The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42594

The First-Year Engineering Student Entrepreneurial Mindset: A Longitudinal Investigation Utilizing Indirect Assessment Scores

Sherri M. Youssef, The Ohio State University

Sherri Youssef is a PhD candidate in the Engineering Education Department at The Ohio State University. Her research interests include understanding the motivation of regional campus undergraduate engineering students to persist and how the need to belong inform one's motivation to persist in engineering. She completed both her M.S. in Mechanical Engineering and her B.S. in Materials Science and Engineering at The Ohio State University as well.

Miss Amanda Marie Singer, The Ohio State University

Amanda Singer is a second-year Ph.D. student in the Department of Engineering Education at The Ohio State University. She graduated in 2021 from Michigan Tech with a Bachelor's and Master's of Science in Environmental Engineering. Her current research interests include engineering identity formation, community college engineering education, and mixed methods research.

Carter James Huber, The Ohio State University
Dr. Rachel Louis Kajfez, The Ohio State University

Dr. Rachel Louis Kajfez is an Associate Professor in the Department of Engineering Education at The Ohio State University. She earned her B.S. and M.S. degrees in Civil Engineering from Ohio State and earned her Ph.D. in Engineering Education from Virginia Tech. Her research interests focus on the intersection between motivation and identity, first-year engineering programs, mixed methods research, and innovative approaches to teaching. She is the principal investigator for the Research on Identity and Motivation in Engineering (RIME) Collaborative.

Dr. Krista M Kecskemety, The Ohio State University

Krista Kecskemety is an Associate Professor of Practice in the Department of Engineering Education at The Ohio State University and the Director of the Fundamentals of Engineering for Honors Program. Krista received her B.S. in Aerospace Engineering at The Ohio State University in 2006 and received her M.S. from Ohio State in 2007. In 2012, Krista completed her Ph.D. in Aerospace Engineering at Ohio State. Her engineering education research interests include investigating first-year engineering student experiences, faculty experiences, and the research to practice cycle within first-year engineering.

The First-Year Engineering Student Entrepreneurial Mindset: A Longitudinal Investigation Utilizing Indirect Assessment Scores

1. Introduction

Since the turn of the century, global and national calls have been made to develop a more innovative and entrepreneurial society to support economic growth [1]. Such calls have emphasized the development of entrepreneurial concepts and skills in addition to the foundational mathematical and scientific expertise required within engineering [2], [3]. Inclusion of these concepts and skills support the growth of an entrepreneurial mindset (EM) which is a collection of mental habits that target one's impact on society and the value they create for it [4]. Methods to implement an EM in education emphasize one's approach to critical thinking, innovation, and value creation as both a learning activity and outcome (i.e., [5], [6]). The execution of EM-focused curricula and the subsequent outcomes have resulted in student-centered benefits, namely, the growth of their professional skills [7]. Students report that such education contributes to their ability to communicate professionally and influences their ability to collaborate with others [7]. Moreover, entrepreneurial coursework has been linked to student ability to recognize customer and social aspects of designs [8]. In addition, the development of an EM has shown to prepare entry-level engineers with a global awareness and intention to create value economically, socially, and environmentally [9], [10].

To meet these global and national calls, the Kern Entrepreneurial Engineering Network (KEEN) formed with the mission of instilling an EM in current and future engineering students [11]. With an EM, engineers will be prepared to work in our increasingly global market, understand their local and global impact, and translate their technical work to a business context [12], [13]. KEEN is a collaborative network of 61 universities dedicated to integrating an EM into technical engineering education via entrepreneurial minded learning (EML) and the 3Cs: Curiosity, Connections, and Creating Value [4]. Through the 3Cs, EML develops and promotes skills related to information gathering, concept connections, and product or service valuation. KEEN has emerged as an EML leader in higher education, supporting faculty members across partnering institutions in the creation, implementation, and sharing of engineering and EM-focused course content.

Although each of the 3Cs have varying applications within an educational context, each center around key ideas. Curiosity refers to one's ability to explore new ideas and perspectives, question opinions or beliefs, and test new ideas [4]. Connections refers to one's ability to synthesize information from a variety of sources, recognize interactions and interdependencies, and to think outside of the box [4]. Creating Value refers to positively impacting others through one's work, creatively think through and solve problems, and to possess and articulate a clear vision of one's end goal [4]. Through KEEN's partnership with universities, countless faculty working towards this shared mission have applied EML in their classrooms and supported the growth of an EM in engineering students nationwide [4].

Through our research, we examined results from our implementation of 3Cs indirect assessments for students enrolled a first-year engineering honors course sequence over the 2021-2022 and 2022-2023 academic years to determine the effect of EM-focused instruction and first-year design projects on EM growth. We analyzed responses in a pre/post manner within these academic years and holistically analyzed across academic years. We used the cross-year analysis to address the impact of curricular changes. Finally, we provide implications and pedagogical approaches that can support the development of an EM in the future.

2. Background

The Ohio State University (OSU) partnered with KEEN in 2017 and has since integrated EML across several courses in its engineering curriculum. This initiative first began with the redesign of the First Year Engineering Program (FYEP) standard course sequence. Alterations to the standard sequence were developed with the best practices garnered from a multi-institution investigation of formal learning approaches of EM in first year engineering courses [14]–[17]. The incorporation of the EML framework led to an increase in student performance, encouraging the institution to integrate EML into its engineering capstone courses and the FYEP honors course sequence. EM-focused learning outcomes and curricular assessments of these outcomes were created to support their integration into these courses [18]. Institutionally, EML has been incorporated into Professional Learning Communities (PLCs) and training efforts to support the implementation of EM instruction [19], [20].

Data was collected and used previously from the standard and honors course sequences to create an assessment toolkit of the 3Cs. This was completed via the development of direct and indirect assessments for each of the 3Cs by researchers on our team over the years [21]–[24]. Each assessment was formulated for individual student assessment. Since this paper targets responses from students in our FYEP honors course sequence to our indirect assessments, all discussions will focus on our 3Cs indirect assessments. However, additional information on the direct assessments, including the direct assessment prompts, scoring rubrics, and some implementation results, can be found elsewhere [22]–[24].

The implementation of EML and the resultant student outcomes have been of high interest within the FYEP. Within this program are the first-year engineering courses which are offered as a two-semester sequence with an optional sequence for honors designated students. The first course focuses on problem solving through computational tools, specifically Excel, MATLAB, and C/C++ programming. This course ends with a software design project where students work in groups to create a game of their choosing in C++ [25], [26]. Students engage with the design process and consider the audience of their game in this project, but significant instruction on stakeholders and value creation is not included.

The second semester course targets design and SolidWorks via two options for an overarching design project. The first is an autonomous robot design/build project while the second is an alternative, research-based design project. Both project options require students to work in teams of four throughout the semester. In the robot design/build project, students are tasked with building and programming a robot to complete a set of defined tasks on a course. The scenarios of the courses and the tasks change year to year, but the assignments remain similar. In 2021-2022, students were asked to design a robot to help with automation tasks in a diner while in 2022-2023 they were asked to create a robot to help with tasks at an airport. There is a built in "customer" to the project, but the customers' needs and the tasks the robot must perform are well-defined.

The research-based project over the 2021-2022 academic year was to design a medical nanotechnology device for disease detection and complete a microfluidics lab on a chip experiment. Students read journal articles and used newfound knowledge from these articles to inform their designs throughout the project. Much like the robot design/build project, the stakeholder needs and tasks for the alternative were well-defined. The research-based project for the 2022-2023 academic year was redesigned to be more open ended and to expand the themes of the course. Specifically, it asked students to identify an opportunity and problem within the themes of either medical nanotechnology or sustainability. The course still focused on research and reading journal articles but also expanded assignments to consider value creation, needs, and the impact of their projects. The end of both design projects reserved one day to focus on EM and asked them to reflect on questions they had about engineering, to create a concept map as a group about EM, and to identify the value they had created for stakeholders in their projects. In 2021-2022, this was the first introduction to EM for both projects and was designed as a reflection. In 2022-2023, it was the first introduction to EM for the robot project, but the research-based project had heavily focused on EM and value creation throughout the semester. Student workload across the design projects was reduced in 2022-2023 compared to the year prior. For example, students were given additional time to brainstorm their designs and create them, reducing the overall number of tasks they needed to complete during the semester. Additionally, more faculty who taught these courses in 2022-2023 had more exposure and practice implementing EML through PLCs at our institution.

3. Methods

3.1 Assessment Development and Implementation

To assess first-year engineering students' ability to demonstrate an EM, indirect assessments for each of the 3Cs were implemented into the FYEP honors course sequence during the 2021-2022 and 2022-2023 academic years. The suite of assessments was administered to students as a part of their routine coursework via Qualtrics surveys and was implemented near the beginning and end of the academic year to measure changes in students' EM in response to the FYEP curriculum. All assessments except for the Curiosity indirect assessment that uses Kashdan et al.'s [27] 5-Dimensional Curiosity Scale were developed by a previous team of OSU researchers [21].

The Curiosity indirect assessment applies Kashdan et al.'s [27] Five-Dimensional Curiosity Scale (5DC) which has been validated and previously used within an engineering education context [27]. The five dimensions or constructs of Curiosity in this scale are Joyous Exploration (JE - the elements of curiosity that spark joy,) Deprivation Sensitivity (DS – curiosity that causes tension), Stress Tolerance (ST – curiosity that associated with the unknown), Social Curiosity (SC – curiosity with interpersonal interactions), and Thrill Seeking (TS – risky behaviors or situations one partakes in due to curiosity with associated experiences). The Connections and Creating Value indirect assessments [21] were developed and validated for use in a first-year engineering context. Explanatory Factor Analysis (EFA) was conducted for both indirect assessments and lead to four Connections factors: Integrate Outside Information (CF1), Consider Social, Economic, and Environmental Factors (CF2), Define Connections (CF3), and Make Connections within Engineering Design (CF4). EFA on the Creating Value indirect assessment gave rise to three factors: Create Value within Engineering Design (CVF1), Attitude and Approach Toward Value Creation (CVF2), and Create Value for Others (CVF3). These indirect assessments apply 7-point, Likert-type scales constructed around KEEN's EML context and institutionally developed EM learning outcomes [21].

Indirect assessments corresponding to each of the 3Cs use a 7-point Likert-type scale which required students to rate statements using the following: (1) Does not describe me at all, (2) Barely describes me, (3) Somewhat describes me, (4) Neutral, (5) Generally describes me, (6) Mostly describes me, and (7) Completely describes me. Note that the ST construct on the Curiosity indirect assessment was reverse coded with the following 7-point Likert-type scale: (1) Completely describes me, (2) Mostly describes me, (3) Generally describes me, (4) Neutral, (5) Somewhat describes, (6) Barely describes me, and (7) Does not describe me at all. Items associated with this construct were negatively worded such that low ratings indicated negative responses to stress.

3.2 Indirect Assessment Analysis

The 7-point Likert-type scale data from each of the indirect assessments were extracted from Qualtrics and cleaned to eliminate participants who did not complete the ratings across all scale items. Indirect assessment data from 103 students in the 2021-2022 cohort and 127 students belonging to the 2022-2023 cohort were included for analysis.

Upon cleaning the data, averages were computed for each of the Curiosity, Connections, and Creating Value constructs identified from prior work [21]. Construct averages were computed per participant following the scoring instructions defined by Kashdan et al. [27]. Q-Q plots for the pre- and post-data of each construct for both cohorts were constructed and analyzed for normality. Normal data was found in all datasets, giving rise to the use of parametric testing in our analysis. As such, paired t-testing was used to compare pre- and post- assessment responses.

The change in score over the course of the year was also calculated for each student for each of their indirect scores, separately, by subtracting the student's post- score from their pre- score for each of the Curiosity, Connections, and Creating Value constructs. Accordingly, a positive change in score indicates that a student scored higher at the end of the academic year than at the beginning and a negative score indicates that a student scored lower at the end of the academic year than at the beginning. This directionality of calculations was chosen to clearly identify if post-assessment responses increased from students' pre-assessment responses.

3.3 Longitudinal Analysis

We compared the change in average response within both cohorts to begin identifying the EM growth seen across them. Additionally, the normality of the data allowed us to conduct independent samples t-testing to assess the difference in average assessment performance across cohorts. The post data obtained from both cohorts was used to conduct this testing.

4. Results

4.1 2021-2022 Indirect Assessment Findings

The pre and post descriptive statistics and significance testing completed for all five Curiosity constructs are presented in Table 1 and visually represented in Figure 1. Students exhibited an increase in their average JE responses and decreases in their average DS and ST responses. These changes were not statistically significant while significant increases were seen in their average responses to SC and TS items.

Table 1: 2021-2022 Curiosity Constructs Descriptive Statistics and Paired t-testing; **$\alpha = 0.05$

Construct	Mean (St. Dev.)	Mean Diff.	t	df	Two-sided p
JE_Pre	5.65 (0.77)	0.017	-0.201		0.841
JE_Post	5.67 (0.86)				
DS_Pre	5.25 (0.86)	-0.054	0.597		0.552
DS_Post	5.20 (1.07)				
ST_Pre	3.45 (1.18)	-0.169	1.366	102	0.175
ST_Post	3.28 (1.26)				
SC_Pre	5.00 (0.85)	0.367	-4.450		<.001**
SC_Post	5.37 (1.00)				
TS_Pre	4.33 (1.15)	0.484	-5.781		<.001**
TS_Post	4.82 (1.10)				

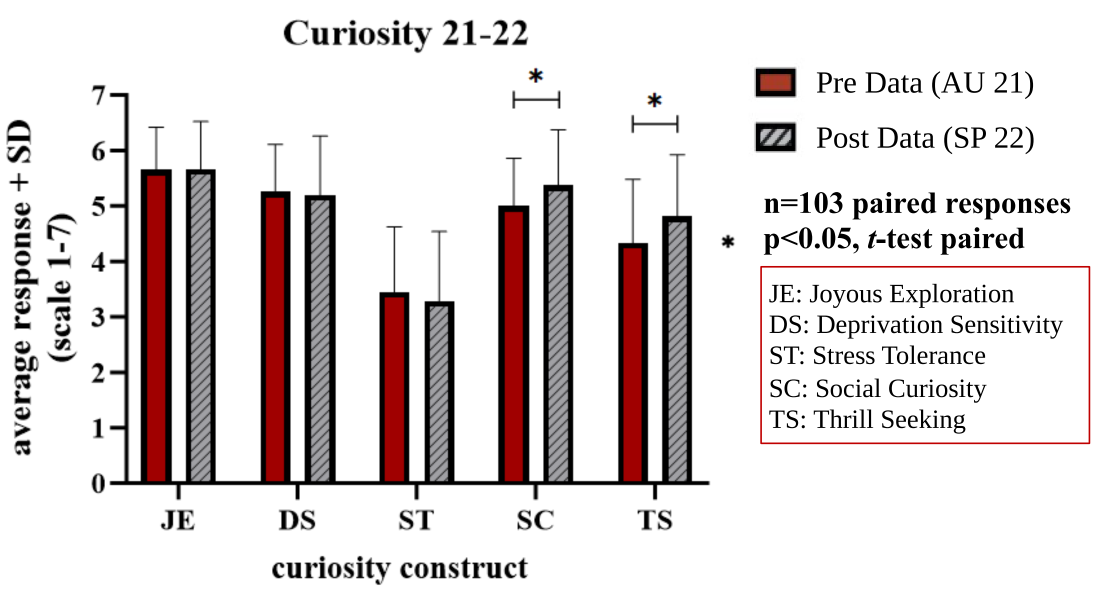

Figure 1: 2021-2022 Curiosity Construct Findings

Table 2 and Figure 2 present the descriptive statistics and significance testing for all four Connections factors in the same manner as those of the Curiosity constructs. Students exhibited an increase in average response to items in all four Connections factors, with significant increases for both CF1 and CF4.

Table 2: 2021-2022 Connections Factors Descriptive Statistics and Paired t-testing; $^{**}\alpha = 0.05$, $^{*}\alpha = 0.10$

Construct	Mean (St. Dev.)	Mean Diff.	t	df	Two-sided p
CF1_Pre	4.97 (0.88)	0.597	-6.062	102	<.001**
CF1_Post	5.57 (0.85)				
CF2_Pre	5.13 (1.07)	0.210	-1.778		0.078*
CF2_Post	5.34 (1.18)				
CF3_Pre	5.64 (0.84)	0.149	-1.650		0.102
CF3_Post	5.79 (0.84)				
CF4_Pre	4.61 (0.98)	0.557	-5.445		<.001**
CF4_Post	5.16 (0.961)				

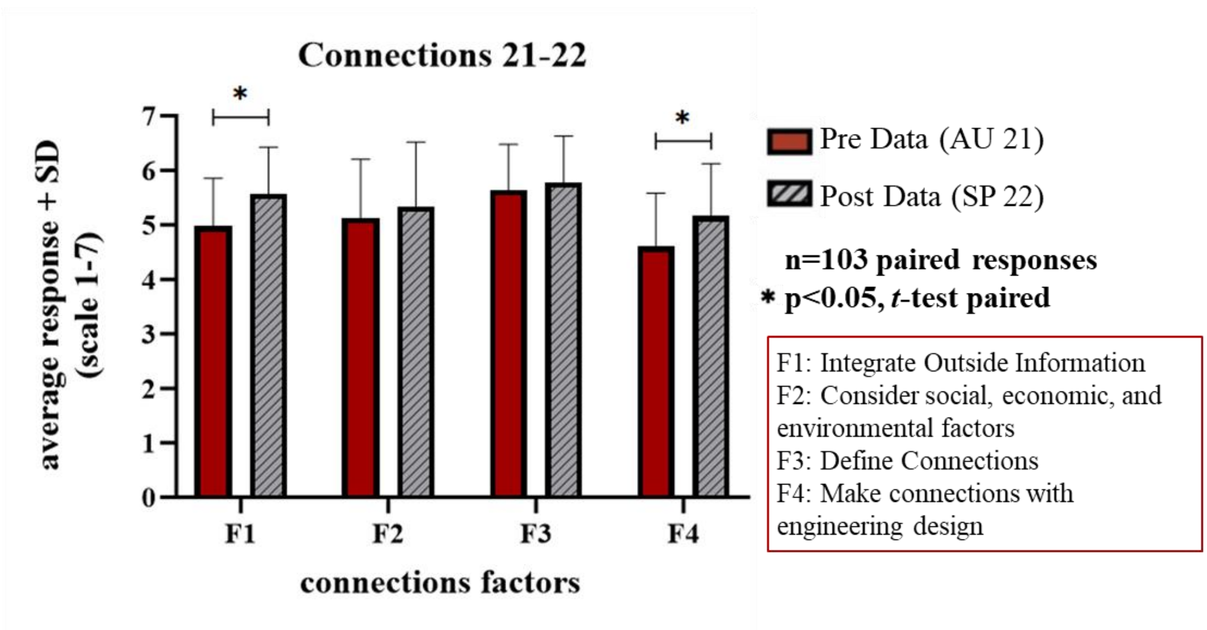

Figure 2: 2021-2022 Connections Factors Findings

Lastly, the descriptive statistics and significance testing computed for all three Creating Value factors are presented in Table 3 and visually presented in Figure 3. Students exhibited a significant increase in average response to all three factors.

Table 3: 2021-2022 Creating Value Descriptive Statistics and Paired t-testing; **$\alpha = 0.05$

Construct	Mean (St. Dev.)	Mean Diff.	t	df	Two-sided p
CVF1_Pre	4.48 (0.95)	0.766	-7.426	102	<.001**
CVF1_Post	5.25 (0.87)				
CVF2_Pre	4.93 (0.85)	0.579	-6.954		<.001**
CVF2_Post	5.51 (0.83)				
CVF3_Pre	4.90 (1.05)	0.414	-3.829		<.001**
CVF3_Post	5.31 (1.08)				

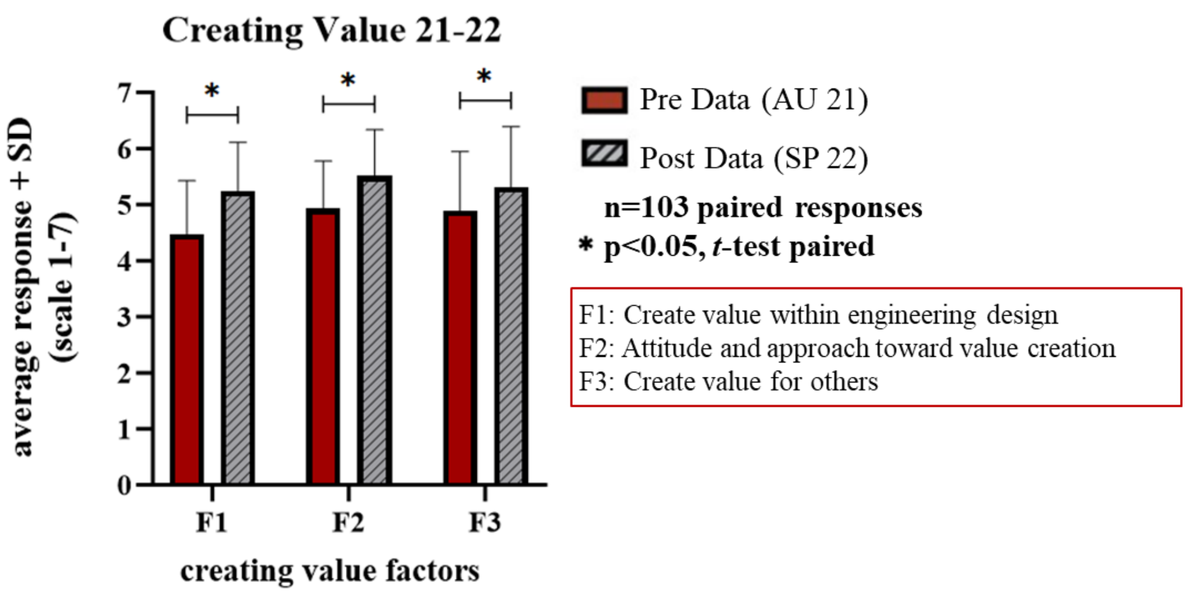

Figure 3: 2021-2022 Creating Value Factor Findings

4.2 2022-2023 Indirect Assessment Findings

Much like for the 2021-2022 findings, Table 4 presents the pre and post descriptive statistics and significance testing of all five curiosity constructs while Figure 4 depicts the same findings visually. Average scores for all five constructs increased where those of JE and TS increased significantly.

Table 4: 2022-2023 Curiosity Construct Descriptive Statistics and Paired t-testing; $**\alpha = 0.05$, $*\ \alpha = 0.10$

Construct	Mean (St. Dev)	Mean Diff.	t	df	Two-sided p
JE_Pre	5.36 (0.82)	0.198	-3.227	102	0.002**
JE_Post	5.56 (0.74)				
DS_Pre	5.12 (1.04)	0.060	-0.726		0.469
DS_Post	5.18 (0.98)				
ST_Pre	3.83 (1.15)	0.090	-1.083		0.281
ST_Post	3.92 (1.16)				
SC_Pre	5.28 (0.85)	0.121	-1.656		0.100*
SC_Post	5.40 (0.89)				
TS_Pre	4.26 (1.12)	0.213	-2.728		0.007**
TS_Post	4.47 (1.10)				

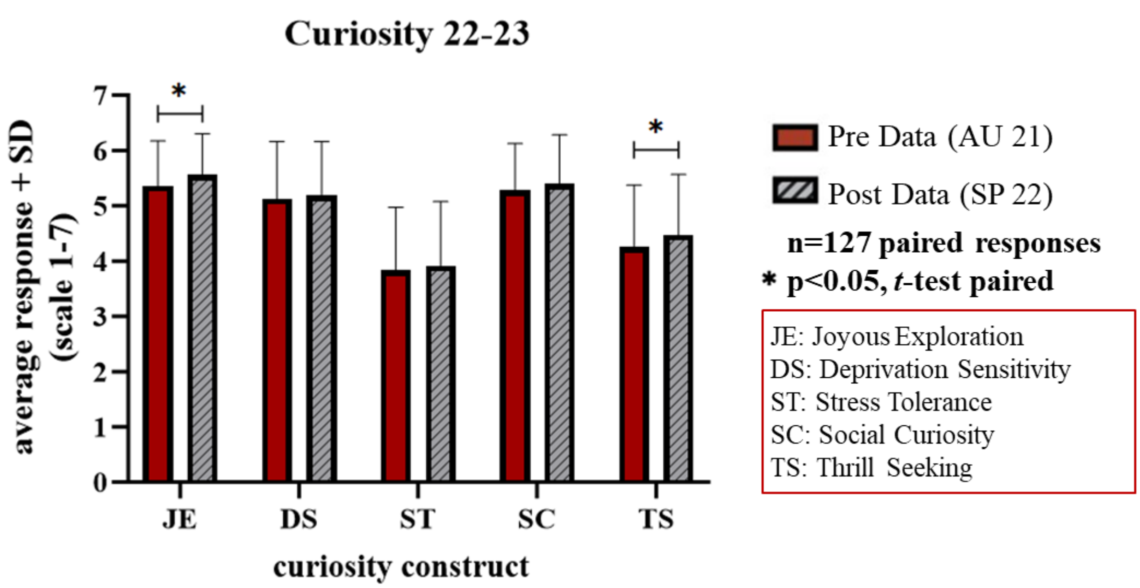

Figure 4: 2022-2023 Curiosity Construct Findings

Table 5 and Figure 5 present the descriptive statistics and significant findings regarding the four Connections factors. The average score for all four Connections factors significantly increased over the academic year.

Table 5: 2022-2023 Connections Factors Descriptive Statistics and Paired t-testing; **$\alpha = 0.05$

Construct	Mean (St. Dev.)	Mean Diff.	t	df	Two-sided p
CF1_Pre	4.95 (0.88)	0.449	-5.507	126	<.001**
CF1_Post	5.40 (0.85)				
CF2_Pre	4.94 (1.07)	0.276	-2.797		0.006**
CF2_Post	5.22 (1.18)				
CF3_Pre	5.48 (0.84)	0.173	-2.503		0.014**
CF3_Post	5.65 (0.84)				
CF4_Pre	4.61 (0.98)	0.417	-5.437		<.001**
CF4_Post	5.04 (0.961)				

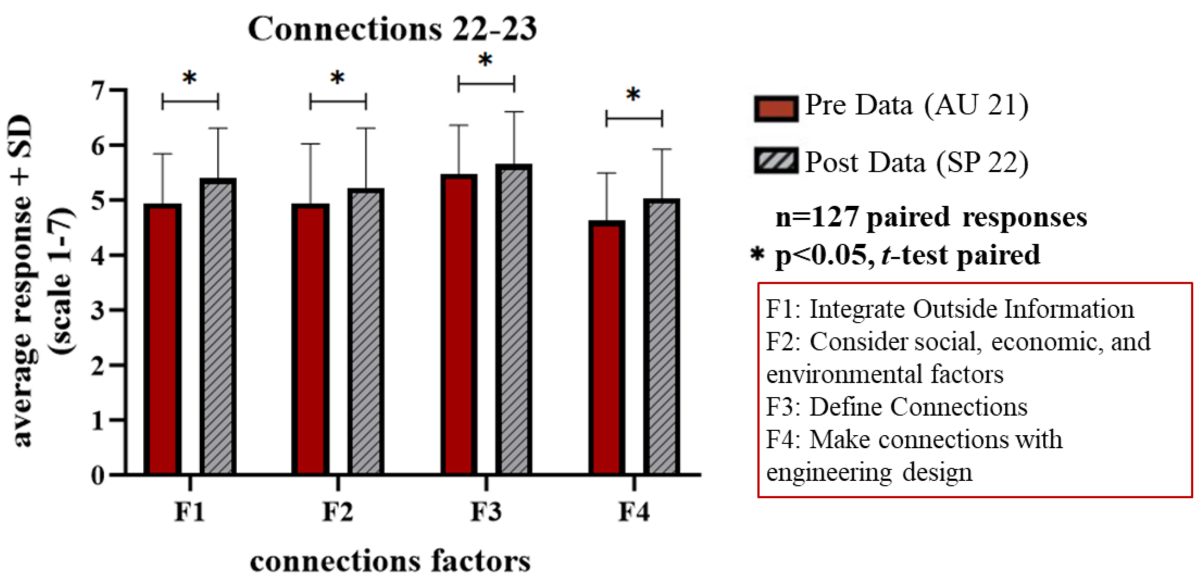

Figure 5: 2022-2023 Connections Factors Findings

Lastly, Table 6 and Figure 6 present the descriptive statistics and significance testing for all three Creating Value factors. The average score for all three factors increased significantly over the academic year.

Table 6: 2022-2023 Creating Value Descriptive Statistics and Paired t-testing; $**\alpha = 0.05$

Construct	Mean (St. Dev.)	Mean Diff.	t	df	Two-sided p
CVF1_Pre	4.48 (0.95)	0.766	-7.426		<.001**
CVF1_Post	5.25 (0.87)				
CVF2_Pre	4.93 (0.85)	0.579	-6.954	102	<.001**
CVF2_Post	5.51 (0.83)				
CVF3_Pre	4.90 (1.05)	0.414	-3.829		<.001**
CVF3_Post	5.31 (1.08)				

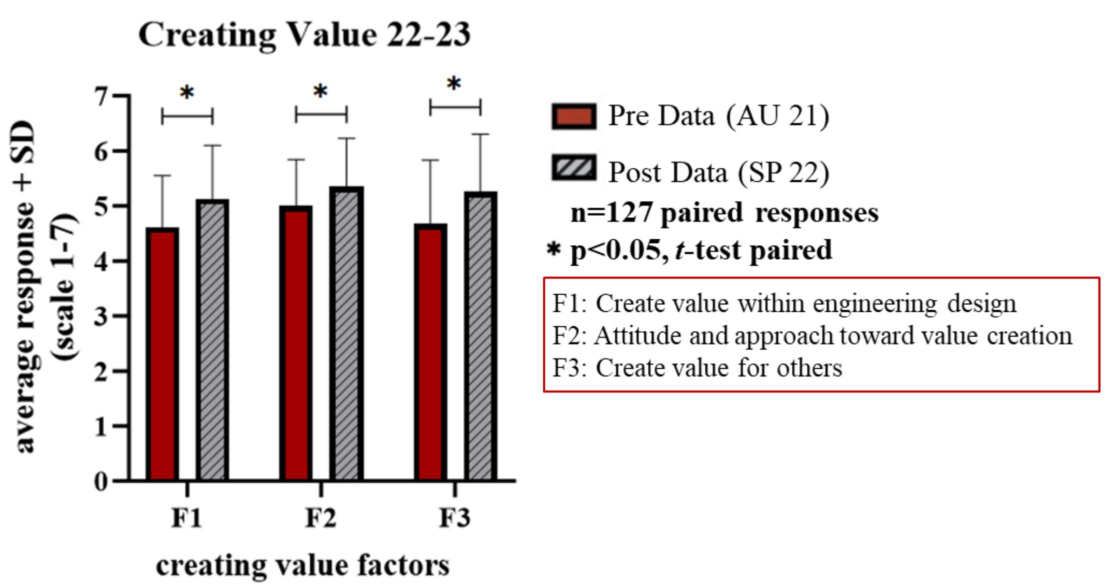

Figure 6: 2022-2023 Creating Value Construct Findings

4.3 Cross-Cohort Indirect Assessment Findings

Independent Samples t-testing was conducted with the post data from both cohorts due to the normality found within both sets of data. Two-sided p-values were calculated and are presented in Table 7. Equal variances were assumed in this analysis since all significance values computed via Levene's Test for Equality of Variances were above 0.05. A significant difference in the average responses to items between cohorts was found among the ST and TS construct only.

Table 7: Significance Testing Across Cohorts; $**\alpha = 0.05$

Construct/Factor	JE	DS	ST	SC	TS	CF1	CF2	CF3	CF4	CVF1	CVF2	CVF3
t	1.016	0.099	-3.994	-0.221	2.383	1.469	0.797	1.128	1.007	0.942	1.451	0.398
df						228						
Two-sided	0.311	0.921	<.001**	0.825	0.018**	0.143	0.426	0.254	0.315	0.347	0.148	0.691

5. Discussion

5.1 Broader Impacts on Students' Curiosity

Across the two years of implementation, differences arose between average responses for our 3Cs indirect assessments, with most of the differences occurring in our Curiosity indirect assessment. In the 2021-2022 academic year, increases in average responses for the JE, SC, and TS constructs were observed with the latter two being significant changes. The increases seen may be attributed to the collaborative nature behind all second semester projects and the unique scenarios that guided students' work. Students must purposefully engage with their groups regularly, work together, coordinate roles and task, and communicate regularly to create a functional final deliverable by the end of the semester [28], [29]. In these pursuits, teammates help each other to grow and develop the social skills entry-level engineers need [30]. Additionally, the unique scenarios guiding both design projects may offer students a new perspective as they realize that engineering has a broad impact on society beyond what is traditionally known as engineering work.

The average response for all five Curiosity constructs increased in 2022-2023 implementation, with significant increases occurring within student responses to JE and TS items. These changes may be attributed to the increased number of faculty teaching this course who participated in our institution's PLCs. PLC participation teaches faculty about the EM and how to integrate EML into their courses via the 3Cs [19], [20]. We suspect the guidance our instructors received on instilling curiosity in their students translated into measurable growth in students' curiosity mindset.

Findings across cohorts indicate that the average responses for ST and TS items were significant in distinct ways. In Table 7, students' ST response noticeably increased while that of their TS response did not. This change in ST translates to reduced feelings of stress in the second cohort compared to the first. The reduced workload students in the second cohort may have positively contributed to the smaller stress response exhibited. As previously highlighted, students in this cohort were given more time to gather information, brainstorm designs, and create their design protypes. Providing students more time to complete these steps vital to EM and engineering design allows for students to engage deeply with the process, think critically, and ask questions that are vital to solving the problem at hand [31]. These aspects of EM and engineering design align with foundational ideas and behaviors associated with curiosity [32]. The decrease in TS response found across cohorts coupled with the significance denoted in Table 7 may indicate that the instruction students received in 2022-2023 had less emphasis on TS-behavior than that of the year prior, giving rise to this result.

5.2 Broader Impacts on Students' Connection-Making Skills

Students' ability to make connections within both the 2021-2022 and 2022-2023 academic years increased, with significant increases occurring for CF1 and CF4 in the first cohort and all four factors in the second cohort. All four factors relate closely to the work required of students in both types of second semester design projects. CF1 (Integrate Outside Information) directly aligns with the work students complete in both projects. Specifically, students read journal articles and used newfound knowledge to inform their project designs in the research-based project and use knowledge gained from class and their constraints in the robot design/build project to create their final prototypes. CF2 (Consider Social, Economic, and Environmental Factors) relates to their work in both projects as students receive social, economic, and environmental considerations in the robot design/build project through their constraints and must identify such factors on their own in the research-based project. CF3 (Define Connections) aligns with both projects as students must use concepts and ideas from sources and knowledge gained from class to create their projects. CF4 (Make Connections within Engineering Design) relates to both project options as students needed to connect concepts and ideas to develop tangible and functional final deliverables.

Across cohorts, no significant changes were detected in student responses to all four Connections factors, indicating the instruction tactics implemented in both cohorts did not noticeably improve students' ability to integrate outside information into their work. Both 2021-2022 and 2022-2023 curricula and instruction may be effective in growing students' connection-making skills.

5.3 Broader Impacts on Students Creating-Value Skills

Much like the first cohort, students in the second cohort exhibited significant increases in their ability to create value within engineering design (CVF1), their overall attitude and approach towards value creation (CVF2), and their ability to create value for others (CVF3). These findings may be due to the work and skills students engaged with during their design projects. Work conducted by Youssef et al. [33] found both open-ended and bounded first-year engineering design projects to positively contribute to students' ability to create value. We suspect both curricula and design projects had a lasting impact on students' ability to create value within engineering design, informed their attitude and approach towards value creating, and their ability to create value for others.

Additionally, our across cohort analysis indicated the EM instruction and structure of the design projects implemented in both academic years did not noticeably change students' ability to create value as described by all three factors. Therefore, instruction tactics used to develop students' value-creation skills in both years may be similarly effective. Similar results for the Connections and Creating Value indirect assessments were found where responses to each factor increased over the year. This aligns with a relationship found by Streiner et al. [34] where an increase in one's ability to make Connections is complemented with an increase in their ability to Create Value.

5.4 Across Year Analysis Key Findings and Future Work

The items found in each indirect assessment ask students to rate how much they agree or disagree with each statement. In other words, the results from these indirect assessments describe students' self-perceptions of their ability and/or confidence to apply EM-oriented curiosity, connection-making, and value creating skills. Broadly speaking, the findings that arose from this study indicate that both the robot design/build and research-based design projects positively informed students' perceptions and confidence in performing skills related to each of the 3Cs. In other words, similar EM benefits may exist for students who complete first-year design projects in both an ill-defined manner with direct EM instruction and a bounded manner with one reflective day of EM instruction. However, future work is needed to investigate the effects of the curriculum change for the 2022-2023 research-based project before any claims can be made. A study conducted by Kemppainen et al. [35] found the implementation of open-ended or ill-defined design projects to improve students' creativity, which is positively correlated with curiosity [32], [36]. The findings that arose from both our work and that of Kemppainen et al.'s [37] support the need to investigate the effect of such projects on students' EM growth. Although value creation was also an explicit component of this re-designed research-based project, the average responses to creating value items did not differ greatly from one cohort to the other, indicating both paths of creating value instruction are similarly effective. Olawale et al. [37] found similar findings with their two-semester course sequence where the second course was largely focused on a team-based design project. EM instruction and foundational ideas associated with EM were covered in the first course of this sequence. Specifically, they found that hands-on design and fabrication projects with end users was more instrumental in the development and ability to apply EM than the instruction they received in the first course.

Future work may consider redesigning EM targeted instruction in such a way that elicits more findings in the cross-cohort analysis, namely, significant findings indicative of greater EM growth. One way to engage in this course redesign would be to include more interactive activities associated with real life applications of each of the 3Cs. For example, such an activity may have students work in teams to generate a list of end users affected by a noise pollution problem in a greater metropolitan area, the questions they would ask them, and the sources to consult when gathering information. In this example, students may exercise their curiosity while seeking out ways in which they may create value. They may also make connections in this activity as they identify key ideas, situate them within engineering design, and consider other factors that can inform their design solutions. In Andalibi's [38] work, students were interested in using an EM with technical skills to solve real-world problems. It led to more enjoyment in the coursework among students, reinforced prior knowledge and skills obtained, and fostered a sense of self-determination. Providing students more explicit interaction and engagement with foundational aspects of an EM in this manner can support their comprehension of EM and help grow their skills applying it in realistic scenarios. Such practices can help students identify when and where to apply specific EM elements to create meaningful and impactful solutions for societal problems. In addition, an investigation into the specific instructional strategies implemented by instructors can contribute to a greater understanding of their effect on students' growth with respect to each of the 3Cs. Dissemination of such findings can positively contribute to practitioners' efforts to integrate EML in their courses and further foster EM among their students.

6. Conclusion

Indirect assessments for each of the 3Cs were deployed to students in the first-year engineering honors course sequence over both the 2021-2022 and 2022-2023 academic years to determine how course instruction between the two years informed students' knowledge and growth in mastering skills related to each of the 3Cs. The primary differences between the curricula over these years were how the EM instruction was applied and the amount of training faculty had implementing EML through our institution's PLCs.

Our findings indicate that the curricula and instruction used within both years positively contributed to students' EM growth via the 3Cs. Students from the 2021-2022 academic year exhibited significant increases among the SC and TS constructs, CF1 and CF4, and all three Creating Value Factors. Students in the 2022-2023 academic year exhibited significant increases with their JE and TS construct responses and all Connections and Creating Value factors. Significant findings were detected in our cross-year analysis for the ST and TS constructs. This coupled with the changes seen within cohorts may indicate that both curricula supported students' skill development among these three constructs and factors similarly.

7. References

[1] Augustine et al., Ed., *Rising above the gathering storm: energizing and employing America for a brighter economic future*. Washington, D.C: National Academies Press, 2007.

[2] A. R. Peterfreund, E. Costache, H. L. Chen, S. K. Gilmartin, and S. Sheppard, "Infusing Innovation and Entrepreneurship into Engineering Education: Looking for Change as Seen by ASEE Members, 2012 to 2015," in *Proceedings of the American Society of Engineering Education (ASEE) Conference and Exposition*, New Orleans, Louisiana, Jun. 2016. Accessed: Dec. 13, 2022. [Online]. Available: https://peer.asee.org/infusing-innovation-and-entrepreneurship-into-engineering-education-looking-for-change-as-seen-by-asee-members-2012-to-2015

[3] M. T. Azim and A. H. Al-Kahtani, "Entrepreneurship Education and Training: A Survey of Literature," *Life Sci. J.*, vol. 11, no. 1s, pp. 127–135, 2014.

[4] "The KEEN Framework | Engineering Unleashed." Accessed: Jan. 31, 2024. [Online]. Available: https://engineeringunleashed.com/framework

[5] M. Täks, P. Tynjälä, M. Toding, H. Kukemelk, and U. Venesaar, "Engineering Students' Experiences in Studying Entrepreneurship," *J. Eng. Educ.*, vol. 103, no. 4, pp. 573–598, 2014, doi: 10.1002/jee.20056.

[6] N. Duval-Couetil, A. Shartrand, and T. Reed, "The Role of Entrepreneurship Program Models and Experiential Activities on Engineering Student Outcomes," vol. 5, no. 1, pp. 1–27, 2016.

[7] N. Duval-Couetil and J. Wheadon, "The value of entrepreneurship to recent engineering graduates: A qualitative perspective," in *2013 IEEE Frontiers in Education Conference (FIE)*, Oklahoma City, OK, Oct. 2013, pp. 114–120. doi: 10.1109/FIE.2013.6684798.

[8] E. Kim and G. J. Strimel, "The Influence of Entrepreneurial Mindsets on Student Design Problem Framing," *IEEE Trans. Educ.*, vol. 63, no. 2, pp. 126–135, May 2020, doi: 10.1109/TE.2019.2918253.

[9] T. J. Kriewall, "Instilling the Entrepreneurial Engineering Mindset in College Undergradautes: A Panel Presentation," in *Proceedings of the 2010 Open, Annual Conference*, San Francisco, CA, Mar. 2010, pp. 1–11.

[10] D. Bourn and I. Neal, "The Global Engineer: Incorporating global skills within UK higher education of engineers," Institute of Education, University of London, London, Mar. 2008.

[11] D. Melton, "KEEN Impact Study 2018-2019," Engineering Unleashed. Accessed: Feb. 03, 2024. [Online]. Available: https://engineeringunleashed.com/card/892

[12] N. DeJong-Okamoto, J. Rhee, and N. J. Mourtos, "Educating students to understand the impact of engineering solutions in a global / societal context," in *Proceedings of the 8th UICEE Annual Conference on Engineering Education*, Kingston, Jamaica, 2005, p. 6.

[13] B. Jesiek, Q. Zhu, S. Woo, J. Thompson, and A. Mazzurco, “Global Engineering Competency in Context: Situations and Behaviors,” *Online J. Glob. Eng. Educ.*, vol. 8, no. 1, Mar. 2014, [Online]. Available: https://digitalcommons.uri.edu/ojgee/vol8/iss1/1

[14] D. M. Grzybowski, X. Tang, E. Park, A. Leonard, J. DeLano, and K. Zhao, “Integration of Entrepreneurial-minded Learning,” presented at the 2020 ASEE Virtual Annual Conference Content Access, Virtual Online, Jun. 2020. Accessed: Dec. 13, 2022. [Online]. Available: https://peer.asee.org/integration-of-entrepreneurial-minded-learning

[15] R. Desing, R. Kajfez, K. M. Kecskemety, and D. M. Grzybowski, “Intersections between entrepreneurial minded learning, identity, and motivation in engineering,” *IJEE*, vol. 39, no. 5A, pp. 1389–1407, 2022.

[16] R. Desing, K. M. Kecskemety, R. L. Kajfez, D. M. Grzybowski, and M. F. Cox, “A Multi-institution Investigation into Faculty Approaches for Incorporating the Entrepreneurial Mind-set in First-year Engineering Classrooms,” in *Proceedings of the 2019 American Society of Engineering Education (ASEE) Annual Conference and Exposition*, Tampa, Florida, Jun. 2019. Accessed: Dec. 13, 2022. [Online]. Available: https://peer.asee.org/a-multi-institution-investigation-into-faculty-approaches-for-incorporating-the-entrepreneurial-mind-set-in-first-year-engineering-classrooms

[17] R. Desing, R. L. Kajfez, K. M. Kecskemety, D. M. Grzybowski, and M. F. Cox, “Mapping Entrepreneurial Minded Learning with the Longitudinal Model of Motivation and Identity in First-Year Engineering,” in *Proceedings of the 2018 FYEE Conference*, Glassboro, New Jersey, Jul. 2018. Accessed: Dec. 13, 2022. [Online]. Available: https://peer.asee.org/mapping-entrepreneurial-minded-learning-with-the-longitudinal-model-of-motivation-and-identity-in-first-year-engineering

[18] L. E. Rumreich, F. Logan, Z. Dix, N. R. Sattele, K. M. Kecskemety, and A. D. Christy, “Comparison of Entrepreneurial Mindset Course Learning Objectives: Evaluating Consistency and Clarity,” in *Proceedings of the 2020 American Society of Engineering Education (ASEE) ANnual Conference and Exposition.*, Jun. 2020. Accessed: Dec. 13, 2022. [Online]. Available: https://peer.asee.org/comparison-of-entrepreneurial-mindset-course-learning-objectives-evaluating-consistency-and-clarity

[19] M. Ita, L. Rumreich, K. Kecskemety, and R. Kajfez, “Preparing Instructors to Encourage an Entrepreneurial Mindset,” presented at the 2022 ASEE Annual Conference & Exposition, Minneapolis, Minnesota, Aug. 2022. Accessed: Jan. 31, 2024. [Online]. Available: https://peer.asee.org/preparing-instructors-to-encourage-an-entrepreneurial-mindset

[20] M. E. Ita, L. E. Rumreich, and A. Kalish, “Leveraging Professional Learning Communities for Institutional Change,” in *Faculty Learning Communities: Communities of Practice that Support, Inspire, Engage, and Transform Higher Education Classrooms*, K. N. Rainville, Desrochers, and D. G. Title, Eds., in Transforming Teaching and Learning in Higher Education, no. 4. , Charlotte, NC: Information Age Publishing, 2023.

[21] M. E. Ita, M. E. West, and R. Kajfez, “Development of Survey Instruments to Measure Undergraduate Engineering Students’ Entrepreneurial Mindset: Connections and Creating Value,” *Int. J. Eng. Educ.*, vol. 39, no. 4, pp. 811–822, 2023.

[22] M. West, M. Ita, L. Rumreich, R. Kajfez, and K. Kecskemety, “Development of a Direct Assessment for Measuring Students’ Ability to Make Connections,” in *2021 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual Conference: ASEE Conferences, Jul. 2021, p. 36956. doi: 10.18260/1-2--36956.

[23] M. E. West and R. L. Kajfez, “Creating Value Direct Assessment: A Matrix Approach to Defining Value | Engineering Unleashed.” Accessed: Apr. 19, 2023. [Online]. Available: https://engineeringunleashed.com/card/2448

[24] A. Singer, M. Ita, and R. Kajfez, “Curiosity Direct Assessment,” Engineering Unleashed. Accessed: Jan. 31, 2024. [Online]. Available: https://engineeringunleashed.com/card/3357

[25] K. M. Kecskemety, A. B. Drown, and L. Corrigan, “Examining Software Design Projects in a First-Year Engineering Course: How Assigning an Open-Ended Game Project Impacts Student Experience,” presented at the 2017 ASEE Annual Conference & Exposition, Jun. 2017. Accessed: Jan. 31, 2024. [Online]. Available: https://peer.asee.org/examining-software-design-projects-in-a-first-year-engineering-course-how-assigning-an-open-ended-game-project-impacts-student-experience

[26] L. E. Rumreich and K. M. Kecskemety, “Examining Software Design Projects in a First-Year Engineering Course Through Different Complexity Measures,” in *2019 IEEE Frontiers in Education Conference (FIE)*, Oct. 2019, pp. 1–5. doi: 10.1109/FIE43999.2019.9028569.

[27] T. B. Kashdan *et al.*, “The five-dimensional curiosity scale: Capturing the bandwidth of curiosity and identifying four unique subgroups of curious people,” *J. Res. Personal.*, vol. 73, pp. 130–149, Apr. 2018, doi: 10.1016/j.jrp.2017.11.011.

[28] D. W. Johnson and F. P. Johnson, *Joining Together: Group Theory and Group Skills*, 12th ed. London: Pearson Education, 2016.

[29] D. W. Johnson and R. T. Johnson, “Cooperative Learning: The Foundation for Active Learning,” in *Active Learning - Beyond the Future*, S. M. Brito, Ed., IntechOpen, 2018. doi: 10.5772/intechopen.81086.

[30] B. L. Hartmann and C. T. Jahren, “Leadership: Industry Needs for Entry-Level Engineering Positions,” *J. STEM Educ. Innov. Res.*, vol. 16, no. 3, pp. 13–19, Aug. 2015.

[31] R. J. Volkema, “Problem Formulation in Planning and Design,” *Manag. Sci.*, vol. 29, no. 6, pp. 639–652, 1983.

[32] T. B. Kashdan, P. Rose, and F. D. Fincham, “Curiosity and Exploration: Facilitating Positive Subjective Experiences and Personal Growth Opportunities,” *J. Pers. Assess.*, vol. 82, no. 3, pp. 291–305, Jun. 2004, doi: 10.1207/s15327752jpa8203_05.

[33] S. Youssef, M. E. Ita, and R. L. Kajfez, “Student Comprehension of and Growth in Creating Value with an Entrepreneurial Mindset,” presented at the 2023 ASEE Annual Conference & Exposition, Baltimore, MA, Jun. 2023. Accessed: Feb. 05, 2024. [Online]. Available: https://peer.asee.org/student-comprehension-of-and-growth-in-creating-value-with-an-entrepreneurial-mindset

[34] S. D. Streiner, C. A. Bodnar, K. Mallouk, B. Oestreich, and K. D. Dahm, “Building Toys for Children by Applying Entrepreneurial-minded Learning and Universal Design Principles,” in *Proceedings of the 2020 American Society of Engineering Education (ASEE) ANnual Conference and Exposition.*, Jun. 2020. Accessed: Feb. 05, 2024. [Online]. Available: https://peer.asee.org/building-toys-for-children-by-applying-entrepreneurial-minded-learning-and-universal-design-principles

[35] A. Kemppainen, G. Hein, and N. Manser, “Does an open-ended design project increase creativity in engineering students?,” in *2017 IEEE Frontiers in Education Conference (FIE)*, Indianapolis, IN: IEEE, Oct. 2017, pp. 1–5. doi: 10.1109/FIE.2017.8190507.

[36] T. B. Kashdan and F. D. Fincham, “Facilitating Creativity by Regulating Curiosity,” *Am. Psychol.*, vol. 57, no. 5, pp. 373–374, May 2002, doi: 10.1037//0003-066X.57.5.373.

[37] D. Olawale, S. Spicklemire, J. Sanchez, G. Ricco, P. Talaga, and J. Herzog, “Developing the Entrepreneurial Mindset in STEM Students: Integrating Experiential Entrepreneurship into Engineering Design,” *Int. J. Process Educ.*, vol. 11, no. 1, pp. 41–48, Jul. 2020.

[38] M. Andalibi, “Early Incorporation of Entrepreneurship Mindset in An Engineering Curriculum,” *Int. J. High. Educ.*, vol. 8, no. 4, Art. no. 4, Jul. 2019, doi: 10.5430/ijhe.v8n4p98.