Work-in Progress: Engaging the Undergraduate Thermodynamics Classroom Using Mini-Adventures in the Entrepreneurial Mindset

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Dr. Najmus Saqib is an Assistant Professor of Mechanical Engineering at Marian University. He has been teaching in his field since 2017. Saqib is passionate about student learning. He received his PhD in Mechanical Engineering from Colorado School of Mines, focusing on ”Optical Diagnostics of Lithium-Sulfur and Lithium-Ion Battery Electrolytes using Attenuated Total Reflection Infrared Spectroscopy”. At Mines Saqib was a member of the MODES Lab, led by Dr. Jason M. Porter. His work on Li-S batteries was the first of its kind to use quantitative infrared spectroscopy for operando polysulfide measurements. He has also applied operando spectroscopy to improve the understanding of electrolyte decomposition mechanisms in Li-ion batteries. In addition to his current research interests of developing diagnostic tools for electrochemical storage of renewable energy, Saqib is also interested in the Scholarship of Teaching of Learning (SoTL) and Engineering Education in particular.

Prior to joining Marian, Saqib was one of the founding faculty members of the Mechanical Engineering program at the University of Indianapolis. He served as the program coordinator, undertaking major curriculum development, and led the program through a successful initial ABET accreditation review. He received multiple research grants, he coordinated the campus-wide Research Fellows programs, and his dedication to teaching was recognized through the UIndy Teacher of the Year nomination in 2023.

In the classroom, Saqib likes to challenge his students to tackle real-world engineering problems. He likes to use innovative pedagogical techniques and Entrepreneurial-Minded Learning (EML) to facilitate student learning. Beyond the classroom, he has a passion for mentoring students and helping them achieve their educational and professional goals.

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Marie Stettler Kleine is an Assistant Professor in the Department of Engineering, Design, & Society. She conducts research on engineering practice and pedagogy, exploring its origins, purposes, and potential futures. Marie is especially interested in the roles of values in engineers' pursuit to ”do good.”

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Marie's interest in values and engagement in professional cultures also extends to innovation and its experts.With Matthew Wisnioski and Eric Hintz, Marie co-editedDoes America Need More Innovators?(MIT Press, 2019). This project engages innovation's champions, critics, and reformers in critical participation.

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Aneesha Gogineni received her Master's and PhD in Mechanical Engineering from Wichita State University (Kansas, USA). She joined SVSU in 2016 as Assistant Professor in Mechanical Engineering department. After serving the department for 5 years, she received her tenure, and promoted to Associate Professor in 2021. During this time, she taught courses like Thermodynamics, Heat Transfer, Computational and Experimental Methods using MATLAB, Fluid mechanics, Statics, Engineering Cost Analysis, Heat

transfer lab and MATLAB software lab. Mechanical Engineering at SVSU is an ABET (Accreditation Board for Engineering and Technology) accredited program where her goal as a professor is to provide the knowledge and skills that enable students to achieve success in the program through complex problem solving and hands on active learning. Her research interests are in the field of Heat Ventilation and Air Conditioning, Indoor Air Quality, Heat Exchangers, Bio-Engineering applications and pedagogical studies in active learning. Aneesha Gogineni is a member of ASME (American Society of Mechanical Engineers), ASEE (American Society of Engineering Education) and SWE (Society of Women Engineering). She is currently serving as Vice-Chair Process Industry Division. She is also serving as a co-advisor for Society of Women Engineers (SWE). She received Dow Professor award at Saginaw Valley State University to develop hands on active learning approach in several mechanical engineering courses. She received Ruby Award from first state bank as a recognition for her accomplishments in the STEM field in the great lakes bay region.

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Stephanie Gillespie is the Associate Dean at the Tagliatela College of Engineering at the University of New Haven in West Haven, CT. Since entering academia, she has been passionate about preparing the next generation of engineers with real-life skills, specifically by teaching courses in the area of engineering service learning, first-year engineering courses, and the Grand Challenges of Engineering. Her current research interests span multiple areas of engineering education including makerspaces, multidisciplinary teams, gender diversity and minority retention, and entrepreneurial mindset. Her PhD from Georgia Tech focused on machine learning and signal processing for affective computing, specifically detecting stress and depression in adults with communication disorders. She is actively involved in the Society of Women Engineers and EPICS in IEEE.

Work-in Progress: Engaging the Undergraduate Thermodynamics Classroom using Mini-Entrepreneurial Mindset Learning Adventures

Abstract

With the ever-changing technological developments in engineering, educators are constantly trying to have curricula address the changing needs of the workforce. One means is incorporating the Entrepreneurial Mindset (EM) into various courses in the form of Entrepreneurial Minded Learning (EML) activities. Although notable strides have been made in the implementation of EML across engineering education, there remain significant challenges to more buy-in from instructors and students alike. Thermodynamics, a notoriously abstract and difficult subject matter to effectively engage students, is not immune to the need to change. Thermodynamics is a fundamental engineering science course that is shared by mechanical, chemical, and similar engineering programs, and adopting new material into such a foundational course can be difficult. Engineering instructors have introduced several teaching methods including active learning, interactive lecture demonstrations, video-based lectures, additional online learning activities through learning management systems, project-based learning, and problem-based learning. However, there is still room for improvements in teaching methods for this fundamental class.

To reduce the activation barrier and overcome the entropic inertia that resists curriculum changes, this paper addresses a means to create easy-to-adopt EML modules in an introductory thermodynamics course. The goal is to engage the classroom using small snippets of EML at a time – so called Mini-EML Adventures. By taking a modular approach for implementation, instructors have the ability to pick and choose mini EML modules for a given topic to better engage students, with the hope of reducing the amount of work and development time often required in creating new course material. The approach taken by the authors is to create Mini-EML Adventures using different concepts often encountered in thermodynamics and leveraging the three Cs of EM (curiosity, connections, and creating value) to engage the modern, diverse classroom. The main goal is to elevate existing lecture material into something short, interesting, and EML-friendly. These Mini-EML Adventures contain a one-sentence description, the mindset addressed, targeted skillset, course topic, type of activity, time requirements (generally less than a class period), and materials needed. We provide example activities along with a general template for these activities that can help instructors craft their own Mini-EML Adventures. The goal of this work is to make EML more accessible to instructors to implement in their existing thermodynamic courses and beyond.

Introduction

Creating an engaging classroom atmosphere should be highly valued in higher education. One avenue to better engage students in an engineering classroom is to enable a greater understanding of the whys, opportunities, and impacts behind each lesson. In the summer of 2023, a group of like-minded engineering educators, from various universities across the United States, first gathered together to discuss such an implementation in undergraduate Thermodynamics by creating and developing so-called "Mini-Entrepreneurial Minded Learning (EML) Adventures" that address a wide range of topics. The approach utilizes the three C's of the entrepreneurial mindset (EM) – curiosity, connections, and creating value – through small, ready-to-go modules that would engage a wide variety of student interests. The goal of this effort is to aid in utilizing existing learning material by infusing it with EML-friendly activities that better facilitate learning. Faculty follow a simple general template to develop activities and assist the instructor in crafting their own Mini-EML Adventures. We define a Mini-EML Adventures as a course/classroom module that can be conducted in 15-30 minutes, thus allowing for other content to be taught in a standard hour-long class period. This deviates from a majority of existing EML modules that must often be conducted over multiple class periods, if not multi-week efforts. The goal of this work is to make EML more accessible, recognizing that often incorporating EML into existing curriculum can appear daunting and time consuming to the instructor. Following this initial meeting, the team met virtually to further develop the adventures. What follows is a description of how Mini-EML adventures are being developed, implemented into courses, and then further refined and published as Engineering Unleashed cards.

Background

Engineering education has traditionally emphasized derived, mathematical concepts, in a lecture-heavy classroom. However, a shift towards interactive lectures is underway as numerous universities adopt the Entrepreneurial Minded Learning (EML) framework. The Kern Entrepreneurial Engineering Network (KEEN) is at the forefront of this movement, as a dedicated network promoting universities to integrate the EM framework into their teaching methodologies. This innovative approach combines engineering skillsets with the three C's – curiosity, connections, and creating value [1]. By implementing EM into engineering education, students are provided with opportunities to make a meaningful impact through their designs, fostering a holistic and forward-thinking approach to their learning experience [1].

In collaboration with KEEN, two universities recently added EM elements to their existing first-year engineering courses and the learning outcomes were assessed using student grades. As part of the assessment, student surveys were also collected, and their responses indicated improvement in their social curiosity after being exposed to EML [2]. Research from Grzybowski et al. and Desing et al. showed that integration of EML into engineering curricula significantly improved student performance with respect to technical skills, increased student curiosity, and simultaneously created connections and value [2, 3].

EML components added to project-based learning have significantly increased student learning and engagement. In another study, a junior-level mechatronics course project was modified by embedding EML context into their existing project that involved dynamic systems, selection and integration of sensors, actuators and feedback control [4]. Mehta and Mikesell integrated EML activities within project-based learning in a mechanical engineering manufacturing course. These approaches not only exposed students to real-world challenges but also encouraged them to develop an innovative mindset in both studies [4,5]. Student surveys conducted by the authors indicate positive feedback from students and signs that they appreciate the new educational approach that has improved the active learning process. Additionally, Shenk and Liu recently demonstrated successful implementation of lengthy EML projects in courses at two very different universities (D1 research institution vs small private undergraduate only program) that demonstrated increased student interactions with course material, resulting in enhanced test scores and a spin-off of a generated idea to form a company [6].

With many engineering courses already containing projects, it may be challenging for faculty to find time or space in a course to add an EM-focused project. Davis et al. shared two case studies of incorporating entrepreneurship topics into mechanical engineering automotive courses, and found that faculty often felt overburdened to cover the technical content and were hesitant to add additional skills or activities that may take time away from those topics [7]. While there are multiple methods to integrate EML into classes shared on EngineeringUnleashed.com, one challenge with existing resources is the duration of the proposed activities. Research by Gillespie found faculty who commented on the web resources were often favorable of the activity proposed, but were not always able to adopt them into their own courses claiming courses had too many technical topics to cover and too little class time to add new ideas or projects [8]. They found that fewer than 25% of the sampled classroom-specific resources could be completed in one class period or less. There appears to be a need in the engineering education community for shorter EML activities that enhance students' abilities to learn and engage with technical content.

Active learning is described in different ways, and some of them include: a) "..anything that involves students in doing things and thinking about the things they are doing", b) "involves providing opportunities for students to meaningfully talk and listen, write, read and reflect on the content ideas, issues and concerns of an academic subject", c) "increasing of student participation or 'interactivity', for the purpose of positively affecting student learning and attitudes" [9].

An active learning technique that shows significant improvement in learning outcomes is interactive lecture demonstrations (ILD). Georgiou and Sharma stratified student cohorts into four distinct groups with two groups undergoing ILD experiences, while the remaining two experienced traditional teaching formats [10]. The instructional approach includes presenting a thermodynamics problem to students and formulating their predictions on a designed worksheet. Subsequently, students were encouraged to participate in collaborative discussions with their peers, and finally the instructor would elucidate the solution through board work. In addition, the instructor creates video lectures accessible to students via a learning management system. This multimedia resource serves as a supplemental study guide offering guidance to students and opens the platform to student questions related to the recorded content. In-class collaboration-based active learning has limitations in time and number of student participation. Hence, educators proposed and evaluated online interactive learning activities. Some of these activities include interactive videos, quizzes, online discussion, interactive presentations etc. Gogineni introduced online interactive learning tools like animations, interactive lecture videos, supplemental study guides for thermodynamic property tables, etc. in thermodynamics courses [11]. In response, students suggested exploring flipped classroom models, incorporating a blend of online instructional videos and face-to-face interactive sessions. This model offers an opportunity to seamlessly incorporate short in-class activities without disrupting the designated course syllabus.

The adoption of flipped classroom models has surged in recent years, driven by the prospect of delivering course content online, outside traditional class hours. This enables course instructors to facilitate more dynamic, problem-based learning activities during in-person sessions. Despite the advantages, Wong and Mayled stated the need for additional research on best practices for effectively implementing flipped classroom models [12]. In effort to determine the best format for flipped courses, they introduced EML in a circuits course through project-based labs along with pre-lecture videos and interactive tutorials. The main objective of the study was to enhance student learning and reduce DFW rates (failing grades or withdrawals). The data collected from student test scores indicate a decrease in the percentage of students scoring D and F after the incorporation of EML. Some of the common challenges in flipped class formats addressed in the study are students' disinterest in required pre-work and understanding instructional strategies that can benefit underrepresented groups of engineering students. EML can provide a pathway to address these challenges by leveraging the three C’s of EM mentioned above.

Challenges to EML Adoption and Methods

Instructors seeking to adopt EML into coursework face several challenges. One is definitional. What is EML and what makes an activity EML? The term EML was first coined by KEEN in order to describe learning innovations that would help students develop an entrepreneurial mindset. For this work, EML is described as any learning innovation that helps students understand the opportunities, impacts, curiosities, important connections, or potential value with what they are learning[1]. It can enhance engagement by helping students see the importance, value, and opportunities with each lesson learned. The ultimate goal of EML is to help students develop a more success-oriented set of mindsets, habits of mind, dispositions, and awareness [13,14,15,16].

A second challenge is time. Adopting new material takes time and energy. The process of determining new ideas individually can be intimidating, time consuming, and difficult. With so many demands such as research, meetings, prep-time, etc., it can be discouraging for course instructors to implement new material that is not always easy to identify, particularly in subjects as abstract and lecture-heavy as thermodynamics.

A third challenge instructors face is one of implementation and adoption by students. It takes time to change a student's existing habits. And while a large project may help students develop both their conceptual understanding as well as their mindset, it also is a time consuming task. Organizers of these educational interventions asked whether one can use EML to: a) increase student engagement, b) increase student conceptual understanding, and c) develop their mindset through a series of shorter 15-30 minute learning innovations.

To explore these questions, the following method was used to develop the first of these smaller EML innovations, the so-called Mini-EML Adventures. A group of engineering faculty gathered together on a retreat in the summer of 2023 agreeing to the premise that EM is an effective tool to enhance learning. Participants discussed the definition and significance of EM and EML in a series of group sessions. Once that foundation was laid, instructors gathered around a given course where they first selected technical components from their course, whether an entire topic or a single formula. Second, a context for the learning innovation was chosen. This context is designed to help illuminate why the technical component matters, how it is used, or what opportunities are associated with it. Contextualizing the material provides a way to incorporate real-world problems that develop professional skills and enhance a students ability to begin mastering uncertain, complex, open ended problems. This better prepares them for their post education careers. A secondary purpose is to help increase a student’s intrinsic motivation for the topic beyond just that of an academic hoop to be jumped through [17]. Selecting these contexts was done in several different ways, including group discussions, brainstorming, bisociation, and ideation through generative technology.

Although it may be possible to deliver EML through a particularly engaging set of lectures and discussions, a more active pedagogical approach was sought by the Mini-EML Adventures brainstorming group. Once a technical component and context was selected, the third step was choosing a pedagogical delivery method that included best practices in active learning, problem-based learning, scenario-based learning, story-based learning, peer-based learning, and more [18].

The final step was to ensure the EM components were properly highlighted. The components of EM included at least one of the 3 C’s from the KEEN EM Framework [1]. But each adventure could also include other components, such as systems thinking, learning to be more customer-centric, thinking about things in terms of value propositions, and much more[18].

This intersection of technical content, context, engaging pedagogy, and mindset formed the basis for each Mini-EML Adventure. Once these four components were brought together, groups of engineering instructors worked together to remix components to build out their educational innovations.

The Mini-EML Adventures Process

The Mini-EML Adventures methodology has evolved with each gathering of the Mini-EML Adventures innovation creation groups. It is expected that this methodology will evolve further with upcoming meetings in 2024 and 2025. Currently, the methodology follows four general steps.

First, instructors select a technical component from their course. Since the goal of the Mini-EML Adventures is to enhance technical content, engage students, and build student mindset, each Mini-EML Adventure is built from some essential course component. This could be an equation, a theorem, a derivation, an overview, etc.

Second, instructors determine a real-world connection, context, impact, opportunity, etc. that this technical component is implicated in. A variety of methods have been used to generate these contexts. These include brainstorming, bisociation exercises, and the use of generative AI technology. Regardless, the context forms the basis for the Mini-EML Adventures, and helps students understand why this technical component actually matters outside the classroom. If students do not understand why what they are learning matters, they are unlikely to care.

Third, a pedagogical method is chosen. EML does not encapsulate any one learning style. Instead, it can be demonstrated through active, project-based, peer-based, or experiential-based learning. Participants were given a selection of such learning styles to choose from and encouraged to select the type that best aligned with the activity goals and scope.

Fourth, a mindset component was chosen. Since the “mindset” component is an integral part of “EM,” no Mini-EML Adventure could be considered complete without such components integrated into the activity. Example components included getting students to act on their curiosity, investigate the intersection of disparate ideas, or ask questions that reveal authentic demands or needs. For inspiration, resources from Engineering Unleashed were used [19,20]. By including a focus on a mindset component, students are given an opportunity to expand their learning beyond the technical topic, enhancing the value of the educational activity through the development of professional skills. Note that the target mindset component of the activity is not arbitrarily chosen. It should be rooted in the types of skills the student would need to address a real-world problem pertaining to the topic at hand.

Finally, these four elements were combined in a variety of ways to create the learning intervention – the Mini-EML Adventure.

The following is an example of one such Mini-EML Adventure implemented in a course. The ideal gas law was chosen for the technical component as it is a basic foundation for thermodynamics. For context, a Newsweek article on Doomsday Prepping was used. “The once-fringe act of doomsday prepping is evolving into a booming $2.46 billion industry, tapping into a societal pulse of self-reliance amidst a world of uncertainties [21].” The intervention went on to explore the opportunities in using the ideal gas law to create an “infinite set of matches.” For the hands-on in-class activity, students watched a video on a fire piston being used to start a fire. And, finally, for the mindset elements, students would be asked to do the following:

1) Explore Opportunities: existing fire pistons have many limitations and are not always easy to use. Through manipulations of the ideal gas law, students sketch out a new design that would make it easier for an end user (in class).
2) Opportunity Identification: students explore other opportunities where the principle of the fire piston could be expanded, especially in emergency situations, including the size and design (in class).
3) Market Research: using tools such as Google Trends, students perform basic customer discovery to determine customer interests (as homework).
4) Exploring Further: What if your market research reveals that while there's a rising trend in "sustainable" and "camping" searches, there's a decline in "survivalist" searches. However, a niche community forum dedicated to survivalists shows a keen interest in innovative tools. Would you consider targeting this declining but potentially dedicated market for the "Infinite Match" kit? Defend your answer based on potential benefits and risks (as homework).

Implementation of this adventure was conducted in about 30 minutes. During implementation, the instructor observed interesting group dynamics. About half of the groups were incredibly involved, creative, and very engaged (loud). The other half struggled initially with having the freedom to explore ideas, often asking about what “answers” were supposed to be produced. This is probably an indication of the third challenge mentioned above, where students are not accustomed to different content delivery and resist change. However, by the end of the activity, all groups came up with creative new opportunities for uses of a fire piston and the ideal gas law, including implementation into wood furnaces, access for those with disabilities to start fires, and use in situations where matches might not be convenient.

Additionally, after implementation, the module was refined further to minimize class time implementation and to create new activities that further enhance engagement. One such idea is to purchase these relatively inexpensive contraptions to create a small ember from classroom materials in a laboratory setting, providing students with hands-on experience associated with the ideal gas law.

Further development of ideas and modules continue as of the writing of this paper. While a few of the modules were tested this past school year, refinement continues. As modules are further refined, Mini-EML Adventure "cards" will be published on EngineeringUnleashed.com, where the information is openly available for other instructors to use. Feedback from students and instructors will further improve the modules. As a work in progress paper, this is an ongoing description of our effort and work; assessment strategies and data collection will continue to be gathered.

Opportunities

Those participating in the Mini-EML Adventures workshop see an opportunity due to a strong need and desire for EM content that utilizes best practice pedagogies to enhance student learning. It allows for educators to conveniently introduce course topics that are founded on EML. Mini-EML Adventure modules are designed for flexibility for adoption into the classroom, overcoming a barrier for integrating EM into the curriculum as a whole. Instructors can choose one or more from course-specific lists and modify as necessary, facilitating the use of creative instructional material. The material does not require significant reordering of instructor content, reducing the barrier of adoption. Just as importantly, these adventures are designed as more engaging, open-ended content than traditional examples and homework problems normally found in textbooks. They are designed to enhance student engagement and impact the way that a student understands their value in their future professions.

Conclusions

The collaborative work presented in this paper seeks to improve engineering education through a process of integrating small modules of engaging, active learning pedagogy using real-world context. Modules were developed by infusing said context with EM elements such as stakeholders and the 3 C's. Development of more Mini-Adventures in EML modules continues through periodic reconvening of the instructor group for modifications and new content creation. Further testing of implementation and ideas will continue as well. The efficacy of the Mini-EML Adventures will be assessed in the classroom using a mixed methods approach. First, students' perceptions of the activities will be collected via anonymous surveys and the analyzed responses. Second, student performance will be evaluated and compared to previous years' evaluations that took place without the implementation of this novel approach. Dissemination of the ideas in this paper is occurring through KEEN card publications and *The Crescendo of EML* workshop series [22]. This work strives to make EML more accessible and implementable by a wider range of faculty.

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