Informed Design through the Integration of Entrepreneurial Thinking in Secondary Engineering Programs

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Abstract

Competitive growth in today's economy requires engineers to possess innovation skills to create novel designs. An entrepreneurial mindset enables people to think and then act in a certain way to discover, evaluate, and exploit opportunities by understanding the value proposition of a new idea, identifying the potential market, and adapting ideas to meet the needs and desires of various customer segments. However, secondary students often lack formalized opportunities to look for new opportunities for innovative design, act upon their design ideas, and transform those ideas into reliable investments of time and resources during their school experiences. Therefore, we propose that secondary engineering teachers can employ established entrepreneurial pedagogical interventions as a means to promote more authentic engineering design activities in STEM learning environments. The interventions can aid students in making more informed design decisions, engage them in developing viable solutions to authentic problems while investigating opportunities for exploiting their ideas, and thus, support the innovation capabilities of our future. Consequently, this article highlights methods in which to integrate an entrepreneurial mindset within high school STEM classrooms, specifically those focused on engineering.

Introduction

The innovation capacity of the U.S. continues to be a national concern as the economy increasingly depends on developing an innovation-capable workforce while establishing viable industries (National Academy of Engineering, 2015; 2017). Currently, the country is challenged to remain a leader in the global marketplace by meeting the STEM-related job demands that drive the country's advancement as very little education focuses on innovation (National Academy of Engineering, 2015). As described in the 2015 *Educate to Innovate: Factors that Influence Innovation* report, innovative thinking should be an expectation of the education community, and all students should be exposed to it through a variety of educational formats and delivery methods. Today, competitive growth requires individuals who possess more than just the technical skills to develop a new product design. Instead, it is believed that individuals should develop an entrepreneurial mindset to further their contribution to their own personal success and to that of an organization in which they belong (Bosman & Fernhaber, 2018). This type of mindset can enable people to think and then act in a certain way to discover, evaluate, and exploit opportunities by understanding the value proposition of a new idea, identifying the potential market, and adapting ideas to meet the needs and desires of various customer segments.

Consequently, there have been a variety of initiatives to integrate entrepreneurship into higher education. These initiatives often take the form of stand-alone courses designed to teach entrepreneurial practices or project-based design courses developed to engage students in innovation processes. However, secondary students continue to lack formalized opportunities to act on ideas they develop within their high school engineering and/or STEM programs and transform those ideas into reliable investments while honing their skills to become an innovator within their fields of interest and future employment. Therefore, this article will highlight ways in which to teach an entrepreneurial mindset to high school students. Specifically, the methods highlighted will focus on enabling secondary students to make more informed design decisions when developing technological innovations based on the values of their intended customers. Also, recognizing the challenge related to the overcrowding of the curriculum within secondary schools, this article will focus explicitly on integrating entrepreneurial thinking approaches within design-based pedagogies currently employed in engineering (and science) curriculum. The following sections will (a) describe an entrepreneurial mindset and the associated need in engineering and design, (b) explain the role of the lean startup methodology, business model canvas, and informed design in nurturing the entrepreneurial mindset, (c) provide a rationale for integrating the entrepreneurial mindset into engineering education, (d) show an approach to incorporate the entrepreneurial mindset into secondary engineering curriculum using the business model canvas, and (e) provide an example of such integration.

The Need for An Entrepreneurial Mindset

In 2004, the National Academy of Engineering stressed that not only is the pace of technological innovation continuing to increase but so are the variety of factors determining the success of technological developments. In this highly uncertain and competitive environment, engineering practice is shifting from technical problem solving to a process of innovation that focuses on creating more value (Duderstadt, 2010). As Weilerstein and Byers (2016) believe, it is no longer adequate for engineers to be only technically qualified. In the process of innovation, engineers are expected to be able to think and act with an entrepreneurial mindset to shape and guide their design practices.

Bosman and Fernhaber (2018) emphasize that although one may not be an entrepreneur aiming toward starting and operating a business, an individual can think and act as an entrepreneur in an effort to discover, evaluate, and exploit opportunities for innovation. In a similar manner, McGrath and MacMillan (2000) suggest that an individual can be a habitual entrepreneur by thinking and acting with an entrepreneurial mindset. They identify five characteristics of the entrepreneurial mindset (p. 2-3):

1. Passionately seeking new opportunities.
2. Pursuing opportunities with enormous discipline.
3. Pursuing only the very best opportunities and avoid exhausting themselves and their organizations by chasing after every option.
4. Focusing on execution—specifically, adaptive execution.
5. Engaging the energies of everyone in his or her domain.

These characteristics highlight that an entrepreneurial mindset can guide people to investigate and evaluate opportunities, focusing on the creation of value through the opportunities, and to make decisions, not only focusing on goals but also seeking flexibility to adapt to the needs and desires of people.

Also, when focusing on an engineering design context that seeks to pursue a technological innovation, we can consider an entrepreneurial mindset as one of an engineers' essential skills. Brown (2009) describes that a technological innovation can be created when a design solution is not only technically feasible but also desired by potential customers and viable from business perspective. His point suggests the importance of engineers' habitual mindsets to consider a more broad range of contextual factors beyond technical feasibility when they are engaged in engineering design processes. In a similar context, Kriewall and Mekemson (2010) discuss an entrepreneurial mindset for engineers, distinguishing entrepreneurially minded engineers from engineering entrepreneurs. They describe that an engineer can be instilled with an entrepreneurial mindset while not being an entrepreneur and that the purpose of entrepreneurial engineering, not engineering entrepreneurship, is to design value-added products and processes that create demand through innovation. Also, they illustrate that entrepreneurial engineering involves an integrated understanding of business, customers, and societal values of design as well as technical depth. Thus, for technological innovation, every engineer does not have to become an entrepreneur. Instead, an entrepreneurial mindset can allow engineers to find and understand problems and create innovative solutions with a broader range of perspectives.

If entrepreneurial thinking is a habitual mindset, we can develop this type of thinking through learning experiences and conscious practice. Thum (2012) presents a definition of human mindsets, which describes a mindset as a person's sum of knowledge, including their beliefs and thoughts about the world. Also, in our consciousness, a mindset can play a role as a filter for the information we take in and put out, which may then determine how we receive and react to the information. These descriptions can imply that an entrepreneurial mindset can lead us to perceive information like entrepreneurs. Gupta and Govindrarajam (2002) describe how we shape, reinforce, and change our mindsets. According to their description, we individually shape and use our mindsets to cognitively process new information or knowledge, and our mindsets can be reinforced with experiences aligning with and stimulating our current mindsets. Also, they emphasize that the reinforcement depends largely on how much we have self-consciousness in the process of developing and using the mindsets. Their description allows us to think that we can construct and reconstruct an entrepreneurial mindset through intentional efforts. In terms of the efforts, Bosman and Fernhaber (2018) imply that an entrepreneurial mindset can be taught through iterative experiences that allow leaners to investigate and evaluate opportunities, explore the creation of value through the opportunities, and make decisions while adapting to the needs and desires of customers. These actions can then help secondary engineering students shape their design thinking as they work to develop potential technological innovations. Also, students can correctly address the needs of the specified customer segments and assist them in the validation or rejection of assumptions made throughout the design process.

Lean Startup Methodology, Business Model Canvas, and Informed Design

Lean startup is a scientific methodology to make decisions for developing businesses or products under uncertain conditions. This methodology allows an individual to develop, test, and validate assumptions about a business model or product idea. Lean startup involves three principles: 1) developing an intricate business model by summarizing a series of untested hypotheses; 2) testing and revising the hypotheses based on customer feedback on all elements of the business model; and 3) increasing rapidity and flexibility of the iterative cycle (Blank, 2013). Thus, applying these three principles to entrepreneurial processes, individuals can test their assumptions and then amend their approaches as necessary through making small adjustments or more substantial changes to their initial ideas until all of their assumptions are verified. The process includes iterative and incremental development (Blank, 2013). Initially, the methodology was developed in the information technology industry for startup businesses, but it is more and more commonly used for various types of innovation projects in different disciplines (Ries, 2011), specifically in engineering.

The learning of lean startup principles usually involves the use of a standard framework known as *Business Model Canvas* (Osterwalder & Pigneur, 2010). The framework consists of the following nine sections which represent the building blocks of a startup business or new product: (1) value proposition, (2) customer segments, (3) customer relationships, (4) channels, (5) key activities, (6) key resources, (7) key partners, (8) cost structure, and (9) revenue streams. Figure 1 presents the business model canvas and a description of each section. The framework is used to test hypotheses of a value proposition in product development projects. Also, in educational settings, it can be a potentially valuable cognitive organizer for students to learn and apply the lean startup methodology to make informed design decisions throughout engineering design projects.

Informed design refers to a decision-making process to perform design actions with in depth knowledge, as opposed to a simple "guess-and-check" or "trial-and-error" design approach (Grubbs & Strimel, 2015). Crismond and Adams (2012) describe that informed designers delay in making design decisions in order to explore and comprehend their design situation more fully through research, brainstorming, and technological investigations. On the other hand, beginning designers can often per-

<table>
<tr><td rowspan="2">Key Partners
A network of alliances to optimize operations, mitigate risks and acquire resources – strategic alliances, co-opetition, joint ventures, and buying groups</td><td>Key Activities
A set of tasks that are required to keep the business running – production, marketing, sales, research and development</td><td rowspan="2">Value Propositions
A bundle of products or services that a caters to the customer requirements - solves a problem or satisfies a need</td><td>Customer Relationships
A method of managing relationship with each customer segment – personal or automated</td><td rowspan="2">Customer Segments
A group of people that are being served through the value proposition – groups are decided by common interests, needs and behaviors</td></tr>
<tr><td>Key Resources
A set of assets required to make the business work – physical, financial, intellectual or human</td><td>Channels
A method of reaching out to the various customer segments to deliver the value proposition – communication channel, sales channel and distribution channel</td></tr>
<tr><td colspan="3">Cost Structure
A calculation of the input costs for developing products and keeping operations running – fixed cost and variable cost</td><td colspan="2">Revenue Streams
A pricing mechanism for generating cash from each customer – fixed price, auction, bargain, volume based or market pegged</td></tr>
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Figure 1. Osterwalder's Business Model Canvas. (Osterwalder & Pigneur, 2010)

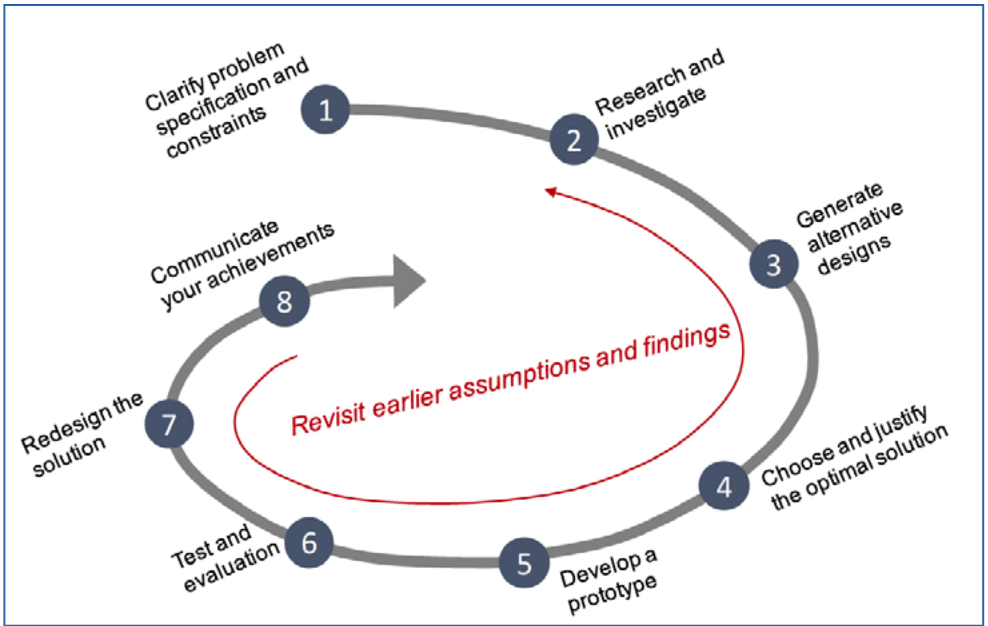

Figure 2. Informed Design Process (Burghardt & Hacker, 2004)

cieve design situations as well-defined problems and act prematurely in developing a solution. Further, Crismond and Adams (2012) highlight seven key performance dimensions that are central to doing informed design which include the acts of (1) learning while designing, (2) making and explaining knowledge-driven decisions, (3) working creatively to generate design insights and solutions, (4) perceiving and taking perspectives intelligently, (5) conducting sustained technological investigations, (6) using design strategies effectively, and (7) integrating and reflecting on knowledge and skills. Burghardt and Hacker (2004) believe that informed design, when used as a pedagogical approach, can enable students to be cognizant of their prior knowledge, determine current knowledge gaps, and properly gather the information necessary to reach viable design solutions while being conscious of the potential consequences of their decisions. Figure 2 illustrates the cycle of informed design. The cycle is similar to typical design process models that involve an iterative cycle. However, in informed design, the iteration cycles focus more on research and investigation rather than trial-and-error problem solving. Thus, when integrating design with entrepreneurial practices such as the learn start-up methodology, students can be more engaged in the iterative practices that are believed to support innovation capabilities.

In consideration of these aspects, the lean startup methodology and business model canvas are well positioned to support the informed design process. Mueller and Thoring (2012) compare the characteristics of engineering design thinking and lean startup to discuss how well these two different strategies can be converged to compensate each other. They describe that these two strategies share multiple similarities in terms of creating innovations, focusing on the needs/desires of potential users or customers, testing assumptions about novel ideas, and iteration under extreme uncertainty. Furthermore, they discuss that lean startup practices should involve engineers in early testing/iteration design loops prior to the development of a prototype, which may help them to strengthen engineering design practices by making more informed design decisions based on detailed research and technological investigations. With lean startup methodology, engineers can implement feedback testing and iteration loops earlier, even before prototyping in design processes, which might save time/resources and result in better outputs based on validated assumptions. The discussion implies that converging the lean startup principles into engineering design processes could be effective for students to develop not only an entrepreneurial mindset but also more informed design abilities.

Rationale for Integrating the Entrepreneurial Mindset into Secondary Engineering

An entrepreneurial mindset can be considered an important element of engineering design-based pedagogies. In post-secondary engineering education, there have been multiple discussions about the effectiveness of teaching an entrepreneurial mindset to engineering students. The discussions suggest that teaching entrepreneurial concepts, skills, or mindsets can be an effective way for increasing students interests in the processes of technological innovation (Duval-Couetil, Reed-Rhoads, & Haghighi, 2012) and enhancing engineering design abilities and professional skills (Duval-Couetil et al., 2015). In particular, Duval-Couetil et al. (2015) identify the intersection between learning objectives of entrepreneurship education and the Accreditation Board for Engineering and Technology (ABET) criterion of student outcomes. They explain that the learning outcomes traditionally acquired through entrepreneurship education include "the abilities to address real-world problems, perceive opportunities, lead others, work in multidisciplinary teams, communicate effectively, react and adapt with flexibility in the face of uncertainty, and deal well with risk and failure" (p.10). These outcomes align well with the engineering design skills identified by ABET (Shuman, Besterfield-Sacre & McGourty, 2005). Also, as discussed earlier, Mueller and Thoring (2012) suggest that the development of an entrepreneurial mindset through the lean startup principles could improve engineering design thinking for making more informed decisions. Therefore, we can expect that by teaching an entrepreneurial mindset to high school engineering students, they can also develop informed design abilities, become "better" at speaking the language of innovation, and create innovative solutions to design challenges.

Recognizing the effectiveness of teaching an entrepreneurial mindset, post-secondary engineering programs have provided learning opportunities to their students in various ways. Students have been offered opportunities to participate in business school-based programs, enroll in courses for a minor or certificate in entrepreneurship, or to take stand-alone courses targeting only engineering majors (Duval-Couetil et al., 2015). However, there have been concerns about engineering students' limited space in their academic programs to take more elective courses for an entrepreneurial mindset (Standish-Kuon & Rice, 2002). For these reasons, there have been discussions about how to best integrate an entrepreneurial mindset within engineering design courses (Davis & Rose, 2007; Hazelwood, Valdevit, & Ritter, 2010; Ochs et al., 2006; Sullivan, Carlson & Carlson, 2001). Considering the challenge related to the overcrowding of the curriculum within secondary schools, we also seek for a way to embed an entrepreneurial mindset within high school students' design-based learning activities.

Although there have been fewer discussions about teaching an entrepreneurial mindset at the P-12 level, educators have become interested in integrating it into students' engineering design activities in recent years (Benton et al., 2013). For example, Huang, Kuscera, Jackson, Nair, & Cox-Petersen (2018) found that providing secondary students with learning experiences focused on employing lean startup methods can be effective for engaging them in STEM learning and retaining or improving their interests toward STEM careers. More specifically, over the course of their 3-year project designed to research the effectiveness of using business venture creation principles to engage secondary students in STEM learning and develop interests in STEM, they discovered that interests towards careers in engineering, computer science, and/or entrepreneurship consistently increased from year 1 to year 3. Based on these potential promises and increased interests, the following section will discuss one way to design and implement learning activities for teaching

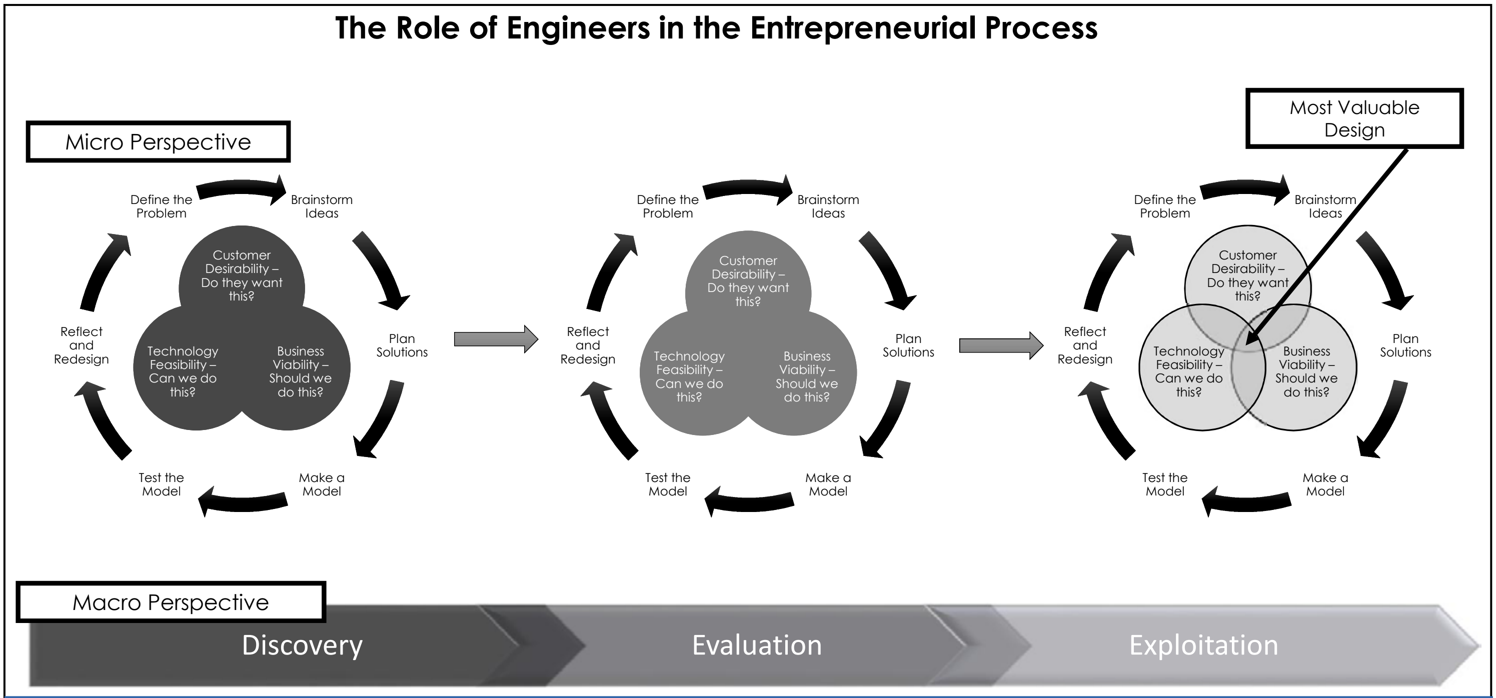

Figure 3. The role of engineering in the entrepreneurial process. Reprinted by permission from: Springer Nature [Springer eBook] [Teaching the Entrepreneurial Mindset to Engineers] (L. Bosman & S. Fernhaber) © 2018.

secondary students an entrepreneurial mindset within engineering curricula.

Integrating the Entrepreneurial Mindset into Secondary Engineering Curriculum

First, we emphasize that educators should be cognizant of specific intentions in designing and implementing learning activities to teach an entrepreneurial mindset within engineering design contexts. Bosman and Fernhaber (2018, p.26) identify four major intentions:

1. The learning activity should provide an experience to discover, evaluate, and/or exploit opportunities. Opportunities that create the most value should be aimed at customer desirability, technology feasibility, and business viability.
2. The learning activity should provide an experience to develop professional skills (i.e. collaboration and communication).
3. The learning activity should provide an experience for continued practice, reflection, and feedback.
4. The learning activity should be aligned with and reinforce the learning goals, learning objectives, and learning assessment.

Bosman and Fernhaber (2018) use Figure 3 as a rationale for the four major intentions. From a micro perspective, engineers continuously improve new products and processes with the overall goal of creating the most valuable design (which exists at the center of customer desirability, business viability, and technological feasibility). At the same time, from a macro perspective, continual iterations move the design process through time from opportunity discovery to evaluation and finally, exploitation. Hence, the combination alludes to Intention 1. However it is important to note that change doesn't happen in silos, which provides purpose for Intention 2 with a focus on collaboration and communication. Considering the goal to transform habits into a mindset, Intention 3 highlights the importance of practice and feedback. Intention 4 simply provides support for the backward design curriculum development approach (Wiggins & McTighe, 2005), ensuring desired results (learning objectives), determines acceptable evidence (learning assessment), and pedagogical approach (learning activity) are in alignment.

The business model canvas can allow educators to satisfy the four intentions by offering an experiential and cooperative learning environment. The canvas can serve as a guide for student design teams and provide a means for documenting their design work. For the first intention, the business model canvas can immerse students in experiences to discover, evaluate, and exploit opportunities while meeting multiple criteria for developing value-creating solutions to an engineering design task. Successful ideas for a technological innovation must meet customer desirability, business viability, and technology feasibility (Brown, 2009). Therefore, it is important for students to identify and consider various factors involved in an opportunity for innovation. The nine sections of the canvas provide them with multiple research questions about business circumstances and various stakeholders including targeted customers for a value proposition. Then, within the business model canvas, students can develop, test, and verify their assumptions about customer desirability and business viability as well as the technical feasibility of their ideas before making a design decision.

We recommend that student design teams start with the section of value proposition, followed by customer segments, customer relationships, channels, key activities, key resources, key partners, cost structure, and revenue streams. Also, we recommend starting with a hypothesis for a value proposition and mapping it with appropriate customer segments. The hypothesis is tested by reaching out to members of the customer segment and asking them questions to prove, disprove, and refine assumptions about the problem and the potential solution. Usually, interactions with ten different customers in the same segment, also known as customer interviews, can be sufficient for students to initially validate a hypothesis. Once a consensus is achieved within the team, a value proposition is carried further, revised, or forfeited altogether.

For the second intention, as a visual representation, the business model canvas can facilitate students' communication and collaboration in a team-based design project. Innovative design is very rarely done in isolation (Bosman & Fernhaber, 2018), so it is important for students to learn how to effectively and efficiently communicate and collaborate with their peers in design processes. The business model canvas can be printed out on large papers and posted on the walls of a classroom, so each of student teams works on their business model canvas by filling in the sections. Also, we recommend using post-it-notes instead of permanent markers, which would assist students to share individual ideas and synthesize different perspectives and thoughts through increasing flexibility in decision-making processes. See Figure 4.

For the third intention, the business model canvas can provide students with opportunities to practice, reflect, and receive feedback on their design-making processes.

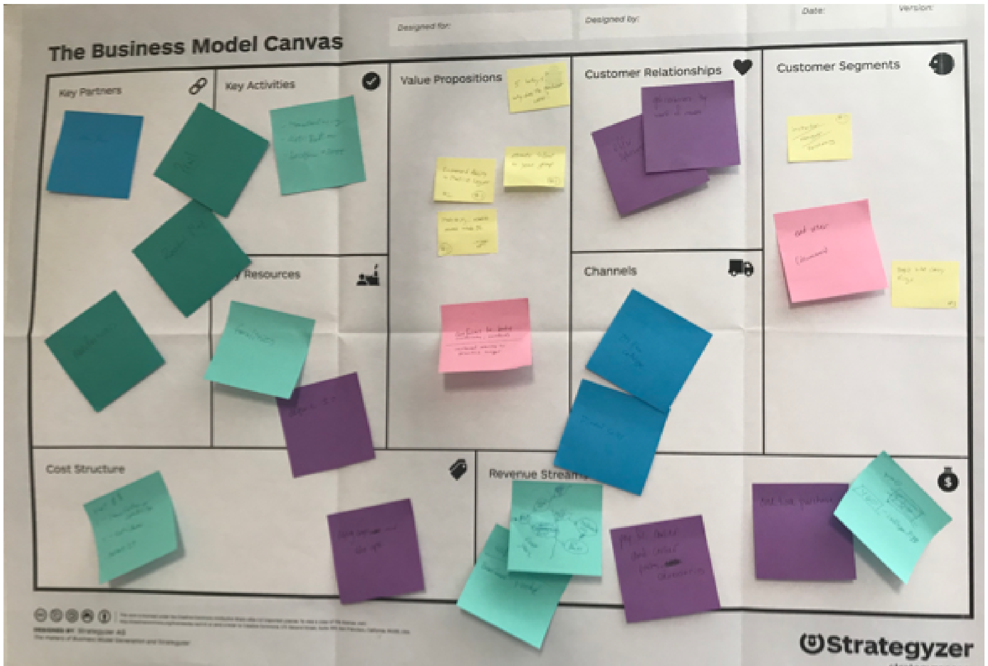

Figure 4. A student design team's business model canvas.

An entrepreneurial mindset can be molded by iterative experiences stimulating the mindset (Bosman & Fernhaber, 2018). During the research and experimentation with the business model canvas, students revise or pivot their ideas throughout an iterative cycle of developing and testing assumptions. The iteration can allow students to shape and enhance their entrepreneurial mindset.

Lastly, for the fourth intention, the business model canvas can assist educators to apply the backward design approach in their curriculum and instruction design. The backward design approach enables educators to identify and prioritize learning outcomes in detail before thinking of pedagogical strategies and assessment plans. The nine sections of the canvas represent big ideas of an entrepreneurial mindset, so educators can think of how each big idea can be related to informed design and what content knowledge secondary engineering students should learn. Also, using the business model canvas involves various cognitive processes from lower-levels (remembering, understanding, and applying) to higher-levels (analyzing, evaluating, and creating) of the revised Bloom's taxonomy. Therefore, with the business model canvas, educators can determine what learning outcomes are appropriate to secondary engineering students and how to assess whether students have achieved the learning outcomes within the canvas, and then design learning experiences around these assessment tasks. Designed through the backward design process, the learning activity can have an alignment with learning goals, objectives, and assessments of an entrepreneurial mindset in engineering design contexts.

Lean Startup Activities to Drive Informed Design Decisions

Business Model Canvas	Design Practice	Informed Design Decisions or Activities
Value Propositions	Project Framing & Scoping	• Defining value propositions • Creating a project charter • Generating initial ideas
Customer Segments		• Defining target customer segments • Mapping each value position against the customer segments
	Low-Fidelity Prototyping and Testing	• Developing a low-fidelity prototype with ethnographic perspectives • Testing the low-fidelity prototype with early adopters or lead users
Channels		• Creating a workflow for reaching out to each customer segment • Creating a fishbone diagram for identifying the cause-effect relationship of the problems solved by each channel
Customer Relationships		• Creating a user journey map for defining the series of the user interactions with the product • Creating causal maps for node-to-node interactions between a customer and the product
Revenue Streams	Mid-Fidelity Prototyping and Testing	• Conducting A/B testing for identifying the design that can generate highest revenue • Identifying revenue streams • Mapping the revenue stream against other factors (e.g. product quality, user lead time, and cost) using 2-axis maps
Key Resources		• Identifying spaces, setup, tools, machinery, and materials for developing their product
Key Activities		• Identifying key activities for developing their product • Building and revising mid-fidelity prototypes
Key Partners		• Identifying potential partners for alliances to optimize the process of producing and delivering their product
Cost Structure	High-Fidelity Prototyping	• Building and revising high-fidelity prototypes • Calculating the input cost for developing the final prototype • Identifying the cost structure involving fixed and variable cost

Table 1. Lean Startup Activities to Drive Informed Design Decisions

An Example of Integrating an Entrepreneurial Mindset into an Engineering Design Project

In this section, we discuss a method to integrate an entrepreneurial mindset into an engineering design project by employing the business model canvas. We recommend instructors to discuss the concept of design thinking while guiding student teams through the corresponding sections of the business model canvas. Table 1 and the following paragraphs provide an outline of

Figure 5. A student design team detailing a user journey for their solution.

the lean startup practices and associated design activities intended to inform engineering design decisions.

First, when project scoping, student teams can focus on *value propositions* of the business model canvas. Team members may have different perspectives and thoughts about values of their product, so they can identify multiple value propositions and enrich their creativity by integrating their various ideas. Then, students should create a project charter based on the defined value propositions, which can help them avoid scope creep within their design project.

Next, when developing low-fidelity prototypes to test design concepts, student teams can focus on *customer segments, channels, and customer relationships* of the business model canvas. Fidelity, in terms of prototyping, refers to how closely the prototype looks and acts like the finished product (McElroy, 2017). Low fidelity prototypes are typically made from inexpensive and easily accessible materials that require little skill to manipulate, while high-fidelity prototypes are made in the final material and look and function as the finished product. Though a low-fidelity prototype does not function as a finished product, they do allow a design team to identify initial problems with their design by testing high-level concepts within a reasonable cost and timeframe. To do so, students must first identify customer segments to be targeted for their value propositions and then map each value proposition against a customer. Then, they can create a low-fidelity prototype in consideration of the principle of ethnography and test their hypothesis on the value propositions and target customer segments with the prototype. While lead users and early adopters help in testing the hypothesis, value propositions may be discarded or pivoted based on these early customer interactions. Also, students can define channels through creating a workflow for reaching out to each customer segment and a fishbone diagram for identifying the cause-effect relationship of the problems solved by each channel. They can also make a user journey map to define the series of user interactions with the product while maintaining customer relationships (See Figure 5). Because analytical techniques are usually ineffective in defining causal relationships, we recommend using causal maps for node-to-node interactions. Design thinkers usually create fictional characters to demonstrate how different user groups or customer segments will interact with the product.

Lastly, when developing and testing mid-fidelity and high-fidelity prototypes, students can focus on the *revenue streams, key resources, key activities, key partners*, and *cost structures* of the business model canvas. A mid- or high-fidelity prototype enables students to incorporate visual design elements and functionality by testing more refined assumptions, finalizing their design concept, and communicating their final design decisions. Also, to identify which version of their product is more acceptable to the users, students can employ A/B testing whereas two or more versions of the same product are given to the users, and then the one that generates the highest interest is selected (See Figure 6). This is a simple yet powerful technique mostly used in web development projects. Next, the revenue stream may be mapped against other factors, such as product quality, user lead-time, and cost, using 2-axis maps. Also, as entrepreneurs need to keep a track of key resources, such as hardware, personnel, and funding required to keep a business running, student teams should define the space, setup, tools, machinery, and materials to develop their product. The key activities to transform ideas into a viable prototype must be documented and agreed upon by all team members. Finally, the team members will converge towards a common design for developing the high-fidelity prototype.

Conclusion

In this article, we are not suggesting that every student should become an entrepreneur. However, we emphasize that students can improve their design abilities for producing technological innovations through the teaching of an entrepreneurial mindset—as it can serve as a guide for an individual to make informed design decisions that create customer, business, and social values. Accordingly, we believe that an entrepreneurial mindset can be taught within current secondary engineering programs as an additional element to design-based pedagogies.

Helping students develop an entrepreneurial mindset may hold great potential for secondary engineering classrooms. The business model canvas, a tool that is used by

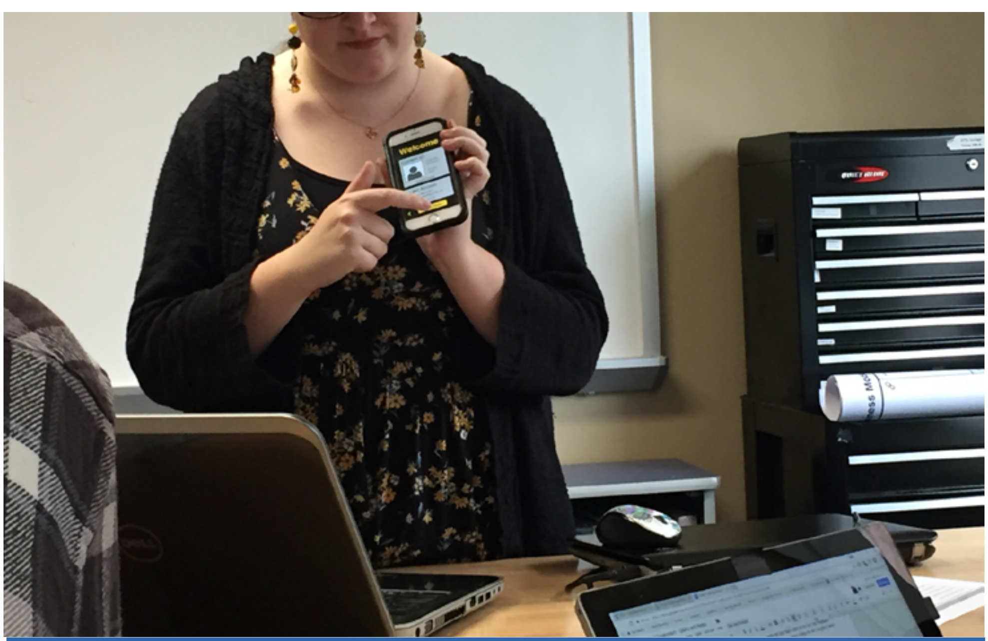

Figure 6. A student conducting A/B testing of a mid-fidelity smartphone application prototype.

entrepreneurs and startup companies for launching lean enterprises, has now been employed as a pedagogical approach to enhance the entrepreneurial thinking abilities of students. Therefore, we propose that secondary teachers can use the business model canvas and its corresponding strategies as an interactive learning guide for engaging high school students in developing viable solutions to real-world problems and investigating the exploitation of opportunities. In addition, we propose that these strategies may also help students document and track their design progress in a time-bound manner. Lean startup strategies, such as the business model canvas, have been adopted by *National Science Foundation* as a formal methodology for the delivery of their Innovation-Corps program. Our intent is to propose its use and extend its purpose as a means to aid students in making informed design decisions and promoting more authentic engineering design activities in secondary classrooms. However, further efforts are necessary to better understand to what extent these strategies can help secondary engineering students enhance their design competence, increase their motivation in design projects, and ultimately, foster their innovation capabilities.

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