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An Entrepreneurship Venture for Training K–12 Teachers to Use Engineering as a Context for Learning

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Abstract: In this paper, the authors present their experiences from participating in a National Science Foundation (NSF) I-Corps L training program established for business startups, using Blank's Lean LaunchPad, Osterwalder's Business Model Canvas, and associated tools. They used the entrepreneurial skills acquired through this training to scale-up their emerging innovation, the Cincinnati Engineering Enhanced Math and Science Program (CEEMS), which had been developed, implemented, and evaluated with successful results over a period of seven years in a targeted 14 school-district partnership in Greater Cincinnati. The overriding goal was to improve student learning and success rates in K–12 math and science courses by helping to accelerate the process of bringing effective educational innovation, CEEMS, to scale. In CEEMS, teachers were trained in using challenge-based learning (CBL) and the engineering design process (EDP), teaching pedagogies to transform their classrooms into student-centered, hands-on learning environments, while also assisting students to improve their evaluation scores related to science, math, and engineering instruction. CEEMS teachers acquired the necessary skills through coursework, professional development (PD) workshops, and longitudinal professional guidance provided by assigned coaches over a period of two years to become proficient in developing CBL–EDP curriculum, teaching it, and assessing student learning and reflecting after teaching. The authors have documented how they used customer market research conducted during the I-Corps L training to define their minimum viable product (MVP) to duplicate the successful CEEMS methodology through a condensed (≤16 week) self-paced, completely online training program with virtual coaching support. The authors also describe the process they used to move forward very quickly from an MVP to a more complete product offering, its branding, the process of trademarking it, and finally licensing it to an established non-profit organization (NPO) for future marketing. Details of the whole experience are presented with the hope that it will serve as a useful guide for other venture creators.

Keywords: challenge-based learning; engineering design process; student engagement; online professional development training; coaching

1. Introduction

1.1. The Need

The American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and the National Science Foundation (NSF) all promote student-centered pedagogies, such as inquiry, constructivism, and project-based learning, as ways to increase student engagement and achievement in science [1]. K–12 teachers are required to teach state mandated academic standards for specific courses and grade levels. Additionally, they also face high-stakes testing accountability, classroom management, and interruptions to instructional time due to testing, assemblies, special programs, etc. With the advent of the Next Generation Science Standards (NGSS) [2], many states (even those who have not adopted NGSS) have placed more of an emphasis on incorporating engineering design into science standards. While Common Core State Standards (CCSS) for Mathematical Practice [3] do not directly mention engineering, they promote teaching students "habits of mind". Engineering design is one vehicle to develop these critical habits. In a math classroom, engineering design challenges engage students through problem solving, critical thinking, sense making, reasoning, collaboration, communication, precise measurement, collection and analysis, graphing of data, and so on. In order to encourage the use of engineering design, *Understanding the Status and Improving the Prospects* [4] advocates for a more systematic linkage between engineering design and scientific and mathematical inquiry to improve learning. As such, engineering design has a key role in both NGSS and CCSS.

Despite this new engineering focus, K–12 science and mathematics teachers are often intimidated and unsure how to incorporate engineering practices in their classrooms. As a result, professional development (PD) has emerged to address this very issue. The most powerful instrument for change lies at the core of education—teaching itself [5–7]. Successful learning is a shared experience between a knowledgeable, enthusiastic teacher and curious, self-assured students [8–13]. The efficacy of combining PD that improves teaching effectiveness with standards-based (K–12) curriculum is becoming evident [14–17], as are better ways of retaining effective teachers [18]. Teacher education needs to be iterative; it depends on sustained, coherent, collaborative, and reflective high-quality PD [19–22], high-level science content [23], and an understanding of the social, contextual, and distributed nature of learning [24].

The components of an integrated framework in science, technology, engineering, and math (STEM) education often include a trans-disciplinary curriculum and an inquiry-based approach [25–29]. Embedded in it is authentic learning, engineering education and the engineering design process (EDP), project-based and problem-based learning (PBL), career exploration, and a collaborative learning environment. Currently, K–12 schools often give students an incomplete and inaccurate depiction of what engineering entails because methods differ between the sciences and engineering. Thus, there is a pressing need for in-service training that will prepare instructors to instruct in engineering as well as math and science.

In science education, engineering design is increasingly being viewed as a gateway to authentic learning that can support increased student understanding of scientific concepts (e.g., [30–32]). Mehalik et al. [33] suggest that a systems design approach for teaching science concepts is superior in terms of knowledge gain, engagement, and retention when compared to a scripted inquiry approach. Parallel to design approaches are those that show how science becomes the vehicle for prompting design, as is the case with PBL pedagogy (e.g., [34]). For example, an inquiry project designed by Snetsinger et al. [35] began with the question "How can one harness the energy of the wind to create electricity?" and students worked in teams to address the design challenge. Whether the approach to science is through design or design through science, the convergence between science and engineering design are explored in ways that represent the real world [36]. Design has the potential to stimulate interest and make science accessible to all.

In order to capture the attention and aspirations of students, innovative, real-world applicable units prove particularly valuable; however, they require teachers who are not only confident in their abilities to design and implement them, but are also given the opportunity to do so. In order to develop units that highlight real world problem solving, teachers often benefit from having a structure to scaffold their lesson. Challenge-based learning (CBL) provides that structure or scaffolding. In CBL, scaffolding structures guide student progress through the challenge [37]. CBL environments can mimic design or provide motivating reasons for students to solve problems to address a societal issue and in the process learn STEM content. The success of these approaches for learning engineering has been demonstrated [38,39]. The advantage over traditional design activity is that when this is situated as science and math activity instead, students are more likely to fully explore variables, rather than stop when design criteria are met [38–42]. A CBL STEM classroom creates learning environments designed to engage students in "doing" and facilitating students' active engagement in their own learning [43].

1.2. Our Response to the Needs: A Teacher PD Program for Select School Districts in Cincinnati

The Cincinnati Engineering Enhanced Mathematics and Science Program (CEEMS) [44] was a $9.2 million targeted Math and Science Partnership (MSP) grant (#DGE-1102990) funded by NSF from 2011 to 2018, for which the primary author of this paper was the Principal Investigator and the co-author was a Resource Team Member (coach) on the project team. The CEEMS vision was to establish a cadre of in-service teachers, who would implement the authentic articulation of engineering with science and mathematics in 6–12th grade classrooms. It afforded a much-needed opportunity to study how students learn mathematics and science when engineering is used as the context. CEEMS was led by the University of Cincinnati as the higher education Core Partner in partnership with 14 Core Partner school districts. CEEMS worked to meet the growing need for engineering-educated teachers who were equipped to provide learners with opportunities to meet the NGSS, CCSS for Mathematical Practice, and Ohio's Learning Standards [45] for K–12 science and mathematics while acquiring universal skills (21st-Century Learning Skills). CEEMS was unique in that teachers were trained under coaches to develop and teach curricular units in which CBL and the EDP were integrated and individually suited to their own classroom.

The CEEMS CBL approach [46–51] has its roots in the seminal work freely disseminated by Apple, Inc. [52]. In this version of CBL, students begin with a big idea, such as public health. They collaborate in teams to generate an *essential question*, offer insight on how that big idea relates to it, and the class as a whole then state it as a *challenge* that they would like to solve. After the challenge is defined, the entire class generates *guiding questions* that need to be answered. Student teams seek to find answers to the guiding questions by participating in a variety of learning activities, conducting research, learning new material (independently, in groups or as part of a teacher-led lesson), performing experiments, interviewing, and exploring various avenues to assist in crafting the best solution to the challenge. CEEMS adds a twist by requiring that the challenge be solved using the EDP. By synthesizing CBL and the EDP, teachers use the challenge to get students engaged and interested in the problem and then guide them to use the EDP to seek out multiple solutions. Put simply, the EDP is a series of steps that engineers follow to devise solutions for problems. More details about the EDP are presented later in this paper. However, the nature of the EDP is inherently flexible because there are constraints, trade-offs, and performance objectives for any challenge or problem that make a variety of potential solutions available. As such, the EDP is an iterative process that requires constant revision and optimization. Using prior knowledge and experiences, students identify the best alternative and implement the most efficient solution. Finally, student teams share their solution to the challenge using one of many possible formats such as oral presentations, written reports, marketing flyers, videos, and other creative means.

It should be noted that CBL is similar to, yet distinct from, both project-based learning and problem-based learning. All three pedagogies are student-centered, interdisciplinary, collaborative, reflective, and oriented around a real-world problem. In contrast, in CEEMS, CBL provides students with the opportunity to use the EDP to define the question they want to answer, and to provide input on the challenge to be solved. While problem, project, and CBL by themselves all work well for teaching engineering, the CEEMS approach has shown that learners are often more invested in solving a problem if they define it and set the parameters themselves. Giving learners more control can prove frightening for educators. What if they choose to solve a problem that bears little relation to the state standards they are expected to learn? As a result, it requires much practice and support for teachers to become adept practitioners of a CBL–EDP integrated approach, while still ensuring that students learn the required content.

Using the CBL and EDP pedagogies in CEEMS, as described above, eight new courses (three credit hours each) focusing on engineering, science, and math content, and a seminar-based capstone course (one credit hour) were used to train in-service, 6–12th grade math or science teachers with current licensure in math or science, during the Summer Institute for Teachers (SIT). SIT participants took a total of six courses (three courses per summer) and two education seminar courses (one course per summer) over the course of two 7-week summer programs, for a total of 20 semester credit hours. The seminar-based capstone course was structured to provide PD to help the teachers design engineering challenges which incorporate the EDP that could be applied in their own classrooms using their own teaching standards. As part of this seminar course, two Resource Team Members (coaches), consisting of a retired or semi-retired educator and engineer, were assigned to each teacher. They provided critical support during the summer development of units by brainstorming ideas, reviewing units in progress, and approving those units once they reached completion. After the successful completion of this program, the University of Cincinnati provided the SIT teachers with a Certificate of Engineering Education. Teachers earned 10 credit hours per summer for a total of 20 credit hours.

CEEMS teachers develop units using established templates, which help them to organize their specific information and content in a consistent way that requires them to document how they plan to adhere to the program pedagogies throughout unit implementation. Prior to drafting their first curricular unit, teachers attend a PD workshop where they are introduced to the unit and an activity template that were developed for the CEEMS project. At least four activity templates are utilized for each curricular unit, as well as a pre-test and a post-test that are directly linked to the activities' educational outcomes. The activities are designed to answer the guiding questions identified by the students, and as such have well-defined and measurable educational outcomes. There are some key teaching strategies the teachers are required to plan and document prior to teaching, and to later revise if they are changed during teaching. In each unit template, teachers pre-identify the kinds of misconceptions students would likely have regarding the content and how these issues would be addressed. Additionally, the teachers outline how they plan to differentiate parts of the lesson activities to support the needs of different kinds of learners. The goal for the construction of templates is to maximize organization and preparation before implementation, but in such a way that successful teaching methods and areas for improvement can be easily identified. In the CBL section of the template, teachers have to describe how they plan to relate the math and science content to real world applications, STEM careers, and societal issues (ACS).

During the academic year, two resource team coaches observe a teacher's unit in action during key points (e.g., when CBL and the EDP are implemented) and then have a de-briefing session with the teacher to discuss successes and improvements. In the second year, their role remains the same. After the de-briefing, the teacher records his or her reflections on the implementation process of the unit template, makes any needed edits to the templates based on what occurred during unit implementation (for example, actual student misconceptions and any differentiations addressed), and documents assessment and evaluation results related to growth in student learning.

In summary, in CEEMS there are three important elements that prepare teachers to successfully incorporate the EDP into the teaching of core science and math content, which can be adopted and/or adapted by others. First, teachers experience engineering challenges themselves when taking the SIT courses: by engaging in teamwork and collaboration, learning from failure, and experiencing the iterative nature of the EDP. Second, the CEEMS seminar-based capstone course is structured as a PD program in which teachers are accountable to create implementable content and engineering design activities for their classrooms, which are reviewed, critiqued, and approved by resource team coaches. Finally, teachers are supported and guided as they create and implement engineering design modules. This is accomplished using resource team coaches, who guide the teachers through the process of creating and implementing lessons incorporating engineering design activities: they provide invaluable feedback as teachers reflect on their own practice.

With this tiered approach, the CEEMS project has trained 88 secondary teachers on teaching math and science content and standards using CBL and EDP pedagogies. Those 88 teachers developed, taught, and documented 327 units that utilize CBL and the EDP and align to content standards. The CEEMS secondary math and science units can be found at http://www.ceas3.uc.edu/ceems/. These teachers impacted over 18,000 6–12th grade students. Of the 88 CEEMS teachers, 32 enrolled in, and 21 have completed, the Masters in Curriculum & Instruction with Engineering Education specialization (MCIEE) degree program as of August 2018.

The CEEMS evaluation and research studies use a mixed-methods design to respond to the following questions:

(1) How do students in a design and CBL environment engage in decision making, strategic planning, evaluating a revision of plans, creative thinking, and task persistence?
(2) How do students in design and CBL environments perceive their involvement in STEM careers?
(3) What measures and instruments are most effective at capturing and documenting these leaning tasks?
(4) How are the teachers' gains in knowledge of engineering transferred into instructional plans?
(5) What supports and barriers do teachers encounter as they implement their plans with students?
(6) How do the knowledge gains and implementation factors impact the teachers' pedagogical content knowledge?

The intent of this paper is not to describe and present in detail the results of the CEEMS evaluation [53,54] and research [55] studies conducted, but the key findings from them are summarized below:

1. Student knowledge gains were higher: 8.5% higher on the post-test versus comparison teachers' students, which is statistically significant at a 95% confidence interval.
2. Engineering design practice requires that students use high-level cognitive demand, which involves making connections while solving problems: 89% of students (more than 18,000 participated) reported successfully understanding and implementing the EDP to seek and defend an optimum solution to a real-world problem with constraints.
3. Integration of CBL and EDP instructional practices ensured usage of a wider variety of active learning strategies: Classroom Observation and Analytic Protocol [56] data showed that CEEMS teachers used probative, open-ended questioning that encouraged critical thinking, as well as the EDP and CBL strategies, collaborative grouping, and use of external resources (e.g., videos) as a means to focus the lesson on real-world issues.
4. Student engagement and buy-in was ensured: In post-teaching surveys, teachers reported (100% strongly agreed or agreed) that they saw increased classroom engagement compared to when non-CEEMS units were taught.
5. Teachers saw the benefit of continued use of CEEMS teaching pedagogies (CBL and the EDP) with time: Teachers' current instructional practices (CIP) surveys indicated a significant increase of their usage of these teaching pedagogies during the project (from pre-project to one year, and pre- to post-project/two years) and one year after programming ended.
6. Over time teachers learned to negotiate successfully through barriers and lack of supports reported for student-centered reforms, and to minimize their impact.

1.3. Taking CEEMS beyond Its Partnership

The goals of the CEEMS project were admittedly ambitious—to profoundly change the STEM culture in the Greater Cincinnati area as it pertains to K–12 educational agendas over the grant period (seven years, starting in the fall of 2011). Moreover, we hoped that our project would not only serve the state of Ohio by advancing student proficiency in science, mathematics, and engineering (and, as a result, support the state's pursuit of economic success in the STEM driven milieu of the 21st century), but also provide a template for large-scale, engineering-enhanced initiatives for STEM education reform elsewhere in the country. The CEEMS research and evaluation syntheses reports [53–55] clearly documented that evidence-based approaches (CBL integrated with the EDP) to teaching that actively engage students in their own learning are more effective than traditional lecturing. Our next overriding goal was bringing these effective educational practices to scale.

For Americans to remain competitive, several governmental, corporate, and non-profit organizations and writers have been calling for transformational change in STEM education in the US for many years [57–66], particularly focusing on post-secondary STEM education. However, previous investments have not resulted in the desired level of change, even though STEM educators, researchers, and communities agree on the required change, the vision of what needs to be changed, and the evidence-based best practices that can be used. The inability to propagate and scale STEM educational innovations is the primary reason for this situation. In this paper, the authors have attempted to fill this gap by presenting how they used their participation in the NSF's Innovation Corps for Learning (I-Corps L) pilot initiative to propagate and scale CEEMS educational innovations beyond its 14 school-district partnership in Greater Cincinnati. Hopefully this documentation will help others to plan scaling up their own STEM educational innovations.

CEEMS shows that the following skills are key to successful teacher training and experience: (1) a foundational understanding of the EDP and how to use it to teach in line with current science and mathematics standards; (2) first-hand experience with the process in active and collaborative settings, just as the students will have when methods are used in the classroom; (3) experience with tools, such as the CEEMS unit database (http://www.ceas3.uc.edu/ceems/), that facilitate the development of new units to meet individual curriculum and student needs; (4) guidance by professional coaches as they create and implement engineering design modules; and (5) to document their final unit implementations with improved student knowledge results and personal reflections for other teachers.

The challenge was to use key elements from CEEMS that prepared teachers to use engineering as a context for learning, and to package them into a much shorter PD experience that individual teachers and school districts would find worthwhile and be willing and (more importantly) able to fund. Working with the I-Corps L instructional team, we identified the best methods for packaging the CEEMS PD experiences for teachers to ensure that they get enough immersion in the pedagogies of CBL and the EDP, and enough coaching support to implement with competence. The goal was to bring to scale a tested teacher PD program (CEEMS project) so that it could be sustained and even expanded before its NSF funding ended. If successful, this would significantly change the way math and science are taught in K–12 classrooms, resulting in greater student engagement and achievement. While the overall goal is to train teachers, we have also implicitly considered the educational goals for their students. By synthesizing the CEEMS and I-Corps L approaches, we expect greater numbers of students to pursue STEM disciplines and to produce a larger, more highly qualified technical workforce that more closely reflects the demographics of the US (as identified by the numerous governmental, corporate, and non-profit organizations cited earlier).

2. Research Methods

2.1. Initial Training

During the fall of 2014, NSF awarded a supplement award, I-Corps: Training Teachers to Use Engineering as a Context for Learning (NSF grant #1518619), to a select group from the CEEMS project team. As part of this award, the team participated in a seven-week course of study, along with about 20 other exemplar projects, in order to learn how the business-model design and customer development process can be used to evaluate the sustainable scalability potential of their educational innovation. The participating exemplar projects were selected by the NSF program officers from three directorates: Education and Human Resources (EHR), Computer and Information Science and Engineering (CISE), and Engineering (ENG). The facilitators and coaches for the course included a team of an NSF program officer, business entrepreneurs, university faculty, and industry experts. The training course utilized a Lean Startup [67] methodology which assumes that all you have is a series of untested hypotheses—basically, presumptions about the validity of one's educational innovation idea. The three parts to this methodology include the following: (1) a process of hypothesis testing using a business-modeling tool; (2) "getting out of the building" to test these hypotheses with prospective clients; and (3) the use of agile development [68] to rapidly iterate the product being developed.

The goals of the training course were to work with the participating teams to accomplish the following:

(1) Determine the readiness of their educational innovation for sustainable scalability as a self-supported entity that is able to systematically promote its adoption and enable and facilitate its use;
(2) Enable the team to develop a clear go/no-go decision regarding sustainable scalability of the educational innovation;
(3) Help develop a transition plan and actionable tasks to move the educational innovation forward to sustainable scalability, if the team decides to do so.

The seven-week course ran from January to February 2015 and was started in San Francisco, California with an on-site introductory three-day workshop, in which:

(1) teams were introduced to the Lean Launchpad approach;
(2) teams learned the business model development and customer development process;
(3) teams met with customers (a minimum of 25) and presented what they learned to the class.

The introductory workshop was followed by five weekly online class sessions, and each included reading assignments from the *Startup Owner's Manual* [67], watching online lecturettes, and reporting results via PowerPoint of their "getting out of the building" and "testing our business model assumption" experiences. Each of the five online classes had two parts: an hour and a half for team presentations, and an hour class discussion of the weekly online lecturettes. At the end of February, all teams met for the final lessons-learned workshop where each team presented the lessons learned from their exploration of sustainable scalability and presented a two-minute video showcasing those lessons and their plans to move forward. Each team had the opportunity to meet with the teaching team and receive critical feedback to refine and finalize their final deliverables.

Throughout the program we engaged in customer discovery interviews to understand the potential adopters, collaborators, and users. We used Blank's Lean LaunchPad [69] approach, which is an entrepreneurial method created by Steve Blank to develop a business model by talking to potential customers. As such, we were instructed to conduct at least 100 interviews to test hypotheses related to the nine elements of Osterwalder's Business Model Canvas (see Figure 1): value propositions, customer segments, channels, relationships, revenue streams, key partners, activities, resources, and cost structure. To aid in our collection of research data (our interviews), we utilized Launchpad Central (https://www.launchpadcentral.com/), which permitted the storage of interview summaries as well as a feature that allowed us to continually refine our business model. This feature, the Business Model Canvas, provided a template that we updated throughout our training and customer interviews, and that we shared with our assigned coaches, who reviewed our work and critiqued it, enabling us to continually improve our product. This tool was very useful to help us better define our product offering, as well as to consider the trade-offs that we needed to make.

The customer interviews were analyzed to identify customer types and their needs, and the results obtained were represented in the Value Proposition Canvas (VPC) shown in Figure 2. During the training, the VPC was completed twice: once after the interviews were completed to represent what a typical customer desires, and a second time after the minimum viable product (MVP) had been envisioned, with plans to present it on the final day of the training.

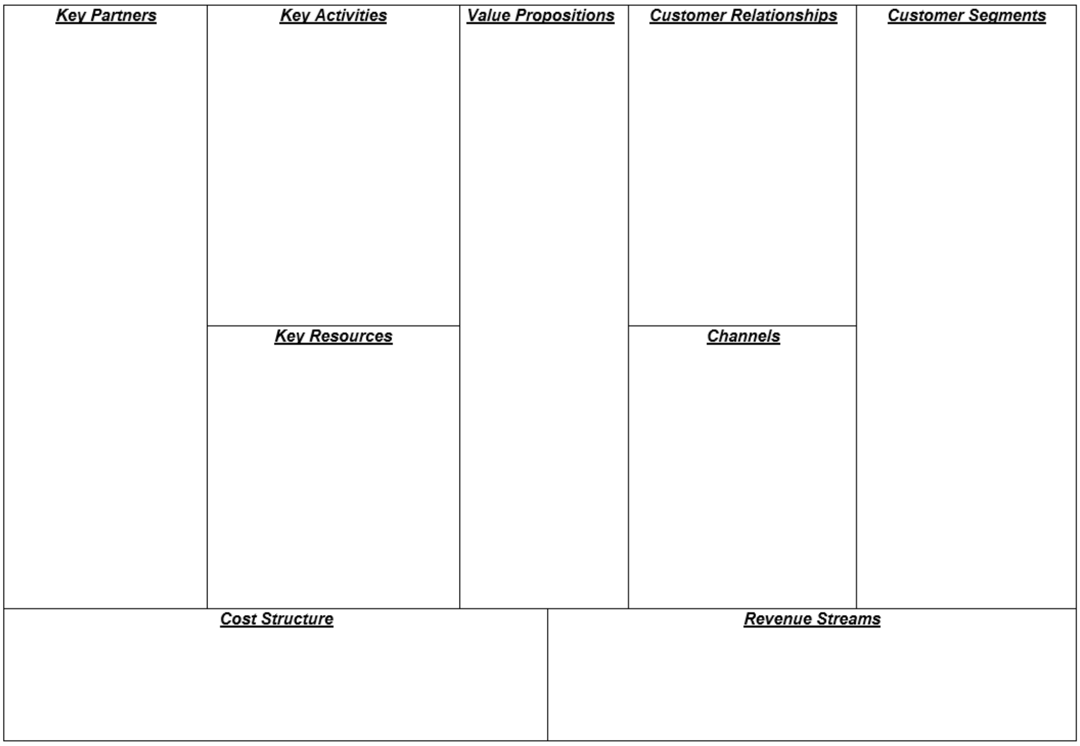

Figure 1. Business Model Canvas (BMC) (adapted from [69]).

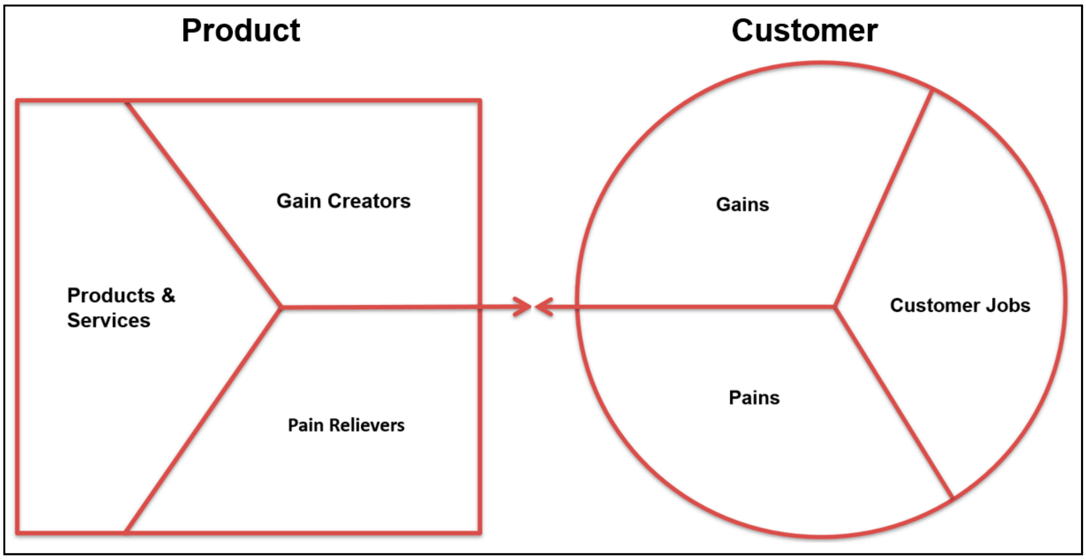

Figure 2. Value Proposition Canvas (VPC) (adapted from [69]).

2.2. Our Development Process

Figure 3 illustrates the flow of the development process we used to create our final product offering. The product in this case is a professional development program (referred to also as a workshop in this paper) for K–12 school teachers and administrators called STEMucation Academy (the official trademark for its name was obtained by the University of Cincinnati Research Institute (UCRI), an Ohio non-profit corporation, on 24 March 2016, from the United States Patent and Trademark Office). Though the flowchart may seem quite complex, it will in fact become quite understandable with more in-depth descriptions to follow.

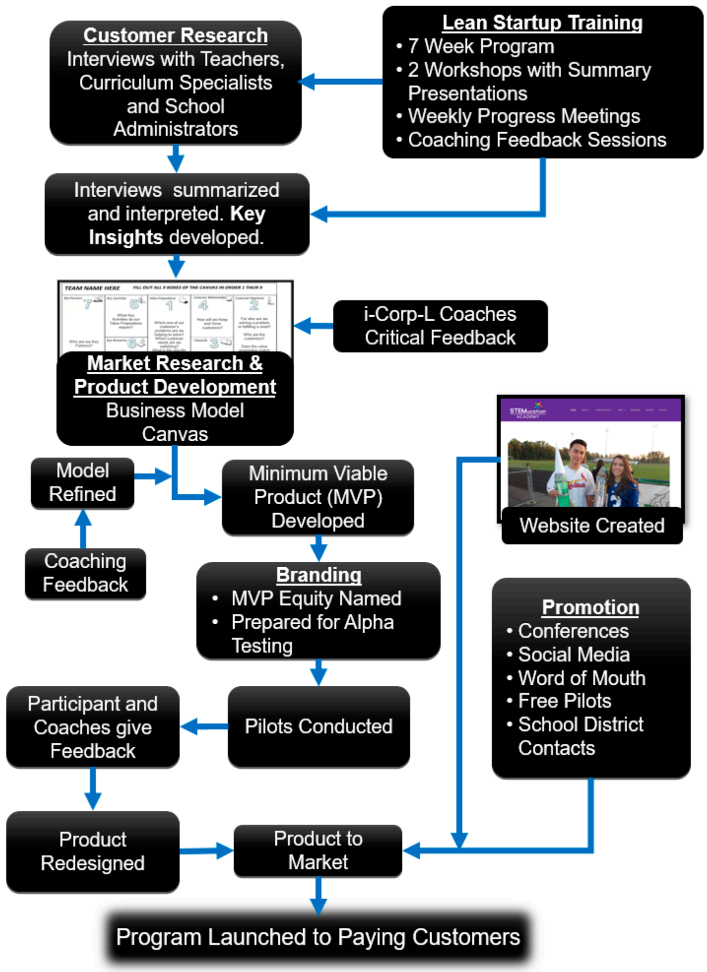

Figure 3. Program development flowchart.

2.3. Customer Research

In the Lean Startup terminology, interviewing customers is all about "getting out of the building" with the purpose of testing the hypotheses that we had formed about our proposed product. Our initial hypotheses were:

(1) science and math K–12 teachers will value the CEEMS [44] model;
(2) there are relatively few alternatives;
(3) we can develop a scalable CEEMS model that retains value.

Our customer research was broad in scope. We reached out to responders from 17 different states for a total of 117 interviews. We targeted 10 to 15 interviews per week. The interviews were tailored to the individual being interviewed based on their ability to focus on pre-selected questions relative to our program development. A typical interviewee was a school administrator, math or science K–12 teacher, curriculum director, the owner or user of a competitive product, etc. These interviews were about 20 min in length and were usually attended by two team members, one to ask the questions and keep the interview on track, and a second to take notes. The interviews were done both face-to-face where practical, and at other times over the phone, to avoid high travel costs. Upon completion of the interview, notes were summarized and input into Launchpad Central. A sample of a summarized interview is shown below:

Interviewee: STEM Facilitator, school in Oklahoma

"Oklahoma has its own science standards which are similar to NGSS minus evolution and climate change. Interviewee used to be science curriculum coordinator before he took on current position. Involved in [a state of Oklahoma funded] MSP (Math & Science Partnership) program where teachers invest two weeks in PD-half of PD involves pedagogy and half of time they are working with OU researcher on actual research. Believes meaningful PD cannot be shorter than two weeks. Waiting list for MSP PD as it is very popular. His MSP does struggle with Saturday follow up only 1/3 show up; teachers have family priorities on Saturdays. Measurement tools for own MSP mostly focuses on teacher change; has some data related to student performance but that is hard to quantify. Some teachers going through MSP then were motivated to seek advanced degrees. In their district most science teachers have less than five years of experience; many have science minors rather than science majors and therefore are lacking in content. As soon as teachers achieve a paradigm shift and get it, they leave district or become consultants. Teacher PD needs to focus on how science works, what science is, and how to integrate science practices. There is no $ in Oklahoma district budgets for outside PD in science and social studies. All PD funds are directed to English/LA and math. All science PD must occur at district level; best is informal in nature when conversations occur about curriculum. Teachers are required to do 15 h of PD per year and can easily get that by coming to district sponsored PD; some PD offered at district is not science specific."

Furthermore, key insights were developed as they related to our hypotheses. These concise summaries were an excellent way for us manage the large amount of information we collected from our 100+ interviews. As an example, the key insight we developed for the above interview was:

"No money in Oklahoma districts for outside PD in science or social studies; all science PD must be homegrown due to lack of funds or rely on grant funding. Does not think PD experience will be meaningful if it is less than two weeks; measuring teacher change may be enough to prove effectiveness."

Referring to the flowchart shown in Figure 3, the top three boxes have been addressed and we are ready to discuss the Market Research and Product Development step. In this step we began completing the Business Model Canvas. As shown in Figure 1, the Business Model Canvas represents a visual overview of the nine building blocks for building a business model [69]. These nine steps are further described in Table 1.

Our training objective then was to gather the information necessary to build a successful business model through customer interviews, getting constant and critical feedback from the I-Corps L coaches, and by evolving our model as we documented our learnings using the very visual Business Model Canvas.

Table 1. The nine building blocks for building a business model.

Building Block	Description
Customer Segments	An organization serves one or several customer segments
Value Propositions	The business model seeks to solve customer problems and satisfy customer needs with value propositions
Channels	Value propositions are delivered through communication, distribution, and sales channels
Customer Relationships	Customer relationships are established and maintained with each customer segment
Revenue Streams	Revenue streams result from value propositions successfully offered to customers
Key Resources	Key resources are the assets required to offer and deliver the previously described elements
Key Activities	Key resources achieve their goals by performing a number of key activities
Key Partnerships	Some activities are outsourced and some resources are acquired outside the enterprise
Cost Structure	The business model elements result in the cost structure

2.4. Our Value Proposition

Early on in our training we were asked to define what we hoped to accomplish. This seemed like it should be a relatively simple task, but the process took quite some time to reach an agreement within our team. The first step in this process was to name our team, so as to better identify ourselves with other I-Corps L teams, as well as with the training staff. Our initial team name was Best Engineered STEM Teachers (BEST), which we used throughout our training and in the early stages of our product development. We later found out that the BEST acronym had been used to represent another organization. Later on, after completion of our training, we adopted the name STEMucation Academy, which is trademarked and in use today.

The second order of business was to succinctly articulate our value proposition. That is, what we offered to our potential customers that was truly unique and would help to meet some of their unmet needs. This was an evolutionary process, as we continuously collected input from potential customers. By "getting out of the building" and talking to potential end-users, we were able to fine-tune our initial proposition. Our value proposition migrated from one of simply helping teachers and administrators, to one of "transforming the classroom into a student-centered, hands-on, real-world learning environment". After the initial pilot of our proposed product, we established that in addition to science teachers, math teachers were an important customer as well. In retrospect, the value proposition is a dynamic statement that continues to evolve even today.

2.5. Establishing Customer Types and Needs

Understanding who the customer is and what their needs are was the most important part of the process. Initially we believed that our customers were middle and high-school science teachers, much like those science teachers that attended the CEEMS program at the University of Cincinnati. Although these are important customers, they were not the only customers. Through our customer research we found four different customer types, also referred to as a "customer archetype". The four archetypes identified were: (1) STEM-focused Teachers and Admin "Evangelists", (2) Novice Science Teachers, (3) Seasoned Science Teachers, and (4) School and District Administrators. It is worth mentioning again that during the I-Corps L training we limited our customer base to secondary-school science teachers and the decision makers who have an impact on their professional development (e.g., administrators, curriculum directors, etc.). Later this was extended to include K–12 in-service math and science teachers across elementary school to high-school grade bands. Each of these customer archetypes have their own unique set of motivations, pain points, and professional development needs that influence their purchasing decisions with respect to professional development. Through our customer research and coaching feedback, we identified those unique needs, which are summarized in Figure 4.

The STEM-Focused Teacher and Admin "Evangelists" are grouped together because of their similar needs. In this case, both are working to integrate STEM lessons into their school district. The "Evangelist" is one who sees the need and is working hard to change the school culture through the introduction of new teaching methods.

The Novice Science Teacher and the Seasoned Science Teacher are differentiated here as they typically have different requirements set by their school district that they must meet. A novice or relatively new teacher might be required to gain a master's degree, and so is seeking courses that offer college credit toward their degree. They are also more likely to need more time at home, due to family or community activities. The Seasoned Science Teacher may have already achieved their master's degree and is simply looking to attain continuing education credits, trying to keep updated on advancing teaching pedagogies, or trying to "stay fresh" as a veteran teacher.

The School and District Administrators are seeking to meet requirements mandated by the state, or they may want to improve their school's education rating, which is usually measured by their state. They typically work to motivate their employees and (more specifically) teaching staff. Introducing new initiatives such as a new STEM program might be a positive or a negative motivational circumstance, depending on how the end-user perceives it. Positioned appropriately, STEM education can have a very positive influence on the life of an administrator as measured by student outcomes. Higher standardized test scores, more student engagement, and motivated teachers are all needs that might be addressed through an appropriate professional development program.

Using the feedback received from the customer interviews, the Value Proposition Canvas was completed, which is shown in Figure 5.

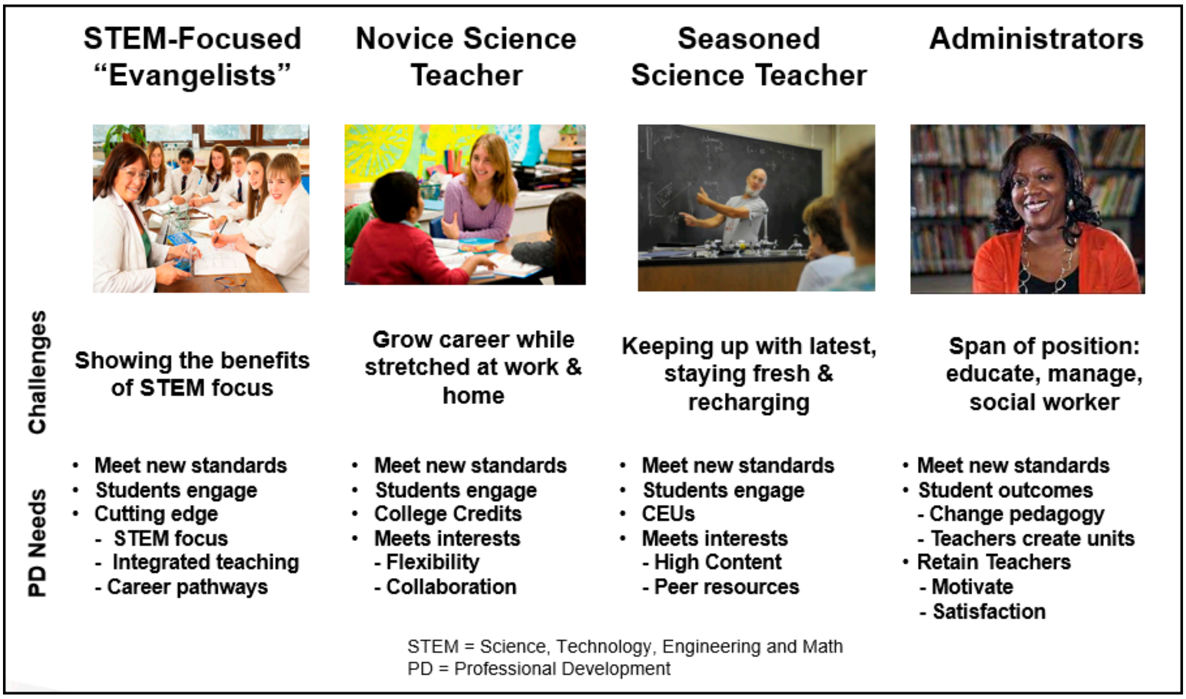

Figure 4. Customer archetypes.

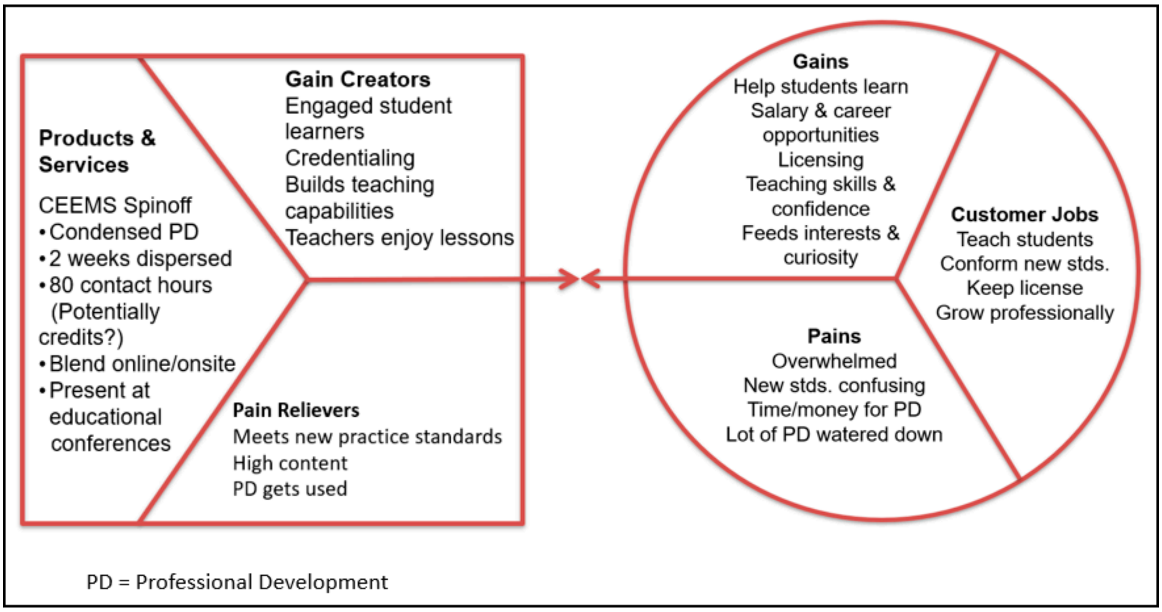

Figure 5. Completed Value Proposition Canvas after customer interviews.

2.6. Marketing Channels

When one purchases an item at a place of business such as a grocery store, you typically don't think about how it got onto the store shelf. Fortunately, we don't have to think about the person that produced the item, nor do we have to think about the warehouse employee or the truck driver who delivered the item to the store. It is important therefore to think about this supply stream or channel and consider how we might make it transparent to the end-user similar to the grocery store analogy.

Initially, the product offering for our professional development program focused on an on-site workshop at the customer's facility or at a site of their choosing. This model closely mirrored the CEEMS program that brought teachers together for a variety of workshops at a university facility. This on-site workshop model had an advantage if the customer was in close proximity to the instructors. One of our goals, however, was to develop a national program, and as such the on-site workshop model proved to be a potential showstopper due to the higher travel costs associated with it. From our interviews, we found that 40% of those interviewed supported the online approach and another 30% "somewhat supported" it. For those that did not support the online training, there were a variety of reasons, as reflected in the comments below:

> "I am more motivated to work hard if I have to physically go somewhere."
>
> "If the PD or course was online, I would likely procrastinate."
>
> "I have three kids and feel I would need to physically get out of the house in order to get work done."
>
> "I enjoy the interpersonal interaction that accompanies face to face PD."
>
> "Online programs are often 'flat' and not inspiring."

A second factor that we needed to consider was that the customer (i.e., math or science teacher) needed a flexible way of obtaining the training to fit their busy schedule. As such, we began evaluating online training delivery. This seemed to meet the needs of most customer archetypes discussed earlier and afforded us the opportunity to take advantage of a growing trend in education, online training.

Our channel to market then became a two-pronged approach to address those that supported the online approach, as well as hosting on-site workshops to address the needs of those that preferred the face-to-face approach.

2.7. Customer Relationships

Two key features of the CEEMS program were (1) the assignment of a personal coach to each of the program participants to assist them as they developed their units of instruction, and (2) the ability to collaborate with other teachers on their units of instruction. These features were validated in our customer interviews, as a number of interviewees expressed an interest in a personal coach and collaborating with other teachers:

> "Having access to coaches and other teachers is important as it helps gain confidence in using CBL and EDP."
>
> "Collaboration with other life science teachers is very important."
>
> "I am open to the online channel but believe that meeting fact to face with other teachers in her district would be beneficial. I do not think that this model will work well if a teacher signs up by themselves."

As noted by these comments, interviewees felt that a relationship with their coach and other teachers would be beneficial to them in developing their lessons. In this day and age, collaboration tools such as Skype, Facetime, WebEx, and Google Hangouts solve the technical challenges of collaboration both with other teachers as well as with a coach. The biggest challenge in establishing these collaborative groups, then, is to be able to get them together at the same scheduled time—something that can only be overcome if it is scheduled at the start of the training program.

2.8. Revenue Streams

The revenue stream represents the cash a company generates from each customer segment. Costs must be subtracted from revenues to create earnings [69]. For our professional development program, the bulk of the cash generated will come from customers signing up for the professional development workshops. Costs associated with implementing the workshops include website domain purchase, annual website maintenance costs, cost of printing advertising materials, workshop and conference handouts, and conference registration fees. As a startup, the upfront costs were covered by grants and donations. A portion of the labor costs were donated to get the startup up and running. During the pilot stage of the startup, all participants attending the workshops were given free access to course materials in exchange for completing the course and providing feedback.

2.9. Key Resources

Key resources can be categorized as physical (facilities, machines, etc.), intellectual (brands, patents, copyrights, etc.), human (people working on PD) and financial (cash, lines of credit, etc.). The resources needed are often underestimated and, as a result, the product development suffers. As an example, our team identified the resources listed in Table 2 that needed to be procured to allow us to go forward with our professional development program. The second column represents how these were addressed, and the third column shows a relative cost (high > $1000/month, medium = $250–1000/month, low < $250/month).

Table 2. Identified key resources.

Key Resource	How Key Resource was Addressed	Relative Cost
Entrepreneur Training	I-Corp L seven-week training program	None (Funded by grant)
A conference room for team meetings	Used conference room at University of Cincinnati where 2 of our team members were employed	None
A Learning Management System (LMS) for workshop course administration	Used BlackBoard and CourseSites for initial pilots. Google Drive tools also used as an alternative.	None
Instructional designer to develop the course outline and manage the LMS	Designer hired and expenses shared with another department	High
Course Developer	Course materials created by Team Members	Medium
Workshop Coaches	Identified a list of CEEMS teachers and Resource Team Members as potential coaches for workshop participants	Low to Medium
Web Site Developer	Outsourced to Northern Kentucky University	Medium
Branding and Brochures	STEMucation Academy branding and brochures created images.	Low
Intellectual Property Protection	Materials copyrighted	None
Workshop Materials	Conference workshops required materials for Engineering Design Process activities	Low
Conference Registration Fees	Paid through existing grants	Low
Startup Funding for aforementioned items	Available from existing grants	High

2.10. Key Activities

"These are the most important actions a company must take to operate successfully" [69]. For our endeavor, initially the five key activities we identified included those noted in Figure 6. Each of these items were identified either through the successful implementation in the CEEMS program, or as a need identified from our customer interviews. Of the five key activities identified, three have either been implemented or refined going forward. The two items that still need attention are numbers 3 and 5, which are mechanisms to connect teachers and build professional learning communities. As we grow the number of teachers that enter the program going forward, these activities will gain more focus.

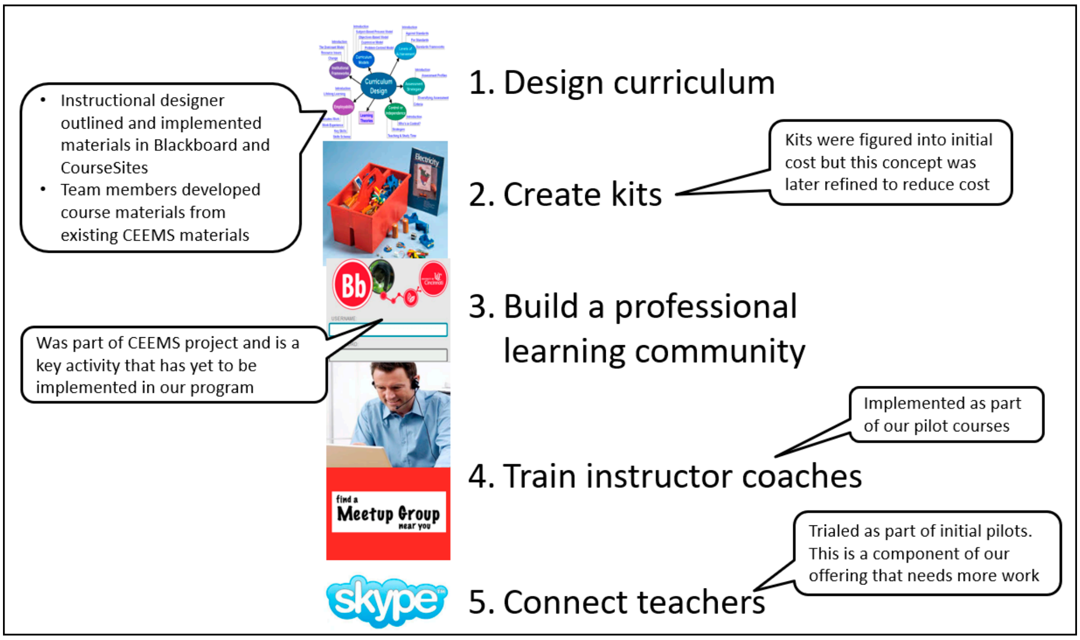

Figure 6. Key activities.

2.11. Key Partnerships

Osterwalder and Pigneur [69] state: "Key partnerships include the network of suppliers and partners that make the business model work." A number of key partnerships have helped to build our program and are listed here:

University of Cincinnati (UC): One of our initial partnerships was with the University of Cincinnati, which provided a number of resources that helped with the initial development of STEMucation Academy. Some of these resources included the incorporation of our program materials into following for-credit course:

> ENGR 7050: Engineering Education Certificate Capstone (3 credits) (University of Cincinnati, 2018): This capstone course provides a structured and supported process for certificate participants to implement what they have learned through certificate courses. Participants will be required to develop and implement one full curricular unit of instruction that utilizes engineering design-based challenges within a course that they teach. Participants will have a mentor to guide them through this process. Completed activities and units are to be written using a common framework and published to an open education resource so other teachers can use them. The course is configured to be taken by a teacher after completing the required course, Engineering Foundations, during a semester when the teacher could teach the unit in a class while simultaneously taking the course.

Other resources that UC provided included the copyrighting of STEMucation Academy, use of a conference room and facilities, use of development software (including BlackBoard, Kaltura, and Articulate), and access to an instructional designer. This partnership has continued through the University of Cincinnati Research Institute (UCRI), an NPO affiliated with UC, and which obtained the trademark for STEMucation Academy.

Northern Kentucky University (NKU): NKU's Center for Applied Informatics supplied the manpower to develop and maintain our website, stemucationacademy.com, which will be highlighted later in this article.

2.12. Cost Structure

The cost structure refers to all of the costs incurred to operate the business model, including startup and ongoing costs. We estimated our startup costs to be around $75K for curriculum development, website development, marketing, and other contingencies. Our fixed costs included website maintenance, domain name fees, and conference fees. Our variable costs were related to the workshop size and frequency.

An initial breakdown of the revenue and costs associated with our program is shown in Figure 7. Based on feedback received during our customer interviews, we targeted $250 as an entry level cost for a one-day workshop. As can be seen in Figure 7, over 50% of the cost was compensation for coaches supporting a participant in the program. As coaching was identified as a key component of the program, this high-value feature was required to support the development of high-quality units of instruction for the classroom. Note that there was no profit built into this model which we later altered to cover future development costs.

Revenue	$250/Teacher
Cost	$250/Teacher
Director	$9
Coaches	$140
Units	$45
Recruiting	$6
Infrastructure	$30
Contingency	$20

Figure 7. Initial breakdown of cash flow per workshop attendee.

2.13. Insights from Our Customer Research

Key Identified Needs: In general, customers expressed a variety of needs that they felt should be addressed by a STEM-based professional development program. Some of the expressed needs are as follows:

- Teachers often found that professional development programs were of no value to them if they could not take what they'd learned back to the classroom and implement it. It is important therefore that new knowledge be easily implementable when teachers finish with the professional development program.
- The ability to collaborate with fellow teachers is necessary to enable them to discuss new lesson ideas, reinforce their knowledge of the new pedagogy, and permit them to discuss best classroom practices.
- Coaching was a very popular concept that most believed would enable them to become more adept at using the CBL pedagogy.
- Creating their own lessons was not only an important concept to the teachers, but to administrators as well, as it provided more flexibility to create lesson plans that are tailored to student needs.
- Classroom practices that stimulate student engagement were identified as necessary.
- A reasonable cost (~$250 for PD) was identified as necessary.

Competitive Comparison: Given the key identified needs, understanding how our proposed program compared to competitive offerings involved an exercise in identifying who we were competing with, what they offered, and their cost structure. A summary of our findings is shown in Table 3. We did attempt to get cost numbers, but have not mentioned these since it was difficult to get reliable numbers for some competitive programs already available (the range varied from free to $23,000). The key differentiators that we compared included the use of engineering practices (both in science and math), the focus on student-centered lessons (i.e., student engagement), the offering of ongoing coaching during the development of a unit of instruction, and the inclusion of a new teaching practice (CBL with the EDP integrated into it). These differentiators were believed to be those that would set our program apart from other programs of a similar nature and, as can be seen from Table 3, most PD offerings are deficient in one or more areas. This comparison gave us more confidence that we can continue to move forward with our proposed model.

Table 3. Competitive comparison.

			BEST Differentiators			
Type	Examples	Description	Engineering Practices	Student Centered	Ongoing Coaching	Δ Teacher Practice
Online Content	Khan Academy MOOCs [1]	Online STEM [5] resources & classroom ideas				
National Science Organizations	AAAS [2] Project 2061	Science curriculum & instruction				
	NSTA [3]	Workshops/Online Science Matters	✔			
	ASEE [4]	STEM Conference associated	✔			
National STEM Program	Engineering Is Elementary	Content & application lessons	✔			
	Project Lead the Way	Blended STEM professional development that links activities to engineering	✔	✔ Problem-based learning only	✔ Not longitudinal	✔
BEST	Online & Face-to-face Workshops	Science & Engineering Practices and Student Driven	✔	✔	✔	✔

1 A MOOC is *a course of study made available over the Internet without charge to a very large number of people*
2 American Association for the Advancement of Science
3 National Science Teachers Association
4 American Society of Engineering Education
5 Science, Technology, Engineering and Math

Note: PD is a highly fragmented market; each School District has their own/local PD offerings that will vary in cost, quality and are additional competitors; Lot of "garbage" PD out there which makes teachers skeptical.

2.14. Final Business Model Canvas and Customer and Revenue Flow

Our I-Corps L team, BEST, completed 100 or more interviews and in week three we did a channel pivot from blended online and on-site (via a national/regional teacher aggregator) to online with meet-ups supplementing online classes. This required a significant revision in our value proposition and customer segments. Our development is reflected in the changes to our Business Model Canvas (early stage in Figure 8, and final in Figure 9). The final customer and revenue flow for our final Business Model Canvas is represented in Figure 10.

Key Partners
- Learning management system (course/chat/discussion board) (e.g., Blackboard)
- Endorsement (e.g., Change the equation designation as ready to scale)
- Large Foundation/business interested in promoting STEM[1] for scholarships
- Skype and Meetup

Key Activities
- Create content for online instruction
- Create kit including components & instructions
- Create online community of practice & lesson archive
- Identify & train instructors and coaches to support online PD[2]
- Identify infrastructure for teacher to teacher connections

Key Resources

Physical
- Facilities office & kit storage (University of Cincinnati)
- Virtual
- Learning management system
- Online infrastructure
- Website with controlled access
- Infrastructure to facilitate teacher to teacher connections

Human
- Curriculum designer
- Course administrator, instructors and coaches
- Web site developer & Manager
- Contract packers

Intellectual Property
- Branding (name, logo)
- Copyright
- Financial
- Start-up Funding

Value Propositions
- Helps meet the new standards that require engineering & technology in teaching science and math
- Students are engaged because they understand why learning is relevant to them and the lessons are fun and interactive

Customer Relationships
- BEST[3] with teachers: personalized training & coaching and co-creation of lessons.
- BEST with administrators: Expert resource on STEM education
- Teacher with teacher: Peer coach and lesson sharing, community of practice facilitated by BEST

Channels

Marketing
- Online
- Direct mail
- Education conferences

Instruction Online/Onsite

Initial Sites
- Educational conferences that attract large numbers of teachers
- Large school districts with 30+ teachers

Follow-on Sites
- Schools districts for a group of teachers

Customer Segments
- Segment 1: School administrators & agencies that set budgets and approve teacher professional development
- Segment 2a: Secondary science teachers seeking a master's degree and/or college credit to maintain their license and advance their teaching skills
- Segment 2b: Secondary science teachers who want to earn continuing education units to maintain their license and build their STEM teaching skills

Cost Structure

Revenue Streams

1. STEM—Science, Technology, Engineering and Math; 2. PD—Professional Development; 3. BEST—Best Engineered STEM Teachers

Figure 8. Business Model Canvas—early stage.

Key Partners
- National science and math associations (AAAS[1])
- National & regional teacher associations NCTM[2], NSTA[3], ASEE[4], SECO[5], etc.)
- Administrator Associations (AASA[6])
- STEM[7] Organizations
- Educational service organizations
- Teacher unions
- Longer term—Organizations that set national & state curriculum and teacher PD[8] requirements (e.g., Department of Education)

Key Activities
- Create content for online course
- Create website with online community for practice and lesson archive
- Identify and train instructors & coaches to support online PD
- Create kit including components & instructions

Key Resources
- Trained & available workshop instructors
- Contract coaches to support & mentor
- Program management and development
- Business growth and marketing
- Web design & development
- Local facilities for workshops

Value Propositions
- BEST[9] is a teacher recommended, online professional development program that helps secondary teachers meet new science and engineering practices
- Teachers transform their classrooms into a student centered, hands-on, real-world, learning environments where students become critical thinkers & problem solvers

Customer Relationships
- BEST with Teachers: personalized training & coaching and co-creation of lessons
- BEST with Administrators: Expert resource on STEM education
- Teacher with Teacher: Peer coach and lesson sharing, community of practice facilitated by BEST

Channels
- Direct sales via schools, education associations & conferences
- Administrator & teacher referrals based on positive outcomes
- Combined online & onsite
  - University of Cincinnati for master's credits
  - Local school for groups of teachers

Customer Segments
1. Science & math Teachers for grades 6–12
   a. <5 yrs. experience seeking a master's degree and/or college credit to maintain their license and advance their teaching skills
   b. Experienced teachers > 5 years and < 20 years who want to earn continuing education units to maintain their license and build their STEM teaching skills
2. School administrators & agencies that set budgets and approve teacher professional development

Cost Structure
- Instructor salaries
- Program development and administration
- Website & instruction materials

Revenue Streams
- Revenue will come from tuition and PD workshop fees. Group discounts.
  - The intent is that we become a sustainable entity (nonprofit).
  - Once a recognized brand: potential for expanded services & revenue

1 AAAS—American Association for the Advancement of Science
2 NCTM—National Council of Teachers of Mathematics
3 NSTA—National Science Teachers of America
4 ASEE—American Society of Engineering Education
5 SECO—Science Education Council of Ohio
6 AASA—American Association of School Administrators
7 STEM—Science, Technology, Engineering and Math
8 PD—Professional Development
9 BEST— Best Engineered STEM Teachers

Figure 9. Business Model Canvas—final.

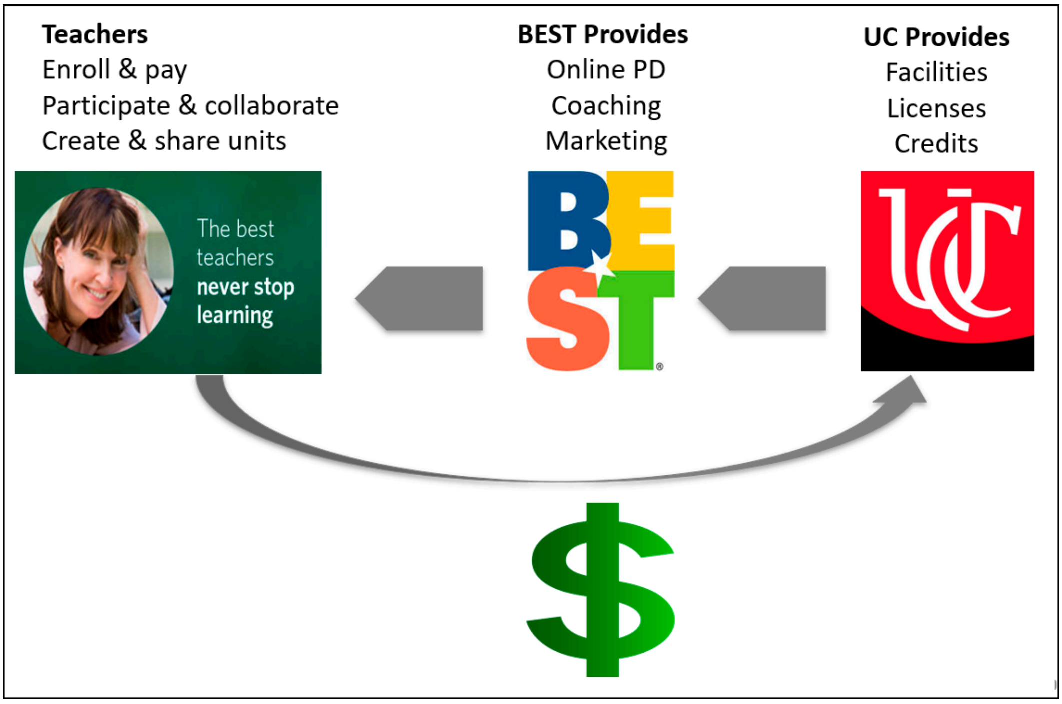

Figure 10. Customer and revenue flow.

3. Results

3.1. The Creation of an Online Professional Development Program with Virtual Coaching: The MVP

As we moved forward, we believe we had a grasp of what potential customers needed and what they were willing to spend for a professional development (PD) program focused on a CBL pedagogy that also uses the EDP to solve the challenge. Referring back to Figure 3, we are now moving into the space of creating a minimum viable product (MVP). An MVP is "a concise summary of the smallest possible group of features that will work as a stand-alone product while still solving at least the 'core' problem and demonstrating the product's value" [70].

In our case, the initial years of the CEEMS program (2012/2013) served as the basis for the MVP; it was easily developed into a customer product. Customer feedback was positive as was our 2015 American Society of Engineering Education conference experience, so it allowed us to move forward very quickly from the MVP to a more complete product offering.

In this section, we will describe the attributes of one of the workshops that was developed: the Advanced Online Workshop. In particular, this workshop encompasses all the basic components of the CEEMS PD training program (i.e., the Engineering Education Certificate Capstone course). Other workshop options and a full online PD program that can be taken for course credit are described later.

Keeping our customer interview data in mind, we set out to further develop our MVP into a professional development program that would enable teachers to transform their classrooms into student-centered, hands-on, real-world learning environments where their students could become multifaceted critical thinkers and problem solvers. This program purposefully habituates the EDP into a teacher's mindset, who creates engineering challenges for their students to solve. For those not familiar with the EDP, Figure 11 illustrates this process. Engineers typically start by clearly defining the problem to be solved ("identify and define") and then background research is done to clarify what is known about the problem ("gather information"). As is typically the case, multiple solutions to the problem are identified ("identify alternatives") before an initial solution is selected to go forward with ("select solutions"). This initial solution is trialed ("implement solution") and appraised for its effectiveness in solving the problem ("evaluate solution"). The initial solution might then be modified ("refine") and the process is repeated until an acceptable solution is found. Throughout this process, there is continual communication ("communicate") with team members and stakeholders and the final solution is then communicated to the key project stakeholders ("communicate solution").

Furthermore, by breaking our training program into modules that correlate with the critical steps of the EDP, we sought to raise awareness of the EDP and to provide teachers with an opportunity to use it as they developed their unit of instruction. As such, the first module introduces engineering design while the remaining modules (2–8) follow the steps of the EDP as noted in Figure 11. Module 8 covers both the refinement of unit documents (based on coaching feedback) as well as the communication of the unit documents to the Program Coordinator for archiving (STEMucation Academy website). The "communicate" box in the center of the diagram is not a step in the process but instead represents the communication process that occurs between the coach and the participant as the unit documents are developed.

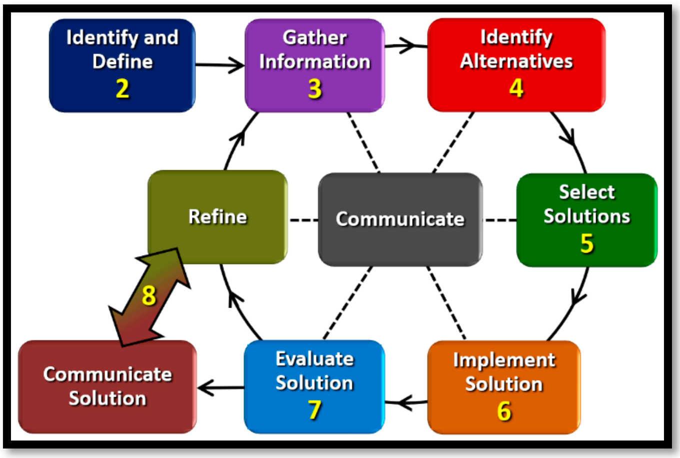

Figure 11. The engineering design process.

Structure of the Program Learning Modules: Each learning module is broken down into learning objectives, an introduction to the module, and homework assignments. Hyperlinks are used to access a variety of documents such as templates, questionnaires, and supplemental reading materials. The six coaching meetings that are required are also incorporated into the modules with fixed agendas to permit both the coach and participant to cover any pertinent issues.

All of the modules are targeted to be completed in 12–16 weeks, depending on when the participant implements the unit of instruction in their classroom, completes the follow-up reflection, and meets a final time with their Coach for a sign-off on the workshop deliverables. It is entirely possible for a teacher to complete the modules much earlier than 12 weeks.

The End Result: Each participant will end up completing a unit of instruction which includes a unit plan and multiple activity plans. The unit plan is an overview of the unit and is used to describe the CBL elements: the big idea, the hook, possible essential and guiding questions, the challenge, career connections, and societal relevance. Typically, there are a minimum of four activity plans that describe exactly what must be done to complete the activity. The activity plans include such things as activity objectives, activity guiding questions, advance preparation requirements, assessments, a materials list, procedures, projected misconceptions, and any differentiation notes. Normally, the last activity is a description of the challenge to be solved using the EDP. These plans are written in a manner so that another teacher may easily and efficiently implement them in their own classrooms.

Examples of some of the units that were developed in the CEEMS program are given in Table 4. Each of the units developed through CEEMS or STEMucation Academy are public resources and are therefore available for free to teachers.

Table 4. Unit examples from the CEEMS program.

Unit Name	Grade and Subject	Hyperlink
Aiken's Angry Birds	High School Physical Science	http://stemucationacademy.com/aiken-angry-birds/
Designer Dogs	Grade 8 Science	http://stemucationacademy.com/designing-dogs/
Feel The Noise	High School Pre-Calculus/Calculus	http://stemucationacademy.com/feel-the-noise/
Trains Always Win	Grade 8 Algebra	http://stemucationacademy.com/trains-always-win/

The Process to Monitor, Guide, and Evaluate Progress: As noted, a Coach is assigned to each workshop participant. The coach's role is to mentor the participant and to monitor and evaluate their progress. To aid the coach in assessing a participant's pre-workshop knowledge, a pre-assessment is given. This assessment appraises the participant's knowledge of such things as CBL, the EDP, 21st-century skills, and collaborative learning. The results of the assessment are used by the coach to determine where participants need to focus their energy. If the participant demonstrates adequate knowledge, this may lead to reducing or eliminating sections of the course.

In the virtual environment, it is necessary to continuously monitor the progress of the participant using a variety of feedback mechanisms. We utilize homework assignments, a rubric, and an oral evaluation guide that stimulates discussions between the participant and the coach. Prior to the implementation of a unit of instruction in the classroom, a pre-implementation checklist is completed by the participant. After the unit is taught, a post-implementation checklist is completed and is used to guide the participant in putting the finishing touches on their unit materials. Part of this post-implementation checklist is to complete a reflection that involves writing notes to themselves or other teachers who might implement the unit in their own classrooms. These notes typically point out areas of the unit that went well or areas that did not go as planned. These notes are essentially a way of reducing problems when the unit is presented again in the future, or that another teacher may have in implementing the unit.

Course participants are asked to provide photos, videos, and samples of student work from the implementation of their unit in the classroom. This supplemental material further documents the unit to aid other teachers in the future. This record is also a way for the coach to assess the participant's work and ultimately to assess the completeness of the unit. Each of these feedback instruments provides valuable insights into the participant's progress and permits mid-course corrections to be made if appropriate. Typically, the participant will complete a module and only then gain access to the next one upon the coach's approval.

Program Completion Requirements: As noted, the workshop has numerous checkpoints that provide continuous feedback to the coach in order to monitor a participant's progress. By the time participants implement their units of instruction, there is a good sense of how well they performed, how good their documentation is, and a decision to assign course credit can then easily be made, if that option is to be used.

It is important to note that if deemed appropriate for other teachers to use, materials that are created by the participant will be archived on an open-source website. An archive of unit materials currently exists on the University of Cincinnati CEEMS website [44] as well as on the STEMucation Academy website [71].

3.2. Branding the MVP

This section details the process used for branding the MVP and the decisions made regarding its visual representation, with the hope that these will serve as useful guides for other venture creators.

Brand Name and Trademark: After the close of the I-Corps L training, the first task at hand for the group was to change its name from Best Engineered STEM Teachers (BEST), as other programs were already using that acronym. The criteria the group used for branding (name and visual identity) included the following items:

(1) It must be consistent with mission and vision, which were fixed as follows:

- Mission: Our program is a teacher-recommended, online professional development program that helps teachers meet new science/mathematics and engineering practice standards.
- Vision: Created to help teachers transform their classrooms into student-centered, hands-on learning environments.

(2) It must clearly communicate the provided services (what it is). We selected the brand name as STEMucation Academy, which combined the words "STEM" (science, technology, engineering, and mathematics) and "education" to convey the message the program offers professional development training in "STEM education". The official trademark for the name was obtained by the University of Cincinnati Research Institute (UCRI), an Ohio non-profit corporation affiliated with UC. The domain name stemucationacademy.org and stemucationacademy.com were also purchased for web development and email usage, respectively.

(3) It must demonstrate the benefits of our service—assisting teachers to improve their evaluation scores related to science, mathematics, and engineering instruction.

(4) It has meaning to target audiences. The STEMucation Academy brand is one that generates feelings of confidence, approachability, collaboration, and individualization.

(5) It must be distinguishable from other PD organizations in that it facilitates the development of new units as needed to meet individual curriculum and student needs, and be guided and vetted by professional coaches.

Logo Look and Usage: Under the guidance of the I-Corps L team, a graphic designer developed a logo based on the initiative's equity, and its inspiration is a star along with the name STEMucation Academy (Figure 12).

Figure 12. STEMucation logo.

3.3. Testing Our Model

From our customer feedback and an analysis of our competition, our initial professional development model was designed to target science teachers teaching grades 6 to 12. To test some of the aspects of our model, we piloted a face-to-face training workshop, "Integrating Engineering into Your Science Classroom," at the American Society for Engineering Education (ASEE) Annual Conference and Exposition on 13 June 2015 as part of the K–12 workshop series organized by the ASEE's K–12 division. Also, this was the first time the branding of STEMucation Academy, described in the previous section, was used in the PowerPoint presentation, handouts, and promotional materials prepared for the event. The overall goal of this experiential learning workshop was to develop and execute a student-centered engineering design challenge based on academic standards. The team envisioned the possibility of converting this entire experience into an online teacher PD program including individualized coaching to aid teachers in the development of a design challenge-based unit for his/her classroom. This workshop consisted of a 75-minute session that was free to those attending the ASEE Conference. Ten participants attended the workshop. Two veteran exemplar CEEMS high-school teachers (math and science) were recruited to direct the workshop, and the contents and delivery modalities were designed by the I-Corps L team in collaboration with them. Overall the workshop was well received. Some positive outcomes:

- We were able to implement an engineering design activity to simulate a classroom challenge
- Participants were able to work on their own unit of instruction and presented their plans
- We received first-hand feedback from the ultimate users on what our planned online PD program or workshops should make clear:
    - What does it look like to teach STEM by integrating engineering into one's classroom?
    - How can and does science and math education benefit from including the EDP?

3.4. Creating the Marketing Website

Providing information to current program graduates and potential future customers is provided through an online website at stemucationacademy.com. As most individuals are familiar with website navigation, we will point out just a few tips for navigating the website.

The website contains seven major segments: Home, About, Training Options, Units, Resources, Register, and Contact. The Home page features comments from the Program Director and Program Coordinator as well as scrolling photos taken during CBL classroom activities and various training programs. The About page provides background information on the benefits of CBL, key program attributes such as higher student achievement, and the highly valued personal coaching assistance the program provides. Training Options illustrates the features and costs of the four training programs, including two online and two on-site workshops. For the One-Day Introductory On-Site Workshop and the Introductory Online Workshop, a single engineering design challenge activity is developed and implemented in the classroom. For the Three-Day and the Advanced Online Workshops, a full CBL–EDP unit of instruction is developed which includes at least four activities, one of which is solving a challenge using the EDP. A fifth option includes customized workshops to fit customer needs. To aid teachers in the development of materials for their classes, the Units option provides access to classroom-ready units of instruction that utilize the CBL methodology with integration of the EDP to solve the challenge. The Resources page includes materials that were presented at a conference as well as journal articles published by the CEEMS project team that provide more background information on the CBL and EDP teaching methodologies. The Register page can be used by those who would like to sign up for one of the workshops and Contact can be used to get more information. The Register section includes a step-by-step process for registration, submission of documents to make the enrollment payment, instructions when they will be informed of the assigned coach and the go-ahead to start the training program and obligations thereafter. The contact form will send an email message to teacherpd@stemucationacademy.com, which is monitored continuously by the STEMucation Academy Program Coordinator.

3.5. Alpha Testing: Piloting the Online PD Program

The STEMucation Academy's online PD program was fully developed and available for internal testing by the end of the 2015 Fall Semester. It was piloted with six individual in-service teachers for free during the 2016 Summer and Fall semesters. Teachers were recruited from a nationwide search, and a group of six teachers completed the program together in the 2017 Spring Semester. The group of six in-service teachers who completed the program together were enrolled in a course they were taking at the University of Cincinnati College of Education, Criminal Justice, and Human Services, though not all students enrolled in the course took the online PD program. This enabled us to test the modalities of the "teacher collaboration" aspect modeled in the online PD program (teachers disparately located and teachers taking a course together). Since STEMucation Academy is self-paced, it required 3–6 weeks for teachers to complete the program, depending when the unit was scheduled for teaching. This verified that our projected completion period of 12–16 weeks, as mentioned in Section 3.1, was more than realistic. Past veteran CEEMS teachers and Resource Team Members (CEEMS coaches) were employed as coaches for both these pilot programs. In both online pilot implementations, the teachers who completed the program reported that they felt much more comfortable and competent in their ability to create and teach a unit incorporating an engineering design challenge in an end-of-the-program survey. They also praised the flexible nature of the online format. A few of the quotes provided by the participants of the online PD program are mentioned below:

- "I liked that I could go at my own pace, look ahead to all of the modules so I could get the whole picture before actually doing each module, and I liked that there was someone I could contact to bounce ideas off."
- "The self-pace was great!"
- "I liked how I could go back and re-watch something to help me understand."
- "The resources were great."
- "My coach was great! She was very helpful and supportive."
- "I had an awesome coach who I enjoyed working with. She was always giving me ideas and helped me in any way."
- "I liked the timeline of the workshop. Having due dates for parts of the STEM unit was helpful. Working with a mentor was also helpful."

In the end-of-the-program survey for the pilot implementations, the teachers who completed the program reported that overall:

(1) they felt much more comfortable and competent in their ability to create and teach a unit incorporating an engineering design challenge;
(2) the coach was great and was the key support to their success in completing the online PD course;
(3) the breakdown of modules into engineering process steps was helpful in learning about the EDP.

Besides the above strengths, some challenges were also reported, which resulted in making following changes in the online PD program:

A. <u>Fluency in Using Blackboard</u>: CourseSites by Blackboard was used to offer the STEMucation Academy's online PD program for both pilots. A debrief with the coaches was held after each pilot. Generally, the feedback received from the coaches was positive. All coaches felt that even though CourseSites was an appropriate platform for the online PD program, they reported that a few student teachers initially had challenges navigating CourseSites. Overall coaches felt the student teachers were capable of mastering all subject areas, were communicative, and put forth an above-average amount of effort to master the techniques being taught in the online PD program. Due to the issues arising from the use of CourseSites, an alternative learning management system was sought. As most coaches and participants are familiar with cloud-based products such as Google Drive, YouTube, and Microsoft Office products such as Word and PowerPoint, a decision was made to convert the online program materials to a format that allowed the participants and coaches to get "up and running" more quickly. This also permitted modifications to the online program to be made by personnel not experienced in the use of CourseSites. A study guide was created for each of the eight STEMucation Academy modules. These study guides are in PDF format, which is universally readable on all types of digital devices including tablets, smartphones, and computers. The study guides include a module overview, module objectives, assignments, and other instructions to help the participant navigate the course. Hyperlinks to videos and other course supplements are imbedded in the modules. At the time of writing this paper, the new format has been evaluated and is being used by teachers currently enrolled in the STEMucation Academy's online PD course.
B. <u>Need for Better Management of the Discussion Board</u>: Some participants expressed a need for better management of the discussion board to ensure timely interactions with the coaches and on-time completion of the modules. Based on this feedback and the fact that the course participants did not always participate in one-on-one discussions with their coach, the discussion board was dropped and the one-on-one meetings between participant and coach became

mandatory. This alternate form of communication allows the coach to better assess the participants' progress and, if needed, offer mid-course corrections.

C. Issues with Purpose and Submission of Rubrics. We found participants wanted more explanation of the course requirements and the rubric elements used to assign a grade. Having a clear definition of expected performance would help the participant understand what their work product should focus on. Each of the eight modules contain a number of assignments and each assignment has one or more rubric elements associated with it. Overall there are more than 20 rubric elements distributed over the eight modules. A sample rubric element is illustrated in Table 5.

Table 5. Sample rubric.

Rubric Element	Excellent (100–90%)	Acceptable (89–60%)	Unacceptable (59–0%)
Possible Essential Questions	At least 3 possible Essential Questions have been clearly written and are well related to the Big Idea for each if the identified challenges	1 or 2 possible Essential Questions have been documented for each of the identified challenges	No possible Essential Questions have been documented
(15)	(15–13.5)	(13.5–9)	(8.85–0)

The rubric in this case was used to define the desired performance requirements and is broken up into 3 levels: (1) excellent performance, (2) acceptable performance, or (3) unacceptable performance. Point levels are assigned to each rubric element based on the complexity of the assignment and its relative importance to the overall course learning objectives. When the coach assigns a score, it provides an opportunity for discussion with the participant regarding their work. In some cases, the coach may recommend reworking the participant's unit and activity plans, or the coach may simply reinforce the fact that the participant's work is commensurate with an excellent or acceptable performance. By clearly defining the expected performance and articulating this to the participants prior to and during the course, it is believed that participants will develop higher-quality work.

Another aspect of the rubric was to improve consistency between the coaches who are evaluating a student teacher's performance. In a typical classroom setting, a single instructor assesses student performance and assigns a grade. This is a model of consistency, as one "evaluator" is appraising the work of each participant in the course. In the STEMucation Academy approach, multiple coaches may be involved and a potential problem with inconsistent evaluation of performance may arise due to the different expectations of the coaches. Again, the rubric provides a uniform approach to evaluating performance and helps to ensure fair assessments are made among course participants.

3.6. Moving Forward: Licensing Out the Program for Marketing

Once STEMucation Academy's online PD program was fully developed and vetted, we began looking for opportunities to license the program to an established non-profit organization (NPO) to promote and market it to paying customers. In September 2018, UCRI and UC's Innovation Office signed a licensure contract with the Science Education Council of Ohio (SECO) for the online PD program. SECO is a well-established NPO in Ohio that has been organizing professional development workshops, programs, and conferences in the region for 14 years (https://scienceeducationofohio1.wildapricot.org/). Also, SECO is the Ohio chapter of the National Science Teachers Association (NSTA). The SECO Board of Directors have agreed to license STEMucation Academy's online PD program since it provides them an opportunity to have a national footprint and bring visibility to its mission: "The Science Education Council of Ohio (SECO) is a collaborative community that believes everyone deserves the benefit of a strong science education in order to engage with an ever-changing world." SECO is developing an informational webpage related to STEMucation Academy and a registration page for enrollees on its webpage. SECO will enroll and assign coaches to the enrollees from a list of qualified, certified coaches supplied by STEMucation Academy. STEMucation Academy will maintain the course modules and provide access to the enrollees, and its Program Coordinator will be the liaison between the enrollees and the coaches to monitor progress. The Program Coordinator will also maintain a required online training program for the coaches.

Upon completion of the program, participants will receive 45 contact hours and have the option of purchasing three graduate credit hours from a partner University that SECO uses for offering graduate credits for its other PD offerings.

3.7. Ongoing Efforts for Broader Impacts

As mentioned in Section 2.1 in the CEEMS project, eight in-class graduate courses and one seminar course served as the cornerstone for all teachers during the Summer Institute for Teachers (SIT). These courses were packaged to offer the SIT participants a Graduate Secondary Engineering Education Certificate (GSEEC) from UC. Once the GSEEC program was fully established at UC, STEMucation Academy converted four key CEEMS courses to complete online courses and added a new online course that duplicated the CEEMS PD seminar course in a complete virtual environment. In this newest course, teachers work under the guidance of a coach to develop, teach, and document student learning results, and to put their units into a format for web dissemination to other teachers. The five online courses are packaged to offer a 12-credit GSEEC distance education program to reach a wider geographic audience:

The required courses (three graduate credits each) are:

- Engineering Foundations
- Engineering Education Certificate Capstone

Elective courses (option to select two, at three graduate credits each):

- Models and Applications of Physical Sciences
- Engineering Applications in Math—this contains two sections, one for high-school teachers and the other for middle-school teachers (it could also be taken by elementary school teachers)
- Engineering Models

The course descriptions for these courses and details of the GSEEC program can be found on the STEMucation Academy website [71]. STEMucation Academy is currently working out the logistics of offering this complete online 12-credit GSEEC program to paying customers and will soon be announcing its availability.

4. Concluding Remarks

The published literature clearly recognizes that the best way to improve undergraduate STEM education is by investing in math, science, engineering, and technology (STEM) K–12 teachers. A number of Federal agencies and corporate foundations have invested significant resources in an effort to improve teaching and learning across STEM disciplines. However, this has not produced the increasingly necessary transformational changes in STEM education the US desperately requires. Addressing the persistent challenges that limit evidence-based instructional practices in STEM education is still an urgent need, yet the rate and extent of large-scale adoption is very low because STEM educators, researchers, and communities do not have the basic training to systematically accelerate the process of bringing effective educational innovations to scale. Even when successful, their impact has mostly remained local to where the practices were developed.

In this paper, the authors have presented their experiences from participating in an NSF I-Corps L training program established for business startups using Blank's Lean LaunchPad, Osterwalder's Business Model Canvas, and associated tools. They used the entrepreneurial skills acquired through this training to scale-up their professional program, the Cincinnati Engineering Enhanced Math and Science Program (CEEMS). CEEMS had been developed, implemented, and evaluated with successful results over a period of seven years in a targeted 14 school-district partnership in Greater Cincinnati.

CEEMS worked intensively with secondary school (grades 6–12) math and science teachers, who participated for a two-year period in the project to develop and implement new units of instruction to meet teachers' individual curriculum and student needs. The programs specifically addressed the needed academic standards through engineering design challenges.

The main aim of CEEMS was to train teachers to encounter new emerging science/mathematics and engineering practice standards (NGSS, CCSS for Mathematical Practice, and the recently revised Ohio Learning Standards for K–12 science and mathematics juxtaposed with Universal Skills/21st-Century Learning Skills), with demonstrated and documented higher student performance. To achieve this aim, the CEEMS teachers were trained in using CBL and the EDP teaching pedagogies to transform their classrooms into student-centered, hands-on learning environments, while also assisting them to improve their evaluation scores related to science, math, and engineering instruction.

The CEEMS teachers acquired the skills to successfully implement the above through a two-year commitment to complete 20 credits of graduate coursework. Their tuition fees covered course credits and additional funds covered longitudinal face-to-face guidance, critical reviews of their work, and continuous feedback and approval by professional coaches during both the development and implementation stages. In CEEMS this was possible because NSF funds covered all these costs. Recognizing limitations in the I-Corps L project, a goal was established to bring to scale a tested teacher PD program, CEEMS, so that the practice of its primary pedagogies (CBL and the EDP) could be sustained and even expanded on when funding from the NSF ran dry. The parameters for the scale-up were set to be:

- include online and face-to-face channels of service (make both options available);
- make it self-paced and flexible to fit the teacher's curricular needs and teaching schedule;
- condense it for successful completion within a semester ($\leq$16 weeks);
- include virtual coaching to assist teachers in producing the curriculum, teaching it, assessing student learning gains, reflecting after teaching, and documenting for web dissemination to other teachers for quality assurance, guidance, and approval;
- ensure costs are fixed at a level that can be paid either by a teacher or by the school district.

The engineering design process is a simple concept to understand, but it is challenging to implement well. Like many skills, it takes practice. That is what a majority of this online PD program created, with attributes dedicated to designing and implementing units of instruction using CBL and EDP to enhance any unit of study, not just math and science. It is envisioned that this collaborative experience between the teacher and the expert coach will showcase "tricks of the trade" for implementing CBL and the EDP in a classroom setting, and increase the confidence and comfort level of the participating teacher to do more on their own later.

In this paper, the authors have documented how they used customer market research conducted during the I-Corps L training to define a minimum viable product (MVP) that incorporated the above attributes. The authors also described the process they used to move forward very quickly from an MVP to a more complete product offering, its branding, the process of trademarking it, piloting and testing the MVP, and finally licensing one of the online professional development programs for teacher training to an established non-profit organization (NPO), the Science Education Council of Ohio (SECO), for future marketing.

The MVP was branded and trademarked as STEMucation Academy by the University of Cincinnati Research Institute (UCRI), an Ohio non-profit corporation affiliated with University of Cincinnati. A dedicated website, http://stemucationacademy.com/, was developed for STEMucation Academy and maintained by the Northern Kentucky University's (NKU's) Center for Applied Informatics. This website presents details of all the PD program offerings by STEMucation Academy and the registration process for any one of those offerings.

Details of the author's I-Corps L training experience and its outcomes are presented in this paper with the hope that they will serve as a useful guide for other venture creators. In summary, the key lessons learned from our I-Corp L experience are:

pick a diverse, committed team; decide how the startup will pay for some of the early expenses, as startups cost money—look for viable partnerships that help move the project forward; most importantly, "get out of the building" to fully understand the customer needs, pains, and revenue flow to develop the MVP; and finally, identify what differentiates the MVP created from the competition.

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