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Building Toys for Children by Applying Entrepreneurial-Minded Learning and Universal Design Principles

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Abstract

Incorporating entrepreneurial-minded learning (EML) into engineering curricula has been an increasingly popular educational practice over the last decade. These practices have often been initiated, supported, and disseminated via the Kern Entrepreneurial Engineering Network (KEEN), which has focused on students developing curiosity about the world around them, connecting information from a variety of sources to guide in analysis, and creating products that provide value to stakeholders. In the College of Engineering at Rowan University we have sought to strategically develop the entrepreneurial mindset in engineering students by building in EML principles – namely the KEEN 3C's of Curiosity, Connections, and Creating Value – into existing and new first and second-year design projects.

This full paper describes one such first-year project that leverages EML and Universal Design Principles as a framework for creating toys for children. In this project, students are tasked with designing an inexpensive toy for kids during hospital visits via the Little House on Wheels Hospitality Cart Program. The project is carried out in four phases where students learn how to (1) understand their intended customer and apply different brainstorming strategies, (2) conduct task and market analyses to better understand how their toy design interfaces with the customer and how it differs from similar toys, (3) carry out economic and manufacturing analyses, and (4) create a prototype of their toy through 3D modeling/printing processes.

At the conclusion of the project, students wrote a design report that was graded using an internally designed rubric, some items of which were mapped to the KEEN 3C's. The final reports were analyzed using this rubric and results relating to entrepreneurial mindset development are discussed.

Introduction

The engineering discipline is expanding beyond traditional design and decision-making processes. It is becoming increasingly important for engineering students to develop an entrepreneurial mindset (EM) which promotes skills such as effective collaboration and communication, persisting and learning from failure, and tolerance for ambiguity [1]. Thus, integrating EM into engineering educational practice has become an increasing area of focus over the past decade. Specifically, there has been unparalleled growth in the number of engineering programs that offer curricular and co-curricular opportunities that assist in developing EM skill sets [2]. One of the primary catalysts for this growth has been the Kern Entrepreneurial Engineering Network (KEEN), which consists of 47 institutions that share the goal of developing undergraduate engineers so that they can "create personal, economic, and societal value through the entrepreneurial mindset" [3]. Many of these efforts have focused on the first-year by leveraging the design process as a touch point for discussing EM-related outcomes [4-9]. In "The Engineering of 2020: Visions of Engineering in the New Century", the National Academy of Engineering put forth a call to prepare students with new knowledge that advances society and creatively applies technology with broad consideration [10]. With many of the desired attributes describing future engineers falling into the EM space, the authors contend that identifying opportunities and formulating strategies to embed EM-related outcomes into the first-year engineering curriculum is essential for preparing the next generation of engineering graduates.

Entrepreneurial-minded learning (EML), which can be thought of as extension of active and collaborating learning, has shown to improve learning by further emphasizing discovery, opportunity identification, and value creation [11]. EML has been embedded within engineering curricula, with the goal of helping students learn and practice entrepreneurial skills and mindsets within an engineering context [12,13]. EML literature suggests three broad learning domains – affective (i.e., self-efficacy), thinking patterns (i.e., developing connections in the pursuit of value creation), and content knowledge/skills [14]. Included in EML content knowledge/skills can be design iteration and prototyping, which is the assessment focus of this paper and is an element not seen in many of other first-year engineering design projects that harnesses EML.

In the College of Engineering at Rowan University, we set out to foster EM in our first-year engineering students by transforming a project that leverages Universal Design Principles as a framework for creating toys for children to include EM-related outcomes inspired by KEEN's three tenets: Curiosity, Connections, and Creating Value (the 3Cs). In this project, students were tasked with designing an inexpensive toy for kids during hospital visits via the Little House on Wheels Hospitality Cart Program. In addition to technical content supported by the project, students were encouraged to:

- be curious about the relevancy of customer feedback,
- reflect on the value added for their intended customer and diverse populations
- comment on team contributions and perceived strengths
- make connections between final design specifications and equitable use

The project was conducted across 15 sections of our multidisciplinary first-year engineering course, in which 18-24 students were enrolled per section (~300 total students). This course meets twice per week: one 75-minute lecture period and one 165-minute lab period where faculty could integrate hands-on engineering design projects. The primary deliverable for the project was a design report, along with the toy itself. Self-developed EM learning objectives and rubrics were used to assess student teams' final reports. It is worth mentioning that the relationship between universal design and EM was not explicitly communicated to the students. The rubric items employed for the project were mapped directly back to the 3Cs to allow for assessment of students' approaches to curiosity, connections, and creating value in the context of the universal design of toys. Students were also asked to reflect throughout the duration of the project on various aspects of design, all of which were linked to EML through the 3Cs. This paper will describe our experiences with utilizing universal design as a strategy for developing EM in first-year engineering students, initial assessment results of EM content knowledge/skills, and future directions for improving and sustaining EML in first-year design projects more generally.

Universal Design Project Description

What is Universal Design?

Design can be thought of as an active, purposeful adaption method that people use to adjust their world to their needs [15]. Through design, humans both remove barriers and develop supportive environments, products, and systems to facilitate achievement of their goals. In this way, design is more than aesthetics – it is how we change the form and organization of our material world and how we interact with it [15]. Universal design (UD) seeks both to avoid creating barriers for users and to provide as much facilitation needed for users to reach their end goal.

UD is the design and composition of an environment so that it can be accessed, understood, and used to the greatest extent possible by all people regardless of their age, size, ability, or disability [16]. Further, it is a process that enables and empowers diverse population by improving human performance, health and wellness, and social participation [15]. UD recognizes the context in which design takes place rather than imposing an absolute standard to every situation.

There are seven UD Principles that are worth highlighting [17, 18]:

1. **Equitable Use** – the design does not disadvantage or stigmatize any group of users
2. **Flexibility in Use** – the design accommodates a wide range of individual preferences and abilities
3. **Simple and Intuitive Use** – use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level
4. **Perceptible Information** – the design communications necessary information effectively to the user regardless of ambient conditions or the users sensory abilities
5. **Tolerance for Error** – the design minimizes hazards and the adverse consequences of accidental or unintended actions
6. **Low Physical Effort** – the design can be used efficiently and comfortably, and with a minimum of fatigue
7. **Size and Space for Approach and Use** – appropriate size and space is provided for approach, reach, manipulation, and use, regardless of the user's body size, posture, or mobility

UD Principles are a collection of design criteria that can be imported into any design project (i.e., the design of children's toys). We can think of them as "Design for All". The goal of this project was to bring together the facets of UD and apply them in a toy design context. We provide a detailed overview of the project, its phases, and final deliverables, in the subsequent section (Project Overview).

Project Overview

Students are put into the context where they have been hired to design an inexpensive toy for either McDonalds Happy Meals or the Little House on Wheels Hospitality Cart, which provides toys for kids during hospital visits. The overarching theme of this project is Universal Design. Prior to starting the project, students are introduced to the seven Universal Design Principles and stepped through examples of each and how they have been applied to engineering products. After this introduction, students went through five distinct phases of work on their project. The UD project phases are shown in Table 1 and elaborated on in the subsections below.

The primary constraints given to the student teams are that the toy must be inexpensive, safe, fun, and usable (must have at least two functions). By the end of the project, students should be able to:

- Describe principles related to product development relevant to Universal Design and apply them to create value for diverse populations
- Expand the utility of a product so that it provides equitable use
- Incorporate insight from multiple perspectives to move forward with product design
- Perform quantitative analysis on engineering design problems using statistics and economic analysis
- Work effectively in problem-solving teams and carry out meaningful performance assessments of individual team members
- Develop technical communication skills in written, oral, and graphical formats

The UD project was completed over the course of five weeks in a 15-week semester. Generally, the 75-minute class meeting was dedicated to a particular engineering topic (product development, statistics, economic analysis, manufacturing, etc.) and the 165-minute session was dedicated to phases of the UD project.

Table 1. Overview of the 5-week UD Project

Design Phase	Week	Detailed Tasks	Deliverables
Phase I Initial Design	1	1. Voice of customer 2. Brainstorm! 3. Customer feedback 4. Select one alternative	Phase I Reflections
Phase II Improve Design	2	1. Task Analysis 2. Universal design recommendations 3. Market analysis	Phase II Reflections
Phase III Final Iteration & Specification	3	1. Document UD rationale 2. Document IP Rationale 3. OnShape 3D model 4. Instructions and labels 5. Economic Analysis	Progress Memo due start of Phase III (week 3) Phase III Reflections
Phase IV Prototype	4	1. 3D print prototype	Prototype
Phase V Communication	5	1. Work on final design report 2. Work on video presentation	Final Report & Video Presentation due later in semester

Additionally, the students are asked to reflect during each stage of the project. Each set of reflection questions (per Phase) are listed in the corresponding project phase summary. As part of the final report, student teams will include responses to individual reflection questions that have been developed to help students reflect on the 3Cs where they were applicable within each phase of the project. This additional reflection piece will help strengthen students' connection to these mindset elements.

Three sections of the first-year engineering course in 2019 were able to work with a local daycare center throughout the project. The students in these sections leveraged the feedback from the children during Phase 1 and received feedback on their initial designs throughout. Final prototypes were also shared with the children at the daycare center, with some of the toys being officially donated. Future iterations of the project will utilize the daycare more intentionally.

Phase I: Customers, Idea Generation, and Design Selection

In Phase I, students are tasked with developing an understanding of their intended customer (i.e., children between the ages of 4 and 6). They do this through the application of voice of customer techniques such as ethnography, surveys, customer brainstorming, etc. [19]. Students work with their teams and apply different brainstorming strategies to create multiple ideas for what could be a toy that will meet their intended customer needs. We provide the students with Design Heuristics Cards [20] to help push students beyond their first set of ideas for toys that could appeal to their prescribed customer base. Students are also required to create an affinity diagram [21] to capture and sort customer needs identified through the voice of customer techniques. After the idea generation portion of the project, students refine their ideas to a top five list. The students then go back out and speak with their intended customers to determine which of their five ideas is most appealing and of interest to their customer base.

Reflection –As you complete the first phase of your universally designed toy, reflect on the issues/things your team will take into consideration in the design. Include answers to the following:

- Did you feel that the customers were able to provide you relevant feedback on your designs? Why or why not?
- Was there ever an instance when a customer provided you with negative feedback? If so, how did this lead you to modify your approach to the design process?
- How can you determine whether your product is adding value for your intended customer?

Phase II: Anthropometry, Task Analysis, and Market Analysis

In Phase II of the project, students learn a variety of skill sets that will help them with the rest of their design process. We apply anthropometry techniques – the measurement of body size, abilities, and other characteristics - to teach students about differences in measures of the hand that they can then relate back to their toy design as the toy they are developing needs to be sized appropriately to fit a range of children's hand sizes [22]. This allows students to apply many of their basic statistical analysis techniques that they have learned directly to their project. Elements studied include average measures and confidence intervals. Students are also introduced to the principles of task analysis. Task analysis allows the students to better understand their design, its components, and its sub-components, which serves as a launching point for being able to identify areas for improvement. In this part of the project, they use the task analysis to help identify what parts of the product could be changed and/or modified to meet universal design requirements. Finally, students perform a basic market analysis. In their market analysis, students research other companies that are making similar toys to what they have proposed. They investigate the differences between their product and the existing products using their sense of curiosity to determine why their product may stand out in the marketplace. They also review the pricing of their competitor's toys which provides them with a better sense of the pricing point that they would need to be able to achieve with their design.

Reflection –As you complete the second phase of your universally designed toy, reflect on the issues/things your team will take into consideration in the design. Include answers to the following:

- Based on the principles for toy design, is your toy friendly to the hand or possibly harmful to the hand? Is your toy adaptable to different hand sizes? How do you see your toy providing value to diverse populations?
- How did your team approach the task and market analysis for your product? Did everyone contribute equally or were certain individual’s backgrounds/skillsets more applicable than others?

- How did your market analysis and review of competitors' products provide insight that assisted with your product development process? Did you discover additional universal design problems?

Phase III: Designing a Better Product

Phase III focuses on students applying the universal design principles learned and the information collected from their task and market analysis to improve upon the existing product. Once they have finalized the design they would like to use for their toy, they must create a three dimensional image of their toy using the OnShape software (https://www.onshape.com/). Student teams also create a set of instructions that could be included with their toy. When designing instructions, the students are prompted to consider how they present the information given the broad range of ages that could be customers for their toys. The last part of phase III focuses on students applying economic analysis to identify what type of manufacturing process would be best suited to their toy. The results of the economic analysis are nearly equivalent among the different manufacturing processes which means that when making their decisions students need to provide not only an economic rationale but also need to think about what process is most beneficial given their final design.

Reflection –As you complete the third phase of your universally designed toy, reflect on the issues/things your team will take into consideration in the design. Include answers to the following:

- How did Universal Design principles influence your final toy design? What specific modifications did you make to the product to enhance its equitable use?
- How did Intellectual Property considerations influence your final toy design?
- How did your evaluation of the economic viability of the three manufacturing processes influence your team's decision to select one manufacturing process?

Phase IV: Creating a Physical Prototype

The last phase of the project, Phase IV, has the students take their design one step further by creating an actual prototype of the design. As students needed to complete a three dimensional image of their toy in OnShape, they are required to 3D print a portion of their prototype, supplementing the rest with the use of supplied materials (craft supplies, cardboard, metal scraps, etc.). We want to provide students with choice over which prototyping method might best apply given their selected design, but still require that some part of the toy be 3D printed.

Phase V: Working on Communicative Deliverables

The UD project represented 20% of students' final grades in the course. There are three major deliverables associated with this project. First, students submit a **3-page memo** halfway through the project detailing the progress they have made and their plans for completing their design.

This memo allows the instructor to provide timely feedback on each group's direction and allows students to learn through failure that will help improve the overall final design. Students will submit a **final report** and make **a final presentation (video)** at the end of the project.

The written final design reports were 6-8 pages in length, double-spaced, and followed a design report format which was specified in their course textbook. A checklist of the required report components are listed in Table 2. The reports were graded using the rubric shown in the Appendix. The mapping to Curiosity, Connections, and Creating Value is shown in the second column of the rubric.

Table 2. Final Design Report Checklist

Sections	Content
Title Page	• Project title • Names and date • One graphic/picture of final design (OnShape or Prototype)
Executive Summary	• One-page summary of the project
Table of Contents	
Problem Definition	• Introduce and define the problem • Why is the problem important? • Steps taken to address the problem
Customer Needs	• Describe the users and customer needs of your product. Clearly describe the product to the reader. ○ VoC techniques used ○ Affinity Diagram of customer needs
Product Description	• How the toy functions, how it compares to other products on the market, estimated costs, and selected manufacturing technique. • Use OnShape drawings to document final design. Include dimensions and materials.
Discussion	• Rationales for final design (Universal Design & Intellectual Property) • Describe trade-offs made in the design
Prototype	• Introduce and describe prototype • Purpose of prototype and overview of key features (include pictures as appropriate) • Strengths and weaknesses of prototype • Recommendations for future work
References	• List of references used and cited (use APA author-year citations in report)
Appendices	• A – Interview questions and notes taken from customer interviews and/or other VoC techniques (Phase 1); Initial Sketches • B – Task Analysis (Phase 2) • C - Onshape Drawings (Phase 3) • D – Economic Analysis of Manufacturing Processes (Phase 3) • E – Reflections

Students were also required to present information about their toy in the form of a video. The videos were 5-6 minutes long and needed to include information regarding the potential market, voice of customer techniques used, final prototype, tradeoffs made between toy features, UD Principles, and intellectual property, and recommendations for future action. These presentations were not assessed using an EM rubric.

Assessment

The primary assessment tools used for the UD project is the rubric shown in the Appendix, which was used to assess the final design report. These rubrics were used to guide instructors in assigning grades to student teams and to assess the learning of the first-year cohort more generally, especially as it relates to EM. The rubric consists of a list of aspects of the final design report and three written descriptors corresponding to excellent, minimally acceptable and unacceptable performance with respect to each aspect. A 5-point scale was used, where 5 corresponds to excellent, 3 to minimally acceptable, and 1 to unacceptable. Instructors can assign ratings anywhere from 1-5 for each aspect of the product. Thus, ratings such as 2 or 4 were applied when the report showed a blend of two of the descriptors. While these scores were directly used in the assessment of the final report, the specific weighting of each aspect in determining overall grade was left up to the individual instructor and varied from section to section. This approach ensured an assessment as free from bias as possible while still providing individual instructor freedom on students' final grades.

The rubric used is sub-divided into two categories: a communication rubric and a project-specific rubric. The communication rubric addresses aspects of the report, namely Organization; Clarity and Presentation; Abstract/Summary; and Figures, Tables, and Graphics. These aspects specifically measure effective communication and are applicable to deliverables stemming from most any project. These same communication rubrics were used for other engineering projects during the spring 2019 semester. The rubric for the remaining four categories- Scenario; Ideation and Design Process; Product Prototype; and Final Design and Recommendations- were designed to measure student achievement of the technical and EM-related goals of the UD project. These four categories are included in the Appendix with descriptors.

The authors developed a mapping between the 4 project-specific categories and the KEEN "three C's." The KEEN leadership team, which has developed a significant level of expertise in the KEEN EM framework, determined the mapping with the goal of analyzing each project rubric element and how it best aligns with the KEEN 3Cs. Using indicators as evidence of student achievement of desired learning outcomes has been well established. This assessment strategy is patterned after that recommend by ABET, in which concrete student actions are used as "performance indicators" that are mapped to the desired broad student outcomes [23]. The mapping between the 3Cs and the rubric items were not made explicit to the students. So while students can work at addressing items outlined on the rubric, they had zero knowledge of how those items may (or may not) align with EM. Several rubric items had no EM mapping (namely, the communication-specific rubric items mention above).

The first category (Scenario) was mapped to “Curiosity.” The authors contend that a student team that demonstrates an understanding of the role of the product and the customer, and how this will inform the design exemplifies curiosity. Ideation and Design Process and Product Prototype were mapped to “Connections,” because this portion of the rubric is measuring how well the students connect brainstormed ideas to design criteria and constraints. This task is reminiscent of the following statement from KEEN’s Framework Poster: “Students must be taught to habitually pursue knowledge and integrate it with their own discoveries to reveal innovative solutions”. Finally, Final Design and Recommendations is mapped to “Creating Value,” because this portion of the rubric is evaluating the students’ understanding of and analysis of the design of the product and how it was informed by the prototype stage.

Results & Discussion

Final Design Report Rubric

Rubric scores for the final design report for the project across 15 sections of our first-year engineering course was used for the primary data analysis. The goal of the analysis is to investigate how student teams scored across the four KEEN-related rubric items, identify which aspects of EM were most targeted by the UD project, which aspects need further development, and explore how the KEEN-related rubric items are related to each other. Table 3 summarizes the rubric scores for 79 teams across 15 sections.

Table 3. Summary of Rubric Scores for Final Report (5=excellent, 3=minimally acceptable, 1= unacceptable

	EM Aspect	**Average Score**	**Standard Deviation**
Scenario	Curiosity	4.22	0.86
Ideation and Design Process	Connections	3.96	0.97
Product Prototype	Connections	4.37	0.83
Final Design and Recommendations	Creating Value	4.16	0.81
Organization	N/A	4.11	0.86
Clarity and Presentation	N/A	4.20	0.85
Abstract/Summary	N/A	3.95	1.10
Figures/Tables/Graphics	N/A	3.80	1.11

Overall, student performance was generally very good; with average scores across all rubric items around 4 (recall the maximum is 5 for each item). Students were particularly strong in the areas related to “Product Prototype” (Connections) which corresponds to descriptions of the prototype, how it was assembled, and how it does (or does not) align with product criteria.

Higher scores for this item also relate to a team's ability to discuss what was learned from making the prototype. This EM-related rubric item had the highest average score and a relatively smaller standard deviation, which initially suggests that most student teams were able to effectively discuss their prototype and make connections between it, the product criteria, and the design process more broadly. On the other hand, the "Ideation and Design Process" (Connections) rubric item had the lowest average score across the EM aspects and a higher standard deviation. This points to a potential area of further development in helping students through the brainstorming process and providing more support around connecting design decisions to appropriate rationale. The high(er) standard deviation suggests that teams either did this very well or struggled. It's worth highlighting that the highest and lowest scoring EM-related rubric items are both focused on 'Connections'. At a high level, this could mean that while students could connect their prototype to design criteria fairly well, they underperformed in the initial brainstorming phase by not considering all design rationale and considerations in the process. We need to do more on the front end of the project to assist students through proper ideation techniques and the consequences it has on the design process.

Our next line of investigation involved exploring the relationships between the rubric items (EM-related and Communication-related). We did this using Kendall's Rank Correlation Coefficient (i.e., Kendall's τ) which is a non-parametric statistic used to measure ordinal association between two quantities. In other words, it measures how similar the orderings of two data sets are when ranked by quantiles. This was chosen over Pearson's Correlation Coefficient because our data is not considered normally distributed and was chosen over Spearman's Rank Correlation Coefficient due to its sensitivity to error (though usually leads to the same inferences). Table 4 reports Kendall's τ for each pair of EM-related rubric items and communication-related items for the final reports.

Table 4. Summary of rubric-item relationships using Kendall's Rank Correlation Coefficient (τ) (maximum = 1, minimum = 0)

Kendall τ correlations	Scenario	Ideation and Design Process	Product Prototype	Final Design and Recommendations
Scenario	*	0.49	0.46	0.36
Ideation and Design Process	0.49	*	0.41	**0.51**
Product Prototype	0.46	0.41	*	0.36
Final Design and Recommendations	0.36	**0.51**	0.36	*
Organization	0.28	0.34	0.29	0.36
Clarity and Presentation	0.06	0.13	0.18	0.18
Abstract/Summary	**0.48**	**0.45**	0.30	0.28
Figures/Tables/Graphics	0.16	0.32	0.37	**0.46**

Red indicates highest value of τ for EM-related rubric items
Blue indicates highest values of τ for communication-related rubric items

We gleaned several takeaways from the analysis conducted above, though these are merely suggestions based on an initial exploratory analysis the rubric items and their relationships:

- There seems to be a stronger relationship between "Ideation and Design Process" (Connections) and "Final Design and Recommendations" (Creating Value). A high score in the latter involves providing clear and complete design that accurately (and thoughtfully) reflects the design process. Combining this with the results in Table 3 suggests that in order to help our students create value with their final designs of their toys, we need to put more emphasis on the ideation and design process earlier in the project by encouraging and supporting students to make decisions on all relevant issues and criteria.
- The quality of a team's Abstract/Summary was the most strongly correlated with Scenario and Ideation, and less so with Product Prototype and Final Design and Recommendations. A possible rationale for this is a team might have intriguing ideas and a good understanding of project goals but make some questionable decisions in their design process. Such a team could write a summary that sounds compelling, with the flaws only becoming evident through the detail of the full report. However, if a team had a flawed understanding of the goals of the project that is a shortcoming that would probably be evident even in the abstract or summary.

However, there are some limitations to this work. As the project was implemented across 15 sections of the first-year course, 12 instructors were involved in the assessment of the project using the rubric developed by the authors. There is inherent variability in instructors' conceptions of the rubric items and in their grading standards, so it is possible that differences observed between sections is due not to the performance of teams but to the instructor(s) whose students examined those teams. We spoke to the faculty prior to their use of the rubric to highlight each of the items and what they were intended to measure. The faculty have also worked extensively with the course's project rubrics and hence the authors feel comfortable with what should be looked for in student's report when grading.

Conclusions

We implemented a project related to the design of children's toys, that leverage the principles of Universal Design, in a multidisciplinary, first-year engineering course. The project also intentionally integrated aspects of EM by incorporating them into the overall project learning outcomes, creating reflection prompts that have students think through their design and teamwork process in relation to the 3Cs (Curiosity, Connections, and Creating Value), and crafted a project rubric that benchmarked the performance of each team and mapped each four rubric items to the 3Cs. Our results showed that student teams performed reasonably well in relation to the rubric items linked to the 3Cs. Students were particularly successful at describing their final prototype, how it was assembled, and connecting that to original product criteria. Students were not as successful at demonstrating the brainstorming process (including considering numerous alternative designs) at the beginning of the project. This suggests that while students are able to talk about their final product and how it does or does not meet customers' needs and criteria, their ability to brainstorm and discuss how they chose between alternative design decisions was still lacking. This leads the authors to believe that the instructors need to more thoroughly describe and instruct their students on ideation, including concepts such as divergent and convergent thinking and/or design heuristics to aid in this process. Results also showed the strongest relationship existed between "Ideation and Design Process" (Connections) and "Final Design and Recommendations" (Creating Value). Considering that the latter rubric item involves clearly communicating a thoughtful design process and how it resulted in their final design, this makes logical sense. But it also reinforces a somewhat implied relationship – improving a student's ability to make connections is related to their ability to create value for a customer (and communicate that value). In fact, all of four of the EM-related rubric items had correlations above 0.30. This is not a high number, but it does support the notion that all 3C are interrelated and can/should be emphasized throughout a design project (i.e., it's not enough to focus on just one element of the EM, they must work in conjunction with each other).

In future work, the authors also plan to analyze responses to the reflections, especially the ones related to the 3Cs. This will give us more insight into the students mindset throughout the project and how that may (or may not have) contributed to their overall final design report and product. Additionally, we plan to interview instructors to better understand their interpretations of the project goals and rubric categories, especially as it relates to EM.

References

[1] C. Bodnar, R. Clark, & M. Besterfield-Sacre, " Lessons learned through sequential offerings of an innovation and entrepreneurship boot camp for sophomore engineering students," *Journal of Engineering Entrepreneurship*, vol. 6, no. 1, pp. 52–67, 2015.

[2] C. D'Amours, C. Lague, & F. Mellor, "Entrepreneurship Curricula and Competitions in the Faculty of Engineering of the University of Ottawa," in *Proceedings of the American Society for Engineering Education. Austin, TX,* 2009.

[3] KEEN. About. https://engineeringunleashed.com/about.aspx. Accessed on February 1st, 2020.

[4] A. Bernal, P. Brackin, R.A. House, J.P. McCormack, A. Watt, & B. Riley, " Entrepreneurial Thinking in a First-Year Engineering Design Studio," in *ASEE 2017 Annual Conference and Exposition,* Columbus, OH, 2017.

[5] Fraley, M., Mary R., & Gretchen H. "Work-in-Progress–Entrepreneurial Mindset in First-Year Engineering Courses." In *First-Year Engineering Experience (FYEE) Conference*, pp. 24-16. 2018.

[6] Huerta, M.V., Jeremi London, Amy Trowbridge, Marvyn Arévalo Avalos, Wen Huang, and Ann McKenna. "Cultivating the entrepreneurial mindset through design: Insights from thematic analysis of first-year engineering students' reflections." In *ASEE Annual Conference and Exposition, Conference Proceedings*, 2017.

[7] Jensen, Matthew James, and J. L. Schlegel. "Implementing an entrepreneurial mindset design project in an introductory engineering course." In *ASEE Annual Conference and Exposition, Conference Proceedings*, 2017.

[8] Park, H, "Fostering and Establishing an Engineering Entrepreneurial Mindset through Freshman Engineering Discovery Courses Integrated with an Entrepreneurially Minded Learning (EML) Pedagogic Approach", *First Year Engineering Experience (FYEE) Conference*, August 6-8, 2017. Daytona Beach, Fl.

[9] C. Wang, "Teaching Entrepreneurial Mindset in a First-Year Introduction to Engineering Course," *ASEE 2017 Annual Conference and Exposition*, Columbus, Ohio, 2017.

[10] Rover, D. T., "New Economy, New Engineer", Journal of Engineering Education, vol. 94, pg. 427–428, 2005.

[11]Melton, D. Stacking Entrepreneurially Minded Learning Alongside Other Pedagogies,KEENzine, Issue 3, pages 6-9, http://online.fliphtml5.com/zyet/hofr/#p=1

[12] N. Duval-Couetil, A. Shartrand, and T. Reed, "The role of entrepreneurship program models and experiential activities on engineering student outcomes," Adv. Eng. Educ., vol. 5, no. 1, pp. 1–27, 2016.

[13] T. Standish-Kuon and M. P. Rice, "Introducing engineering and science students to entrepreneurship: Models and influential factors at six American universities," *J. Eng. Educ.*, vol. 91, no. 1, pp. 33–39, 2002

[14] Wheadon, J., & Duval-Couetil, N., "Elements of Entrepreneurially Minded Learning: KEEN White Paper", *Journal of Engineering Entrepreneurship*, vol. 7, no. 3, pg. 17-25, 2016

[15] E. Steinfeld & J. Maisel. *Universal Design: Creating Inclusive Environments*. John Wiley and Sons, 2012.

[16] NDA. (2019, June 9). What is Universal Design. Retrieved from http://universaldesign.ie/What-is-Universal-Design/.

[17] Center for Universal Design. *The Principles of Universal Design, Version 2.0.* Raleigh: North Carolina State University, 1997.

[18] B. Connell et al. *The Principles of Universal Design*, 1997. Retrieved from www.ncsu.edu/www/ncsu/design/sod/cud/about_ud/udprinciplestext.htm.

[19] R. Cooper & A. Dreher, “Voice-of-Customer Methods: What is the Best Source of New Product Ideas?” Stage-Gate International, 2010. Retrieved from https://www.stage-gate.com/new-product-development-process/voice-of-customer-methods-what-is-the-best-source-of-new-product-ideas/.

[20] Daly, S.R., Yilmaz, S., Christian, J.L., Seifert, C.M. and Gonzalez, R., “Design heuristics in engineering concept generation,” *Journal of Engineering Education*, vol. 101, no. 4, pp.601-629, 2012.

[21] Otto, K and K Wood. *Product Design: Techniques in Reverse Engineering and New Product Development (1st Ed.)*. Upper Saddle River, New Jersey, USA: Prentice Hall, 2001.

[22] Eastman Kodak Company (Ed.). *Ergonomic Design far People at Work*, vol. 1 . New York: Van Nostrand Reinhold, 1983

[23]ABET Revised Student Outcomes, 2018. Retrieved from https://www.abet.org/wp-content/uploads/2017/02/Student-Outcomes-and-Performance-Indicators_revised.pdf

Appendix – Rubric for Universal Design Final Reports

Table 5. Rubric for Universal Design Final Reports (Note – ratings between 2 and 4 indicate a blend of performance of the item descriptions)

Category	**Mapped 3C**	**5 (Excellent)**	**3 (Minimal Acceptable)**	**1 (Unacceptable)**
Organization		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's going on.
Clarity and Presentation		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		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		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 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.	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.