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Work in Progress: Igniting Engineering Fundamentals—A Holistic Approach to First-Year Engineering with Entrepreneurial-Minded Learning and a Project-Based Exploration of Mars

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Introduction

The first-year course, Engineering Fundamentals, was conceived to address the demand for a more comprehensive and engaging introductory engineering experience. In this context, the ongoing initiatives are represented by a meticulously designed effort to amplify the impact on students' interest in engineering. The objective extends beyond merely acquainting engineering students with the intrinsic beauty of the discipline; they are also aspired to be challenged in a secure and enjoyable manner. This paper aims to unveil the motivations, structural framework, and initial outcomes of our reimagined first-year seminar, with a specific focus on evaluating precise engineering skills through the application of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) survey [1].

As a pivotal component of this transformative initiative, we introduce the "Mission to Mars" project, serving as a cornerstone within the Engineering Fundamentals course. Far beyond a conventional educational endeavor, this project epitomizes the commitment to instilling an entrepreneurial mindset [2] in students. This approach is meticulously designed to not only expose students to the challenges and wonders of engineering but also to foster an innovative and entrepreneurial spirit.

The KEEN Framework

The Kern Entrepreneurial Engineering Network's (KEEN) 3Cs framework [2], consisting of Curiosity, Connections, and Creation of Value, is a foundational guide for fostering entrepreneurial mindset and skills among engineering students. Curiosity emphasizes the importance of an inquisitive nature and an eagerness to explore innovative ideas and concepts. Connections highlight the significance of collaboration and networking and connect with their soundings, locality, and prior knowledge on certain topics. Creation of Value underscores the entrepreneurial spirit of adding meaningful contributions to society, encouraging students to go beyond problem-solving and actively create positive solutions. This framework provides a comprehensive approach to developing the multifaceted skills required for success in entrepreneurial endeavors within the engineering field.

Engineering Student Entrepreneurial Mindset Assessment (ESEMA) Survey

The Engineering Student Entrepreneurial Mindset Assessment (ESEMA) is a self-report instrument developed by Brunhaver et al. [1]. It is designed to assess entrepreneurial mindset (EM) in undergraduate engineering students, based on the Kern Entrepreneurial Engineering Network's 3Cs framework - Curiosity, Connections, and Creation of Value [2]. The instrument includes 34 items within seven factors: Ideation (Id), Open-Mindedness (OM), Interest (In), Altruism (Al), Empathy (E), Help Seeking (HS), and an Unnamed (U) factor for negatively worded items. Table 1 shows the factors and items of the instrument. Carroll et al. [3] integrated the used of the ESEMA into a first-year civil engineering curriculum. Their study demonstrates notable improvements in entrepreneurial attitudes among students, particularly in ideation and help-seeking behaviors, as revealed by the ESEMA survey.

Table 1—Engineering Student Entrepreneurial Mindset Assessment Items [1]

Factor 1: Ideation (Id)	
1.	I like to reimagine existing ideas
2.	I like to think about ways to improve accepted solutions
3.	I typically develop new ideas by improving existing solutions
4.	I like to think of wild and crazy ideas
5.	I tend to challenge things that are done by the book
6.	Other people tell me I am good at thinking outside the box
7.	I prefer to challenge adopted solutions rather than blindly accept them
8.	I tend to see my ideas through even if there are setbacks
9.	I look for new things to learn when I am bored
Factor 2: Open-Mindedness (OM)	
10.	I am willing to consider an idea put forth by someone with a different background than my own
11.	I am willing to compromise if another idea seems better than my own
12.	I appreciate the value that different kinds of knowledge can bring to a project
13.	I appreciate the value that individuals with different strengths bring to a team
14.	I recognize that people with different backgrounds from my own might have better ideas than I do
15.	I am willing to learn from others who have different areas of expertise
16.	I recognize the importance of other fields even if I don't know much about them
17.	I am willing to update my plans in response to new information
Factor 3: Interest (In)	
18.	I tend to get involved in a variety of activities
19.	I enjoy being involved in a variety of activities
20.	I participate in a wide range of hobbies
Factor 4: Altruism (Al)	
21.	The idea of tackling society's biggest problems does not motivate me (reverse scored)
22.	I believe it is important that I do things that fix problems in the world
23.	I am driven to do things that improve the lives of others
Factor 5: Empathy (E)	
24.	I can easily tune into how someone else feels
25.	Other people tell me I am good at understanding their feelings
Factor 6: Help Seeking (HS)	
26.	I know when I need to ask for help
27.	I am comfortable asking others for help
Factor 7: Unnamed (U)	
28.	I prefer what I am used to rather than what is unfamiliar (reverse scored)
29.	I would rather work with what is familiar than what is unfamiliar (reverse scored)
30.	I am less likely to change directions on a project after putting forth a lot of effort (reverse scored)
31.	I tend to resist change (reverse scored)
32.	I like to work on problems that have clear solutions (reverse scored)
33.	I prefer tasks that are well-defined (reverse scored)
34.	I tend not to do something when I am unsure of the outcome (reverse scored)

Background and Significance

The concept of the "Mission to Mars" project is based on the collective vision of our diverse faculty members, each contributing unique perspectives to its development. As we endeavored to enhance students' interest in engineering the Mission to Mars concept emerged organically. While the Mars colony project for the first-year design project has been implemented in the past [4], our approach has a heavy hands-on component and aims to incorporate all engineering majors into the project. Aligned with our dedication to instilling an entrepreneurial mindset [2] in students, the project in this course has transformed into a comprehensive learning experience with interdisciplinary relevance, showcasing contributions from all six engineering majors offered: aerospace, biomedical, civil, computer, electrical, and mechanical engineering. Besides this, Engineering Fundamentals utilizes additional elements to fulfill the First-Year Engineering Seminar Core requirement in various programs. A detailed account of the activities and outcomes of the "Mission to Mars" project has been compiled in a KEEN card [5]. This paper focuses on results from the Engineering Student Entrepreneurial Mindset Assessment.

Introducing All Six Engineering Majors

Before this course was created, first-year engineering students enrolled in one of five different introductory courses; four were focused on specific majors (aerospace and mechanical, electrical and computer, civil, biomedical) and the fifth introduced all six. From the outset, this course was intended to replace all five of those courses with a single common introductory class. And as a common course, one of the goals is to provide incoming students with information and experiences to help them choose their major or at least confirm that they want to continue in their selected major. At present, this goal is carried out in two ways. First, six class meetings are devoted to the majors; each major has one dedicated class period with each section: the Major Day. Typically, a Major Day involves an overview of the major through a review of the curriculum and a discussion of career options. Then, the bulk of the time is spent in a hands-on design activity that illustrates aspects of the major (for example, building prosthetic hands to do a task in biomedical engineering, or creating a potato clock in electrical engineering.) The second way of allowing students to explore different majors is through the study of a wicked problem. The current wicked problem is designing an outpost on Mars. The course comprised eight sections with approximately 20 students each, taught by six instructors and six teaching assistants.

Project General Description

The "Mission to Mars" project spanned six weeks, unfolding in three distinct stages for a dynamic learning experience. In the initial 1.5 sessions, students construct basic prototypes using MOLA structure sets, LEGO kits, and programmable electronic boards. The subsequent three sessions focus on refining designs in response to evolving specifications, fostering critical thinking. The project reaches its apex in the final 1.5 sessions, where students tested prototypes against specific metrics and prepare presentations showcasing their design journey. Elevator pitches and posters enable students to communicate their engineering solutions effectively, enhancing both technical prowess and presentation skills.

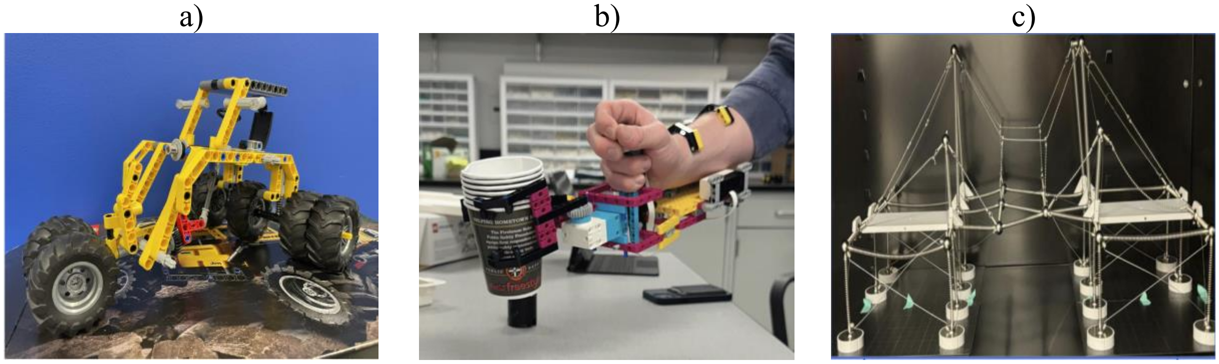
Integrating the 3Cs Framework in Mission to Mars

The project incorporates Curiosity, Connections, and Creating Value into its framework. Students stimulate their curiosity through innovative challenges and scenarios linked to Mars exploration in the project modules. The challenges in the modules need creative problem-solving, eased by the iterative engineering design process and immersive hands-on activities. The interdisciplinary naturally fosters connections between various engineering disciplines and their tangible applications in the real world. The entire project is based on the central theme of Creating Value for the future habitation of Mars.

Project Modules

In a six-team structure with a maximum of four members each, students engaged in six modules over six weeks, intricately designed to align with specific engineering majors. Figure 1 shows students' final prototypes and simulations, the pictures were taken during class, and were presented by students in their posters.

a) b) c)



d) e) f)

Figure 1 – Final Prototypes and Simulations a) Aero Transportation Module [6], b) Communications Module [7], c) Electrical Power Module [8], d) Exploration Module [9], e) Life Support Module [10], f) Living on Mars Module [11].

Aero Transportation

The Aero Transportation Module focused on aerospace engineering using the Lego Technique Firefighter Aircraft [12]. In the initial phase of the Mission to Mars Project, students built a Firefighter Aircraft LEGO model following detailed instructions. After assembly, precise measurements of the model's dimensions and weight were taken, laying the foundation for subsequent aerodynamic analysis. These measurements serve as critical inputs for the analysis and optimization of the model's flight dynamics, preparing students for the challenges of Martian flight in later stages of the project. After completing the initial LEGO model, students transitioned to the redesign phase. In this stage, the focus shifts to optimization for Martian conditions. Students dismantled the original aircraft while retaining crucial components such as the propulsion system. Armed with measurements from the previous phase, students undertake recalculations to account for the gravity and atmospheric density on Mars. This phase challenged students to think critically and creatively as they strive to improve the aircraft's performance and efficiency. In the final part of the module, students apply their redesigned concepts to construct a new iteration of the aircraft. They implement design modifications aimed at minimizing power requirements and achieving sufficient lift while ensuring stability and structural integrity in Martian conditions. Throughout the rebuilding process, students adhered to specific design criteria, including maintaining volume coefficients and payload functionality. Once the redesigned aircraft is complete, students conduct comprehensive evaluations to assess its flight properties on Mars, refining their designs iteratively to achieve optimal performance. This hands-on approach not only familiarizes students with aerospace engineering principles but also underscores the significance of accuracy and attention to detail in aircraft design.

Communications Module

In the Communications Module, linked with computer engineering, students connected electronic boards to explore real-world applications in computer engineering. The communication module entails a three-stage exploration where students tackle the intricate communication needs of a Mars outpost. Beginning with the identification of communication requirements, students proceed to design solutions using carefully selected hardware elements. The subsequent stage involves the simulation of student-designed solutions within a custom hardware block environment, with an iterative process employed for continuous improvement until a stable solution was achieved. Evaluation parameters encompass the depth of identified communication needs, the solution's efficacy, and the transportation weight, a critical factor for Mars missions. Throughout the investigative phase, students delved into diverse communication scenarios, including work-related interactions, recreational activities, infrastructure monitoring, control processes, and safety protocols. By drawing parallels between Earth and Mars communication practices, students explore potential similarities and differences. Identified communication tasks are categorized based on bandwidth and latency requirements, guiding students to select hardware from a provided list. This approach strikes a balance between structured guidance and creative freedom, fostering individualism in crafting unique solutions. The designed network became the start point for students to configure custom hardware nodes, generating simulated data with specified latency parameters between each node. The simulation process encompasses message generation, latency measurement, and dynamic adjustments to traffic levels based on identified nominal levels and building occupancy patterns. Visual feedback from nodes, including current rate and latency numbers, offered insights into network status. The obtained results become a cornerstone for iterative solution enhancements, aligning with identified requirements, and provide students with a valuable opportunity for self-assessment of their communication solution against Mars-specific needs.

Electrical Power

The Electrical Power Module, centered on electrical engineering, utilized electronic boards for simulations, addressing power needs and navigating electrical power system complexities. This module had three stages where students had to address the diverse power needs of a Mars outpost.

Commencing with the identification of power requirements, students embarked on designing solutions for generating and distributing adequate power to meet the identified demands. The subsequent phase involves the simulation of student-designed power solutions within a custom hardware block environment, employing iteration for continual refinement until a stable solution simulation is achieved. Evaluation criteria encompass the depth of identified power needs, the efficacy of the solution, and the transportation weight consideration for Mars missions. During the investigative phase, students explore power scenarios during various activities, such as work, recreation, climate control, food storage, preparation, lighting, and manufacturing. Encouraged to draw inspiration from Earthly activities, students contemplate the similarities and differences in power usage on Mars. Identified power tasks are allocated to different buildings, including the habitat, garage/repair shop, and work/office space. Students then choose generating technology and distribution hardware from a predefined list, balancing guidance with creative freedom for diverse solutions. Using the designed power network as a foundation, students configure custom hardware nodes to simulate power generation, consumption, transmission losses, and delivered voltages. The simulation incorporated dynamic adjustments based on identified nominal levels and building occupancy patterns, mirroring real-world scenarios. Visual feedback from nodes, including current rate and latency numbers, provides insights into the network's status.

Exploration Module

The Exploration Module, coupled with mechanical engineering, challenged students to design Martian exploration vehicles. In the first phase, students assembled a Martian exploration vehicle using LEGO Jeep Wrangler [13]. Students were asked to *think* about the Martian terrain and navigation challenges. The second phase involved an alternate build, where students identify essential and non-essential components, prioritize weight reduction, and modify the vehicle for Martian exploration. This phase encourages students to *address* challenges that are specific to the Martian environment. The third phase focused on the challenges of Martian exploration, highlighting the need for adaptability, durability, and resource efficiency. Students *developed* a modified prototype with new design specifications, guiding them towards a comprehensive learning experience that extends beyond engineering majors. The new specifications included: a) a steerable front end for precise navigation, b) front and rear axle articulation for enhanced terrain adaptability, c) rear-mounted winch for additional mobility, d) removable roof for easy access and adaptability to different missions, e) four front-mounted tractor lights for improved visibility, and f) engineering to survive a drop test from 12 inches on Martian-like terrain. The module concludes with students determining the center of gravity for both the original and modified builds, examining physics concepts related to stability and mass distribution.

Life Support Module

The Life Support Module, associated with biomedical engineering, involved developing exoskeletons using the Lego SPIKE Prime set [14] pieces. The first stage concentrated on delivering a practical learning experience and comprehending life support systems outside Earth's confines. By utilizing the Lego-Spike app and targeted lessons, students established the foundation for innovative solutions, preparing them for the intricacies associated with sustaining life on Mars. The specific activity initiated during this phase was named "Super Cleanup" [15]. The second part students were asked to construct an exoskeleton assistive hand using the Lego Spike Prime set and the expansion pack, utilizing specific requirements. These constraints included a) utilizing only components from the designated Lego Spike kit or its expansion set, b) enabling the user to grasp a grip and trigger hand actuation with a button, automatically latching onto the forearm, supporting both the exoskeleton hand and the lifted weight, lifting a minimum of 0.5 kg (1.1lbs), and c) ensuring interchangeability of the hand portion between at least two different styles or sizes.

Life On Mars Module

The Living on Mars module, linked to civil engineering, centered on innovative building design and space use, applying civil engineering concepts to Mars habitation challenges. Each group of students first constructed a Mola structure that was predesigned using the three standard Mola sets. Step-by-step LEGO-style instructions were created to guide the students through the initial construction process and to familiarize them with most of the structural features available in the Mola structural kits. Following their initial build, each group was provided with specific requirements and constraints for a Martian Habitat. They were tasked with designing and constructing the most-efficient, stable structures that satisfied the given requirements and constraints. Following the design process, each group was also tasked with determining the most efficient construction process. On the last day of class, each group was timed as they constructed their structure to determine which group was the most efficient. Following construction, each structure was subjected to a "windstorm" using two industrial fans.

Methods

There were 186 students in the course in the fall of 2023 spread across eight sections with no more than 24 students in a section. A total of 129 students completed both the pre- and post-surveys resulting in a response rate of 69.4%. Responses from other students who only completed one of the two surveys or left questions blank were removed from the data. Each Likert scale response was coded from 1-5 as directed by Likert et al. [16] with questions 21 and 28-34 reverse scored. The responses were divided into the seven factors and added together separately for the pre- and post-tests for each respondent. The seven factors are Ideation (Id), Open-Mindedness (OM), Interest (In), Altruism (Al), Empathy (E), Help Seeking (HS), and Unnamed (U) as previously described. The total number of questions for each factor were 9, 8, 3, 3, 2, 2, and 7, respectively. The data was analyzed in SPSS. First, the data for each factor and total score for both the pre- and post-tests were checked for normality and outliers. There were six outliers, all of which were removed from data set given that each factor contributes to the overall total. The data were re-checked for normality and means, and standard deviation calculated for each factor and the total score for the pre- and post-tests.

Results and Discussion

Table 2 shows a summary of the results. Ideation, Interest, Help Seeking, and Unnamed had an increased mean score; the other factors saw a decrease in mean score. Ideation increased by 1.85; Interest increased by 0.33; Help Seeking increased by 0.28; and Unnamed increased by 0.21, while Open-Mindedness decreased by 0.67, Altruism decreased by 0.12; and Empathy decreased by 0.02. The total average score increased by 1.86. The pre- and post-survey data for Ideation and the overall total were normally distributed with significance values greater than 0.05 from the Shapiro-

Wilk test [17]. All other factors were not normally distributed. A parametric paired t-test was performed on the Ideation and overall total scores, both of which had p-values less than 0.05. Therefore, both showed statistically significant increases from the pre- to post-test. The data for all other factors were non-parametric (NP). A non-parametric Related-Samples Wilcoxon Signed Rank Test was performed on each data set, none of which were shown to have a statically significant difference (increase or decrease). All p-values were greater than 0.05.

Table 2—Descriptive statistics of pre- and post-test ESEMA surveys

	Pre-survey			Post-survey				
Factor	Mean	St. Dev.	Shapiro-Wilk Sig.	Mean	St. Dev.	Shapiro-Wilk Sig.		p-value
Id	29.91	5.47	0.425	31.76	5.65	0.509	P	<0.001
OM	37.00	3.17	<0.001	36.33	4.16	<0.001	NP	0.123
In	11.17	2.62	<0.001	11.50	2.32	<0.001	NP	0.067
Al	11.79	2.12	<0.001	11.67	2.16	<0.001	NP	0.466
E	7.58	1.82	<0.001	7.56	1.82	<0.001	NP	0.835
HS	6.55	2.23	<0.001	6.83	2.02	<0.001	NP	0.118
U	20.13	4.27	0.101	20.34	4.75	0.173	P	0.485
Total	124.13	12.43	0.104	125.99	12.74	0.508	P	0.032

Conclusions, Lessons Learned and Moving Forward

In conclusion, this reimagined first-year engineering seminar, anchored by the "Mission to Mars" project, represents a pioneering effort to ignite students' passion for engineering while instilling an entrepreneurial mindset. Through the integration of the KEEN framework's 3Cs - Curiosity, Connections, and Creation of Value - we have successfully crafted a curriculum that transcends traditional boundaries, fostering innovation, collaboration, and creative problem-solving. The analysis of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA) survey data underscores the tangible impact of our approach on students' entrepreneurial mindset. The study's quantitative analysis, involving 186 students across eight sections, revealed a response rate of 69.4%. Through meticulous data analysis using SPSS, it was observed notable increases in mean scores for Ideation, Interest, Help Seeking, and Unnamed factors, reflecting positive shifts in students' entrepreneurial mindset. Significant improvements in factors such as Ideation, Interest, and Help Seeking highlight the efficacy of our course in nurturing the multifaceted skills essential for success in engineering and entrepreneurial endeavors. Our findings indicate modest statistically significant improvements in Ideation and overall total scores from pre- to post-tests, validating the effectiveness of this pedagogical approach. Lessons learned from this study will inform future iterations of the course, ensuring continued refinement to better prepare students for dynamic challenges in engineering and entrepreneurship. Methods to enhance the student experience are currently being evaluated, with an assessment planned during the summer following analysis of data from the spring semester, aiming to conduct a longitudinal study to track progress over time.

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