Research-Information	Curiosity	The report provides a detailed history of the product that includes an insightful discussion of innovations and trade-offs within the design of the product.	The report provides an adequate history of the product. Coverage of innovations, sub-designs and trade-offs between them is accurate but sparse.	The report provides little or no historical insight. The reader has no information beyond what is obvious to a typical user of the product.
Historical Research-Sources	Curiosity	Several authoritative sources are used, and attribution of information to sources is clear and follows guidelines.	Multiple sources are listed but there is a possible concern (over reliance on a single source, role of some sources isn't clear, one source is of dubious merit, etc.). Attribution of information to sources is generally done, but source of some information is unclear and/or attribution doesn't always follow guidelines.	There is a fundamental concern about the research, such as failure to use authoritative sources, unattributed questions, no research beyond sources provided by the instructor, etc.
Research Question	Curiosity	The report explores one or more substantial and significant research questions. Answering the research question will shed light on a key aspect of the product's function and/or value.	Report presents one or more research questions, but they are relatively uninspired or low-impact questions.	Report does not present a clear research question.
Experimental and Technical Work	Connections	The experimental plan is well thought out and ideally suited to answering the research question(s). All possible information is obtained from the experiments.	The experimental plan produces some relevant data but isn't optimal. Some useful information that could have been obtained from the experiments either was not collected or is not reported.	The experimental plan is fundamentally flawed in either its design or its execution. The research question cannot be answered using the given data.
Analysis	Creating Value	The report presents an excellent analysis of global, societal, economic and environmental issues. The discussion is thoroughly informed by both historical research and lab work.	The report presents an acceptable analysis of global, societal, economic and environmental issues. The discussion is accurate but often doesn't progress beyond broad and obvious statements. Historical research and/or lab results are used in a meaningful way but there is more that could be said.	The discussion of global, societal, economic and environmental issues is fundamentally flawed. Some of the components are missing completely or are discussed in a way that is inconsistent with the historical research and/or lab results.

Table A-3: Rubric for Universal Design Final Reports

Category	Mapped 3C	5 (Excellent)	3 (Acceptable)	1 (Unacceptable)
Organization	n/a	Report is extremely well organized. Every section has a descriptive heading and a clear and explicitly stated purpose. Cross-referencing to figures and appendices is used effectively wherever it is needed.	Report is divided into reasonable sections but some material may be repeated or oddly placed. Cross-referencing to figures/ appendices is generally used but sometimes missing or haphazard.	The report shows little or no organization. Reader has to expend unreasonable effort to figure out what is going on.

Clarity and Presentation	n/a	Report is written with great clarity and is easy to read and understand. Report is concise and free of grammatical and spelling errors.	Report conveys information adequately, but is at times unclear, wordy and/or unfocused. The number of instances of grammar and/or spelling errors is noticeable but not outrageous.	The report fails to convey information clearly. It has so many problems with ambiguous phrasings, lack of focus, grammar, and/or spelling, that the reader can't follow it.
Abstract/Summary	n/a	Summary stands on its own and provides a compelling overview that includes statement of objectives, provides quantitative results, and summarizes conclusions and recommendations.	Summary is generally adequate but misses some pertinent information.	Summary doesn't address fundamental questions about project, such as objectives, approaches, conclusions and recommendations.
Figures, Tables, Graphics	n/a	Illustrations, figures and tables are clear and informative, well positioned within report, and captioned in sufficient detail to stand on their own.	All needed illustrations, figures, and tables are present and contain useful information, but sometimes lack clarity and/or aren't well described in the captions.	Illustrations, figures and tables are missing or incomprehensible. Captions are missing or haphazard.
Scenario	Curiosity	The report gives a thorough and concise description of the problem to be solved. It demonstrates an understanding of both the envisioned role of the product and the customer, and how this will inform the design.	The report demonstrates a reasonable understanding of the product and the customer and how these inform the design process, but the discussion isn't as clear, thorough, and/or concise as it could be.	The report fundamentally misunderstands or misrepresents the premise of the project.
Ideation and Design Process	Connections	The report demonstrates a brainstorming process in which numerous ideas received serious consideration, and specific, logical criteria were used to choose between alternatives and make design decisions.	The report communicates a brainstorming process in which multiple ideas were considered and gives some rationale for design decisions, but some decisions have an unclear basis and/or some relevant issues apparently didn't get considered.	The report gives little evidence of a brainstorming process or a design process. It is completely unclear how the team arrived at the final product design.
Product Prototype	Connections	The report gives a concise and thorough description of the prototype, how it was assembled, how it does and does not align with the original product criteria, and what was learned from the process of making a prototype. Pictures and graphics are used effectively.	The report describes the prototype in a moderately effective way, but some details on the prototype and/or how it was assembled are not clear. There is some discussion of how the prototype does and does not align with the original product criteria. Pictures and graphics are included and are relevant but could be more helpful.	The description of the prototype and its assembly is incoherent, and there is no insight into how the prototype compares to the original product criteria.
Final Design and Recommendations	Creating Value	The report provides a clear and complete "final" proposed design of the product that reflects sound and thoughtful design process and is informed by lessons learned in the prototype stage. The proposed manufacturing method is based on a sound economic analysis and also addresses practical considerations.	The report provides some logical recommendations regarding the specifications for the product and a proposed manufacturing method However, some aspects of the design or manufacturing are either not fully specified or are based on a decision-making process that is unclear.	The specifications for the product and its manufacturing are deficient either because vital information is missing, because the design or analysis have fundamental errors, or because the product fails to meet the stated needs.

Table A-4: ESEMA Survey Total Averages and Standard Deviations across Two Years

	2018–2019				2019–2020			
	Fall Avg	Fall StDev	Spring Avg	Spring StDev	Fall Avg	Fall StDev	Spring Avg	Spring StDev
Altruism	4.09	0.86	4.22	0.79	4.19	0.79	4.13	0.80
Empathy	3.65	0.99	3.85	0.95	3.70	0.98	3.78	0.95
Help Seeking	3.43	1.04	3.58	1.05	3.44	1.01	3.41	1.01
Ideation	3.23	1.06	3.40	1.00	3.34	1.03	3.33	1.01
Interest	3.66	1.11	3.61	1.04	3.84	1.02	3.91	0.96
Open Mindedness	4.54	0.64	4.47	0.66	4.53	0.63	4.50	0.70

Table A-5: ESEMA Survey Totals in terms of the 3Cs Across Two Years

	2018–2019				2019–2020			
	Fall Avg	Fall StDev	Spring Avg	Spring StDev	Fall Avg	Fall StDev	Spring Avg	Spring StDev
Curiosity (Empathy, Interest)	3.66	1.05	3.73	1.00	3.77	1.00	3.85	0.96
Connections (Help Seeking, Open Mindedness)	3.99	0.98	4.03	0.99	3.99	0.96	3.96	0.99
Creating Value (Altruism, Ideation)	3.66	1.08	3.81	1.01	3.77	1.04	3.73	1.02

Alexandra Jackson is a first-year PhD student at Rowan University working on a dissertation with a concentration in Engineering Education. She just recently completed her bachelor's degree in Electrical and Computer Engineering at Rowan University. Since beginning research in the Engineering Education field, Alexandra has developed interests in entrepreneurial mindset development and assessment of both students and faculty, and plans to continue this research throughout her PhD.

Cheryl A Bodnar is an Associate Professor in the Experiential Engineering Education Department at Rowan University. She also serves as the Assistant Director of Faculty Programs for the Rowan Center of Innovation and Entrepreneurship (RCIE). Her research interests relate to the incorporation of active learning techniques such as game-based learning in undergraduate classes as well as integration of innovation and entrepreneurship into the engineering curriculum. In particular, she is interested in the impact that these tools can have on student perception of the classroom environment, motivation, and learning outcomes.

Scott Streiner is an Assistant Professor in the First-Year Engineering Program and the Engineering Education Research Center (EERC) in the Swanson School of Engineering at the University of Pittsburgh. From 2017–2021, he served as an Assistant Professor in the Experiential Engineering Education Department at Rowan University where he taught first- and second-year engineering students. His current research areas include cultural competency in engineering education, pedagogical innovations through game-based and playful learning, and engineering ethics education. Scott has recently received funding through the National Science Foundation (NSF) to conduct research on the impact of game-based learning on the development of first-year students' ethical reasoning, as well as research on the development of culturally responsive ethics education in global contexts. He is an active member of the Kern Engineering Entrepreneurship Network (KEEN), the American Society for Engineering Education (ASEE), and serves on the First-Year Engineering Education (FYEE) Conference Steering Committee.

Kevin Dahm is a Professor of Chemical Engineering at Rowan University. He earned his BS from Worcester Polytechnic Institute (92) and his PhD from Massachusetts Institute of Technology (98). He has published two books, "Fundamentals of Chemical Engineering Thermodynamics" and "Interpreting Diffuse Reflectance and Transmittance." He has also published papers on effective use of simulation in engineering, teaching design and engineering economics, and assessment of student learning.

Kaitlin Mallouk is an Assistant Professor of Experiential Engineering Education at Rowan University. Prior to beginning that role, she spent five years as an Instructor in the Mechanical Engineering and Experiential Engineering Education Departments at Rowan. Kaitlin has a BS in Chemical Engineering from Cornell University and an MS and PhD in Environmental Engineering in Civil Engineering from the University of Illinois. Dr. Mallouk's research has three main areas: (1) understanding faculty use of innovative pedagogies (funded by NSF); (2) reflection in engineering education, particularly in the formation of and measurement of entrepreneurial mindset; and (3) strategies to improve diversity, equity, and inclusion in engineering (funded by NSF). She is also highly involved in developing new learning experiences for Rowan's undergraduate students through First-Year and Sophomore Engineering Clinic.

Bruce Oestreich is an Instructor with the Experiential Engineering Education Department at Rowan University. He received his BS in Computer Engineering from Illinois Institute of Technology and his MS in Systems Engineering from University of Southern California.