Analysis of the Entrepreneurial Mind-set Elements in Established First-year Engineering Labs: Analysis Process and Lessons Learned and Changes for the Future

Mr. Nicholas Rees Sattele, Ohio State University

Nicholas is an Undergraduate Research Associate with The Ohio State Department of Engineering Education. He is in the process of completing a B.S. in Computer Science and Engineering in the Integrated Business and Engineering Honors Program at Ohio State. His interests include incorporating Entrepreneurial Minded Learning into engineering coursework and interdisciplinary innovation.

Dr. Krista M. Kecskemety, Ohio State University

Krista Kecskemety is an Assistant Professor of Practice in the Department of Engineering Education at The Ohio State University. 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 connection between the two.

Dr. Kadri Akinola Akanni Parris, Ohio State University

Dr. Kadri A.A. Parris is a Senior Lecturer in the Department of Engineering Education at The Ohio State University (OSU). He is the holder of a Master's Degree in Transportation Engineering and received his Doctorate in Civil Engineering (Geotechnical) with a concentration in Pavement Design, both at OSU. In addition, he holds Project Management Professional (PMP) certification with the Project Management Institute (PMI). Dr. Parris is actively involved in curriculum design, introduction of innovative pedagogies of engagement and the practice of engineering education through teaching several courses across the department. He is integrally involved in the design and delivery of the Pre-Freshman and Cooperative Education Program and others of that ilk at OSU, as a part of his specific interest in soft skill development, diversity, recruitment and retention initiatives, as well as public policy.

Analysis of the Entrepreneurial Mindset Elements in Established First-year Engineering Labs: Analysis Process and Lessons Learned and Changes for the Future

Abstract

Developing an Entrepreneurial Mindset in engineering students is important to developing students ready to embrace innovation and engineering in this ever-changing world. Developing this mindset must begin during the first-year of engineering. At The Ohio State University, an investigation was conducted to explore adding a formal Entrepreneurial Mindset curriculum into its existing curriculum for the first year, first semester course offering. This study consists of a document analysis of the existing lab documents in a first-year engineering course to find elements of the Entrepreneurial Mindset. Entrepreneurial Minded Learning (EML) as part of the Kern Entrepreneurial Engineering Network is said to include the elements of curiosity, connections, creating value, communication, character, and collaboration. Using an EML curriculum framework developed by the university, these lab documents were analyzed and coded to find themes of existing EML elements. Additionally, key missing areas were identified within the labs so modifications to the labs could be made to address more EML objectives. While these course assignments were not designed with EML in mind, they still contain many of the EML objectives that are in the EML curriculum framework. Details about the analysis process are included so other educators can follow a similar process to analyze their own existing courses and key lessons learned through the process.

Introduction

In response to declining retention in engineering programs, a number of large engineering schools began incorporating first-year engineering laboratory and project-based coursework to increase student retention and expose students to engineering disciplines outside their major [1-2]. Since then, Entrepreneurial Minded Learning (EML) has gained prominence and has been hypothesized to allow students to be more versatile and solve more modern, open ended problems. Indeed, Duval-Couetil [3] found that over two-thirds of engineering students believed that "entrepreneurship education can broaden…career prospects and choices," almost half were interested in taking EML classes, and those who did take EML classes felt more confident in communication and presentation, although not at a statistically significant level.

Additionally, The Kern Entrepreneurial Engineering Network (KEEN) has provided a framework for incorporating EML curriculum into engineering coursework with the goals of increasing curiosity, connections, and creating value. The Ohio State University is in the process of incorporating EML and KEEN principles into its first-year engineering curriculum. The first-semester half of the first-year engineering class contains several laboratory explorations and a design project that were designed to expose students to different disciplines and teach technical communication skills. These one-day laboratory experiences and multi-day design project were not designed with EML in mind, however, as the university incorporates EML into its curriculum, how well these labs already incorporate these principles is of interest. Therefore, this paper will investigate: *How much EML is already incorporated into the laboratory and design project curriculum and which areas of EML do each exploration lack?* To investigate this task, each lab was coded against an EML curriculum objective matrix that was developed to design and evaluate EML curriculum. This facilitated quantification as to how well each laboratory incorporated EML and identification of categories of EML each lab lack.

Background

The Course

This course is a first-year engineering, first-semester class intended as an introduction to engineering. The course is divided into lecture and laboratory segments. The lecture segment covers engineering problem solving in addition to basic algorithms and coding in MATLAB. The laboratory segment involves weekly, 80-minute meetings that allow students to participate in hands-on activities in a variety of engineering disciplines. Each laboratory has a required pre-lab reading, an in-lab document outlining the procedure, and a post-lab assignment. The pre-lab reading introduces the student to the engineering discipline investigated in each lab and provides all background, formulas, and concepts needed to complete and understand the lab. The in-lab document contains the lab procedure and a problem definition in the context that the student is working for a fictional company. Every lab is completed in groups, typically with four students. Finally, the post-lab assignment tasks the student with submitting a technical communication document including their results in the context of the fictional company they are working for. Typically, the submission is a lab report, memo, or executive summary due within a week. Occasionally, students must complete additional lab worksheets due before they begin their post-lab assignment to ensure the data they collected is valid.

Additionally, the Software Design Project was intended to serve as a final project to test students' coding skills in an open-ended exploration of computer science in a real-world team setting. This project is much longer and tasks students with investigating the business aspect of their project much more than the other labs.

Each lab is described below.

<u>1: Circuits</u>. Students built a number of circuits to demonstrate the validity of different current and voltage and resistance laws. In addition, the investigated why LEDs wired in series and parallel would remain lit when others were not functional. They then made recommendations to a fictional holiday light manufacturer as to which circuit, series or parallel, would be ideal to prevent the entire string from going out with one malfunctioning bulb.

<u>2: Beam Bending</u>. Three cantilever beams of known material and one of unknown material were provided to the students. They are required to then measure deflections of the beams under increasing load then use the data to identify an unknown beam. They then prepare a technical communication memo, individually.

3: Spot Speed Study. Students travel to a nearby road and conduct a spot speed study to analyze speeds of passing cars based on the time it takes each car to travel through a control length of road. Each student prepares a technical email and appropriate attachments.
4: Quality and Productivity. Students take on a variety of roles within a team to assemble three configurations of Mr. Potato Head toys in a timed setting. Two fictional customers submit orders for Potato Heads throughout three runs. In the first run, the manufacturing line is structured to produce in anticipation of demand, the second run is structured to manufacture only after orders have been submitted. Finally, students design a third run based on their profits from each run and qualitative observations to optimize their production, incorporating six sigma and lean manufacturing techniques. Teams typically reassign roles, fire workers, or redesign the layout of the manufacturing at their tables. Teams then do this final, optimized run. Students then write an executive summary, evaluating why different changes were implemented in the third run and how they would improve a future run.
5: Wind Turbine. Students research and design six turbine blades out of balsa wood. They then vary the number of blades used and test the amount of power generated in a small wind tunnel under relatively constant wind speed. Students then write a full lab report individually and recommend to a fictional housing developer if a turbine using that student's design could theoretically power a residential complex.
6: Artificial Muscle. Students use nylon fishing line to create a spring and measure its change in length under various weights and use a heat gun to vary its temperature. Students then complete a post lab worksheet, recording their data and evaluate the profitability of using this method for spring creation. Students also brainstorm potential applications of this technology.
Software Design Project (SDP). Students use knowledge of MATLAB taught in the lecture portion of the course to design a game. Students choose one or more games from a provided list to design or invent their own. Each game carried a point value and students could exceed the point requirements for extra credit. Students then conducted two user interviews to determine requirements for the game and created a team working agreement. Before coding began, students created a flowchart, algorithm, or pseudocode draft. Students then coded their chosen game(s). Additionally, students created a project notebook including a project schedule, business plan, advertisement, and project pitch video. Software documentation was also prepared including a user manual. Students were given multiple class sessions to complete their SDP.

Evaluating EML Curriculum

As entrepreneurial minded learning is gaining popularity, it is becoming much more common for universities to redesign their curriculum to incorporate it. However, there are significant barriers to redesigning entire curriculums and few ways to prove existing curriculum lacks EML to the extent a redesign is needed. This has highlighted the lack of a single, comprehensive framework to evaluate how "entrepreneurial" existing and future curriculum is. As EML has been incorporated, several frameworks have emerged intended to be used by EML programs to assess their effectiveness.

First, Purzer et al have provided a rather comprehensive review of assessments within EML [4]. They found that surveys were the most common tool to evaluate curriculum despite obvious self-report bias when asking students to evaluate themselves. This study also provided an assessment framework to evaluate EML assessment structure. Additionally, KEEN-TTI framework has provided a framework to assess EML [5]. As a survey, the KEEN-TTI framework allows measurement of student growth throughout their academic career, unlike the methods in this study. This framework assesses how much KEEN EML is instilled on the student and can allow educators to make high level curricular changes across a university.

While these frameworks and assessments adequately assess the growth of EML knowledge by students throughout courses, they provide little direction for educators to quickly assess their curriculum. For many, incorporating a survey or new assessment framework can be cumbersome, difficult to design, expensive, and time consuming, especially if only one aspect of the curriculum is being analyzed or if only slight changes to the curriculum is feasible. While a semester or yearlong design project may be the best way to make a course teach many aspects of the entrepreneurial mindset, it is sometimes not feasible or would detract from other learning objectives.

Methods

EML Curriculum Framework

As part of a larger study, faculty at this university participated in a month-long curriculum design institute to look at implementing EML in the first-year engineering courses. The curriculum design institute uses backward design to establish program goals, program objectives and proficiencies levels. In this instance the "Program" is an EML curriculum which would be infused into the standard undergraduate curriculum for engineering students. For the EML curriculum, there were 3 program Goals developed and from that 32 Objectives. This can be seen in Figure 1. For the first program goal, the objectives were subdivided into 3 categories: Opportunity, Design and Impact which correspond with the Engineering Skillset part of the KEEN Framework [6]. From the 32 objectives each one was then given a set of proficiencies: Beginner, Intermediate, and Advanced (although some included a 4th category of "Specialized" after Advanced or a 4th category of "Intermediate-Low" between Beginner and Intermediate). An example of one objective broken out into the 3 proficiencies is shown in Figure 2.

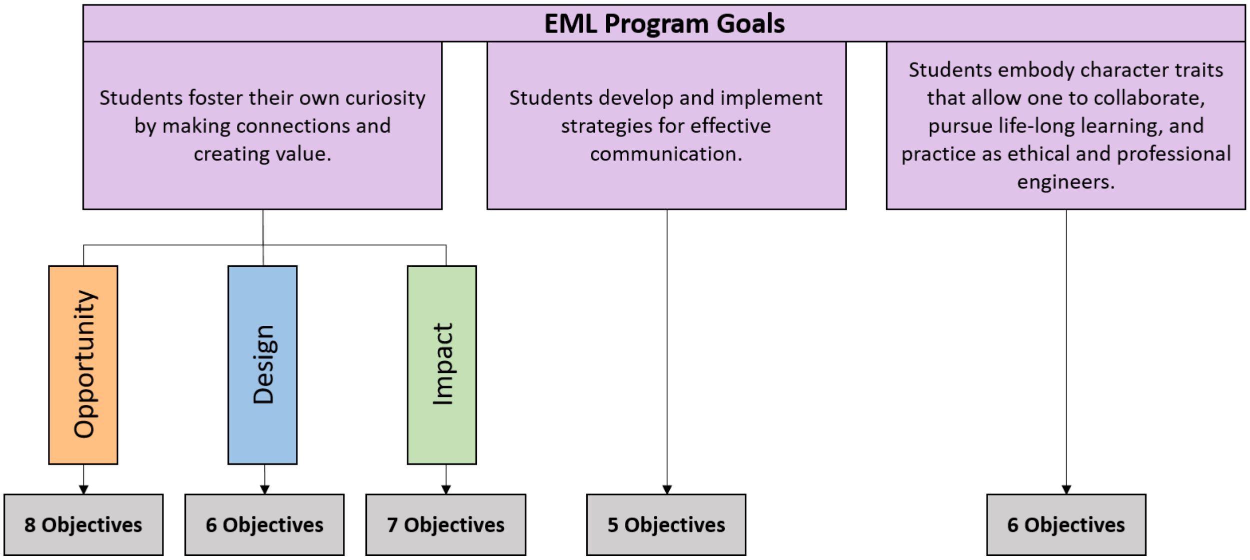

Figure 1: EML Curriculum Framework Program Goals

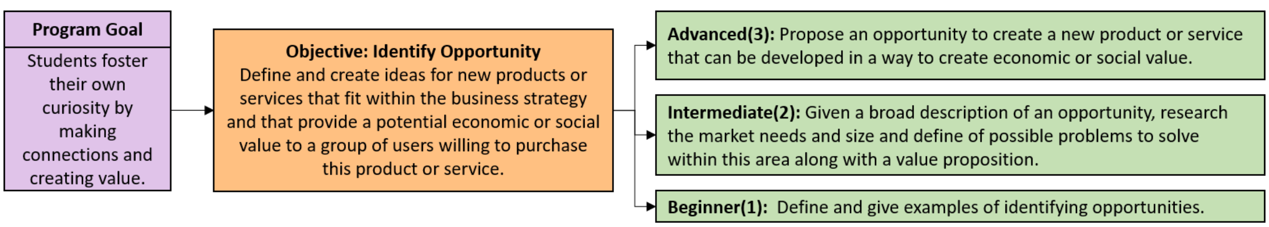

Figure 2: EML Curriculum Framework Proficiency Example

The ultimate goal of this curriculum framework was to use it to develop courses with these EML objectives in mind. However, the curriculum framework can also be used as a starting point to map current courses to EML. This will allow faculty to see the gaps that exist and allow modifications to the course rather than a complete redesign of the course.

Document Analysis

Each lab's procedure, background, and supplemental work including pre and post-lab materials provided the data for this study. The EML curriculum framework described above was used to evaluate each lab. Based on the proficiency levels each lab could then earn 0-3 or 0-4 points within each objective, using the specific descriptions for each proficiency level from each objective category. In total, the 32 objective categories provided a total of 99 possible points to be earned.

For each lab and the Software Design Project, the pre-lab, in-lab, and post-lab documents were read, analyzed, and coded to the curriculum objective matrix independently by two researchers. The two researchers were students who had completed the first-year engineering curriculum. One researcher had completed an EML infused version of the first-year engineering curriculum, and the other had completed the standard first-year engineering curriculum that included these labs and design project. Each lab was then granted a score (0-3 or 0-4) in each evaluative category depending on the lab's level of adoption of that category. The two researchers then discussed and reconciled their results into one final result set, which is what is presented in the results that follows.

Results and Discussion

After the final agreement was met on the scores, a summary of the overall scores was generated, as seen in Table 1.

Table 1: Summary Statistics from Final Data Set

Lab	Curiosity, connections, and creating value.				Communication	Collaboration, ethics and professionalism	Total
	Opportunity	Design	Impact	Total			
Circuits	5	5	4	14	8	3	25
Beam Bending	4	2	4	10	8	2	20
Spot Speed Study	5	2	3	10	10	4.5	24.5
Quality and Productivity (Q&P)	9	9	8	26	9.5	6	41.5
Wind Turbine	6	8.5	8	22.5	8.5	3	34
Artificial Muscle	4.5	7	6	17.5	7	2	26.5
Software Design Project (SDP)	14.5	11.5	7.5	33.5	14	11.5	59
Total Possible:	24	19	23	66	15	18	99

It can be seen that every lab failed to attain a majority of total points with the exception of the Software Design Project (SDP), which ranked first in most categories. The Quality and Productivity (Q&P) lab was also much higher performing than the other labs. The disparity between Q&P, SDP and the remaining labs was quite large in the first major category, with both of them scoring high in opportunity, design, and impact.

Additionally, with the exception of the Artificial Muscle lab, all got a majority of points in the communication category and, with the exception of the SDP, most labs scored low points in the final major category, 'Collaboration, ethics, and professionalism.'

Curiosity, Connections, and Creating Value

As seen in Table 1, most labs fell short in the Curiosity, Connections, and Creating Value category, the foundation of the KEEN program, while the Software Design Project (SDP), Quality and Productivity (Q&P), and Wind Turbine performed slightly better, although still lacking.

For the labs like Spot Speed, Beam Bending, and Circuits that scored low, their procedure primarily involves data collection and analysis. And while fictional companies are included to give these labs legitimacy, they don't task the student with identifying a problem or market, and at times did not require students to design something new or make tradeoffs. Rather, these are all provided in the background of the lab. In summary, very little social or economic value is generated in the low scoring labs. For example, the Circuits, Beam Bending, and Spot Speed Study labs don't task the student with ideation, iteration, weighing alternatives, or making tradeoffs. This can be seen in the extremely similar conclusions students reach in these labs.

However, the SDP and Q&P result in very different outcomes. Unlike the other labs, students are given the opportunity to take the lab in a direction of their choosing either through selecting and designing a game or designing a manufacturing process. These distinctions, with students generating a real and original impact largely explain the point differential with other labs. Unlike many assignments, students don't spend time choosing what to do based on a procedure but are rather forced to make tradeoffs and choose what *not* to do based on constraining factors like time and money. This allowed students to create unique and real value, a central component of the KEEN program. Additionally, because these were not extremely esoteric, students could make connections with curricular and extracurricular knowledge they would have their freshman year.

Additionally, labs like the Wind Turbine and Artificial Muscle, while not design oriented, contained small elements of EML that differentiated them from Circuits, Beam Bending, and Spot Speed. The Wind Turbine lab had students create a turbine blade themselves, allowing them to create connections and utilize knowledge from other classes, namely physics and aerospace. This also allowed students to be creative. Additionally, in the post lab for Wind Turbine, students were asked to analyze the tradeoffs associated with wind energy using the results from the lab and outside research as well as analyze if their wind turbine could power a neighborhood. In the post lab for Artificial Muscle, students were asked to conduct an economic analysis of building the spring, calculating costs and pricing. Students were also asked to brainstorm possible applications of their creation, allowing students to create connections with other realms of knowledge, and create value.

Communication

Every lab tasked students with creating some form of technical communication, however, most labs fell short on allowing students to tailor their communications to their respective audiences. For example, the Software Design Project asked students to create an advertisement and user manual, obviously applicable to the users of their project. On the other hand, while labs provided a fictional context for it, the communication was not tailored to that context. For example, the Wind Turbine lab asks students to make recommendations to a residential neighborhood but asks students to prepare an executive summary, obviously not something most home owners want to read. Additionally, no lab allowed students to investigate their audience and adjust their communication based on the needs of the audience.

Collaboration, Ethics, and Professionalism

Moving on, many labs scored poorly in Collaboration, Ethics, and Professionalism. Common to all labs, none of them tasked the student with evaluating the social and ethical impact of their work or to empathize with the demographics impacted by their findings. For example, students didn't evaluate the social impact of redesigning a road or its speed controls in the Spot Speed lab, layoffs or supply chain changes in Q&P, or wind turbine placement in Wind Turbine.

Additionally, while the data for each lab was collected in a group setting, many labs were not truly collaborative. Specifically, students didn't work to develop interdependence or take on roles to capitalize on their various skill sets. As a first-year engineering class, students from very different backgrounds with very different skill sets are working together, but this diversity is never capitalized on. For labs like Circuits, Beam Bending, Wind Turbine, and Artificial Muscle, students don't take on various roles and don't develop an interdependent relationship. However, due to its size, the SDP allows students to do a variety of tasks, allowing them to explore different aspects of the project and be interdependent with their partner. Spot Speed and Q&P also allow students to take on distinct roles, and because of that, students rely on those in other roles to adequately complete their job.

Conclusions, Recommendations and Future Work

Internal Recommendations

The goals of the labs and SDP were to expose first year engineering students to a variety of engineering disciplines and teach technical communication. So, when evaluated in the lens of EML, it is unsurprising many fell short. Many of these shortcomings are plainly logical given most labs are not design oriented, but even the Software Design Project had room for improvement.

Given these shortcomings, a number of changes could quickly give this first-year laboratory coursework a taste of EML. For example, while the Quality and Productivity (Q&P), Wind Turbine, and Artificial Muscle labs were not design projects like the SDP, they incorporated curiosity, connections, and creating value much more than labs like Circuits, Spot Speed, and Beam Bending. Central to Q&P was the ability of students to redesign the supply chain themselves, allowing them to create value, which caused it to score high in Opportunity, Design, and Impact. For other labs, this should be pursued and could easily be attained by broadening the scope of the lab or by allowing students to use their preliminary findings to create some form of value later in the lab, like in Q&P. Additionally, very small changes to the post lab could allow labs to better incorporate impact. For example, in the Wind Turbine and Artificial Muscle labs, students were simply asked to investigate applications of the technology and look at the applicability of their results. This allowed students to create connections to other classes and do outside research. For other labs like Circuits and Spot

Speed, students were never given the opportunity to investigate the applicability of different types of circuits or investigate which types of speed controls would be helpful, rather than just stating conclusions from the data they found.

Furthermore, the technical communication in each lab could be tailored better to the audience and students could be given more opportunity to investigate those who would be impacted by their results. This would also allow the labs to be more end user oriented and allow students to better empathize with the community that would be impacted by their findings. This would also allow students to assess the social and ethical impact of their findings more closely. Additionally, while the labs are completed in groups, making them more collaborative would make them more entrepreneurially minded. Designing the labs to force students to rely on one another and be interdependent would better emulate project-based work students would expect to find outside the labs.

However, despite room to make the labs implement EML better, the original goals of the labs, to increase exposure to other disciplines and teach technical communication, should not be discarded. For example, while some solutions could increase creativity and the diversity of student conclusions, these could become more time consuming and expensive to grade. Additionally, allowing students to identify a more proper form of communication with their audience might allow them to avoid building technical communication skills by not writing lab reports. Further, the Software Design Project incorporated EML the most, but emulating it for each lab would require much more time as it is more involved.

In conclusion, many labs did not incorporate EML well, but many did incorporate certain aspects of it. For example, small differences like the inclusion of an impact-based question in the write up increased the ability of students to investigate the impact of their work outside the classroom. Additionally, as a design project, the SDP incorporated EML the most, but room for growth was still found in places like allowing students to analyze the social and economic impact of their work. But central to the findings were that labs like Q&P and SDP, which allowed students to create a new process or product, scored higher in most EML categories.

External Recommendations

While the results shown in this paper are specific to this course, this procedure could be used with a course to determine areas for improvement in teaching an EML curriculum. The process of having someone do a document analysis would be a first step, but we would recommend having multiple diverse perspectives doing the analysis. Additionally, it was helpful for this instance to have someone who was familiar with EML and someone who was not doing the analysis independently. Then based on the results, it may be clear some low-level additions that can be made to add some other objectives or achieve higher proficiencies of an objective. Overall this curriculum framework can then be used to look at multiple courses to see how students are meeting EML objectives over the course of their undergraduate career.

Future Work

There are a number of opportunities for future research on this topic. While the evaluation matrix is convenient given there is no intervention or changes needed in the course and curriculum can be rather quickly evaluated, there are some drawbacks. Specifically, the matrix in no way encompasses all that is EML and most likely leaves holes in its evaluation. Additionally, the matrix was created to evaluate a design-project-oriented course and was applied to a curriculum that was not design oriented. Furthermore, only two somewhat similar researchers evaluated the course using the matrix, leaving a lot of room for bias. Future investigations should use more, diverse researchers for data collection.

References

[1] M. Hoit and M. Ohland, “The Impact of a Discipline-Based Introduction to Engineering Course on Improving Retention,” *Journal of Engineering Education*, vol. 87, no. 1, pp. 79–85, Jan. 1998.

[2] D. Knight and J. Sullivan and L. Carlson, "Staying In Engineering: Effects Of A Hands On, Team Based, First Year Projects Course On Student Retention," in Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, 22-25 June 2003, Nashville, Tennessee [Online]. Available: ASEE, https://peer.asee.org/staying-in-engineering-effects-of-a-hands-on-team-based-first-year-projects-course-on-student-retention. [Accessed: February 4, 2019].

[3] N. Duval-Couetil, T. Reed, and S. Haghighi, “Engineering Students and Entrepreneurship Education: Involvement, Attitudes and Outcomes,” *International Journal of Engineering Education*, vol. 28, no. 2, pp. 425–435, Jan. 2012.

[4] S. Purzer, N. Fila, and K. Nataraja, “Evaluation Of Current Assessment Methods In Engineering Entrepreneurship Education,” *Advances in Engineering Education*, vol. 5, no. 1, 2016.

[5] D. Pistrui, J. K. Layer, and S. Dietrich, “Mapping the Behaviors, Motives and Professional Competencies of Entrepreneurially Minded Engineers in Theory and Practice: An Empirical Investigation,” *The Journal of Engineering Entrepreneurship*, vol. 4, no. 1, pp. 39–54, 2013.

[6] “The Framework,” *KEEN - Engineering Unleashed*. [Online]. Available: https://engineeringunleashed.com/mindset-matters/framework.aspx. [Accessed: 04-Feb-2019].