Student Partnerships for Innovation in Engineering Entrepreneurship Development (SPIEED): Developing Entrepreneurial Competencies in Twenty-First Century Engineers

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In Student Partnerships for Innovation in Engineering Entrepreneurship Development (SPIEED) engineering and business students partner to fully commercialize a new technology. In this paper we examine three research questions: What do students learn? How do students learn? Is there net new learning between planning and executing the commercialization of a new technology? We present evidence from student reflection papers that the program enables participants to develop the full range of entrepreneurial competencies. However, the competencies developed in the planning and execution stages appear to differ suggesting the presence of incremental learning. We conclude with the implications of the results.

INTRODUCTION

Engineering educators and policy makers agree that twenty-first century engineers need to be able to address societal problems through innovations and enhanced functionality, work in multicultural environments, understand the business context of engineering, work in interdisciplinary teams, and adapt to changing conditions (Kauffman Foundation, 2008; National Academy of Engineering, 2005; National Science Board, 2007). Polczynski and Jaskolski (2005) have identified two types of engineering, "What-to-do engineering – WTDE" vs. "How-to-do engineering – HTDE." WTDE is easily codified and as a result most WTDE has been outsourced to low wage areas. HTDE requires tacit knowledge, is not easily codified, and involves competencies that provide engineers with a competitive advantage in the global market place. It is the goal of most programs to train their students in HTDE and many programs have broadened their curriculum in order to accomplish this. These programs have shown that by broadening the experiences of engineering students they develop characteristics valued by employers such as multi-functional communication skills, self-direction, and decision making skills in unstructured situations (Ochs, Watkins & Boothe, 2001; Verzat, Byrne & Fayolle, 2009).

Student Partnerships for Innovation in Engineering Entrepreneurship Development (SPIEED) is a program aimed at developing twenty-first century skills in undergraduate engineering and business students through entrepreneurship training. The key innovation in SPIEED is that students not only create a novel product, design the business plan, but actually produce and take the product to market. SPIEED incorporates successful elements from existing engineering entrepreneurship education programs and adds an implementation component to enhance and broaden the learning experience of a large and diverse population of undergraduate business and engineering students. In SPIEED students: INNOVATE through the development of a new technology, product, or service; become ENTREPRENEURS by actually commercializing the technology, product, or service; COMMUNICATE by developing an ability to articulate and share their methodology and understanding with diverse audience; and SUSTAIN the project by selling their innovation, achieving specified return on investment, and providing additional funds to sustain the project for subsequent classes.

This study addresses three research questions. 1) What do students learn in SPIEED? 2) How do students learn in SPIEED? And 3) is there net new learning that occurs through commercializing an original technology? The results of this study will enable us to enlarge the SPIEED program to provide opportunity for developing entrepreneurial skills to a broader audience and to set SPIEED as a model for developing and evaluating engineering entrepreneurship programs.

Background

Entrepreneurial education research has demonstrated that entrepreneurial competencies are learnable and that entrepreneurial learning has a direct impact on the development of entrepreneurial competencies, thus allowing for intervention through entrepreneurship education (Baron & Markman, 2000; Bird, 1995; Fisher, Graham & Compeau, 2008; Lans, Hulsink, Baert & Mulder, 2008; Timmons, 1995). Fisher, et al. (2008) have defined entrepreneurial education as "the process of providing individuals with the concepts and skills to recognize opportunities that others have overlooked, and to have the insight, self-esteem, and knowledge to act where others have hesitated" (p. 315).

Man, Lau and Chan (2002) have identified six entrepreneurial competency areas from the entrepreneurial competency literature: opportunity competencies (recognizing and developing market opportunities), relationship competencies (person-to-person and person-to-group interactions including persuasive ability, communication, and trust), conceptual competencies (decision-making and innovativeness), organizing competencies (organizing various tangible and intangible resources in developing market opportunities), strategic competencies (setting and implementing strategies of the firm), and commitment competencies (moving ahead with the business/venture).

Souitaris, Zerbinati and Al-Lahan (2007), in their study of the impact of entrepreneurship education on attitudes and intentions of science and engineering students, have found that the entrepreneurship program they studied increased the entrepreneurial competencies of the participants. Fisher, et al. (2008) have found that the program they studied resulted in the development of multiple entrepreneurial competencies in the participants. Peterman and Kennedy (2003) have provided additional evidence by demonstrating that exposure to enterprise education affects entrepreneurial intention. Pittaway and Cope (2007), in their systematic review of entrepreneurship education, have found evidence to support the conclusion that entrepreneurship education impacted student propensity and intentionality. The basic premise of this research stream is that entrepreneurial competencies can be learned, and entrepreneurial education programs in general and engineering entrepreneurship programs in particular are effective in achieving this learning (see reviews of entrepreneurship education research by Dickson, Solomon & Weaver, 2008; Gorman, Hanlon, & King, 1997).

Research on how people learn has identified the need for active learning techniques that help people take control of their own learning. Various active learning techniques have been classified under "metacognition." Metacognitive approaches have been shown to increase the ability of learners to transfer what they have learned to new settings and events (Bereiter & Scardamalia, 1989; Bransford, Brown & Cocking, 2000; Wiggins & McTighe, 2001). In recent years, entrepreneurial education has demonstrated a shift from more programmed instruction to metacognitive approaches such as experiential learning or

"learn by doing" (Fisher, et al., 2008).

In SPIEED we propose utilizing elements of Problem-Based Learning (PBL), an experiential learning technique. In PBL, students learn by solving problems and reflecting on their experiences. PBL emphasizes active, transferable learning by situating learning in real-world problems and making students responsible for their own learning. Hmelo-Silver (2004) identified the components of a PBL learning cycle. First, realistic and unstructured problems give learners the opportunity to deal with the ambiguities associated with real-world situations. Second, small collaborative multidisciplinary teams allow students to articulate their current understanding vis á vis the problem, share knowledge, develop hypotheses about the problem, identify knowledge gaps and negotiate ideas. Third, the teacher, who is also a learner, models and facilitates the learning process. Fourth, Self-Directed Learning (SDL) allows students to generate new knowledge to fill their knowledge gaps, revisit or modify their hypotheses, generate new hypotheses and develop multidisciplinary solutions to the problem. The final component is reflection where students reflect on what they learned, how they learned it, how the new knowledge relates to their prior understanding, and how their learning and problem-solving strategies can be transferred to new contexts.

Hmelo-Silver (2004) has provided evidence of the effectiveness of this experiential learning approach in supporting learning in undergraduate and professional educational contexts. Her review of the research on PBL's effectiveness showed that PBL is effective in helping adult learners construct flexible knowledge, develop problem-solving and reasoning strategies that are transferable to new problems, develop collaborative explanations of problems, and increase confidence about learning. Hmelo-Silver (2004) has concluded that PBL suggests a method to promote "active and reflective knowledge-building-for-action" (p. 261).

In addition to the research that has demonstrated the effectiveness of PBL in general; many elements of PBL are evident in successful entrepreneurial engineering programs (Creed, Suuberg & Crawford, 2002; Ochs, et al., 2001; Polczynski & Jaskolski, 2005; Rogers & Stemkoski, 1995; Stanford Technology Ventures Program, 2010). These programs engage students in real-world problems. For example, students in the one-year long entrepreneurial engineering program at Brown University turn seed ideas supplied by local parent companies into viable prototypes and business plans (Creed, et al., 2002). At Lehigh University, students work on real world projects that involve developing new products, software or processes in conjunction with company sponsors (Ochs, et al., 2001). These programs are also characterized by students solving real-world problems in multidisciplinary collaborative teams. At Marquette University, students work in "multidisciplinary teams that possess the full range and depth of entrepreneurial skills and knowledge" (Polczynski & Jaskolski, 2005). The multidisciplinary teams at Lehigh University included not only students from multiple disciplines, but also faculty and staff and entrepreneurial sponsors (Ochs, et al., 2001). The Stanford Technology Ventures Program included students from multiple disciplines and the use of collaborative teams in solving "real" problems (Stanford Technology Ventures Program, 2010). Faculty in these programs played multiple roles; however, consistent roles were that of learners and facilitators of the learning process (Creed, et al., 2002; Polczynski & Jaskolski, 2005). Both faculty and students reflected on the learning and experience gained from participation in these programs.

These programs have reported a measure of success with equipping engineers with entrepreneurial skills and knowledge. One common feature of these programs is that they provide training to engineers in the entrepreneurial planning process, including the development of viable prototypes and business plans, but do not give the program participants the opportunity to actually execute the plan by fully commercializing the new product/service idea. While there are a few general entrepreneurship programs that build in commercialization into their programs (see Fisher, et al., 2008, for examples from Clarkson University and Babson College), the majority of entrepreneurial engineering programs do not include commercialization as a part of the program.

Elements of SPIEED

SPIEED incorporates successful elements from existing engineering entrepreneurship education programs and adds an innovative component that is not found in any other undergraduate engineering entrepreneurship program – real-world implementation. The implementation component provides experiential learning for students and allows entrepreneurial programs to become self-sustaining. SPIEED is a year-long course conducted with students experiencing successive and increasingly complex stages of the full entrepreneurial process over the course of one academic year. Each class has eight to ten engineering students and eight to ten business students. The students are upper-division and as such have completed most all the core and all fundamental functional courses in their various disciplines. SPIEED calls upon them to utilize their functional knowledge in successfully achieving the learning outcomes of the program.

The first stage of SPIEED is the *formulation stage* and is devoted to formulating an entrepreneurial plan. In this stage students are introduced to new technologies and work in multidisciplinary teams to design multiple products with commercial application using the new technologies; select one or more product options among those developed that they believe are most feasible to commercialize and bring to market; and develop a more thorough marketing plan, financial plan, and production plan along with an advanced prototype of the selected product.

The second stage is the *implementation stage* and is devoted to implementing the entrepreneurial plan developed in the first stage. In this stage, students source for raw materials, manufacture the product, and market the product. They prepare business reports and financial statements that reflect the commercialization effort. The students are the main drivers in this course with the instructors serving as coaches and assisting and guiding them on an as needed-basis.

Using elements from PBL, SPIEED contains the following:

1. Problem – students are introduced to innovative technologies from multiple sources and are charged with turning one or more of the innovative technologies into a viable commercial product or service. They create a prototype, develop a business plan, and manufacture and market the product to achieve pre-determined strategic and financial goals. 2. Teams – students work in collaborative multidisciplinary teams composed of engineering students from multiple specialties and business students from multiple functional areas. 3. Faculty– two faculty members, one engineering and one business, design the program to ensure the achievement of specific learning outcomes and coach the student teams. The faculty members are also learners as they have to grapple with the same uncertainties faced by the students in commercializing an innovative technology. 4. Self Directed Learning – students are in charge of their own learning. They select the technology they wish to pursue, they propose several product ideas and decide on the one they intend to pursue. They develop a business plan with full marketing, financial and production sub-plans. They then execute the plan by producing the product, marketing the product and achieving pre-determined financial and strategic goals. 5. Reflection – students continually reflect on their experiences as they pass through the above process. They produce a number of reports and make a number of presentations throughout the program. In addition, they produce one reflection paper at the end of each stage. In these papers they detail what they learned, how they learned what they have learned, the challenges they faced, and how they resolved them. These reflection pieces are the data sources for this paper.

Methodology

Sample

SPIEED has had three cohorts of 56 students to date. The sample is composed of 23 (41 percent) engineering students, 21 (37.5 percent) females, and 38 (68 percent) underrepresented minorities. The students are upper division engineering and business students, which means that they have completed most of the core courses in their various disciplines.

Data

   We employed qualitative research methodologies in which we utilized student reflective papers to explore and document student learning. Students wrote reflective papers at the end of each stage of the process. These narratives gave students the opportunity to articulate specific things they had learned and how they learned them, identify positive and negative experiences, and interpret course experiences and the lessons learned. As part of the SPIEED study these reflective pieces were codified into a more systematic understanding of student experience and learning by the researchers. For the qualitative data inductive coding techniques were utilized to develop a coding scheme (Miles & Huberman, 1994). For each session, each reflection paper was initially analyzed in order to gain familiarity with each case as an independent entity. A line-by-line analysis of each paper was performed to see if there were any identifiable patterns such as regularly occurring words, phrases, or concepts, and so forth. *"In vivo" codes*, the words and phrases used by the students, were identified during the analysis (Strauss & Corbin, 1990, p. 69). We translated these narratives into a codified systematic schema by classifying the modifiers (adjectives, adverbs, emotive language) used into a score per paper. The reflective papers for each session were then combined and coded. We subjected these codes to analyses to determine the entrepreneurial competencies the students learned, how they learned them, and whether or not there was any incremental learning as a result of their participation in the commercialization phase. This project is ongoing, as a result data collection and analysis are continuing.

Results and Discussion

   We report the results in Appendices A through C below. In Appendix A we report the entrepreneurial competencies the participants deveoped in the formulation and implementation stages of SPIEED (what SPIEED students learned and "net new" learning); in Appendix B we discuss the processes whereby these competencies were acquired as described by the participants (how SPEED students learned); and in Appendix C we present data on how the experience changed the preconceptions of participants about each other's disciplines, about the business world, and in general. We present direct quotes from the participants as evidence of our findings.

What Did SPIEED Students Learn?

   As displayed in Appendix A, the students identified a wide range of entrepreneurial competencies in their discussion of what they learned in SPIEED. We classified these into the six entrepreneurial competencies identified by Man, et al., (2002) and described above. The reflection papers in the formulation stage described opportunity competencies (recognizing and developing market opportunities; Man, et al., 2002) in terms of recognizing and developing market opportunities related to their chosen technology as displayed in the following quote from an operations management student:

> When we were first trying to come up with ideas for the product, we all began talking about problems for commuting students and everyone agreed that parking was the issue. The learning came about when a team member mentioned creating a website that shows the number of available parking spots to help students know where to park. We all built from that suggestion. A teammate mentioned the information would have to be mobile and I mentioned that it should be an application. Another teammate suggested having the application be designed by Computer Information System students. We all suggested great ideas and they were all towards the same goal.

   The papers described relational competencies (person-to-person and person-to-group interactions including persuasive ability, communication, and trust; Man, et al., 2002). This was consistent across all the participants. They described in detail learning to communicate with team members, particularly with individuals of different disciplines, backgrounds and functional training. They described learning to negotiate and resolve conflicts. They described the frustrations they experienced as a result of different

individuals viewing the project with different lenses based on their backgrounds. This quote from an accounting student exemplified this:

> For instance, the engineering teammates were not as concerned about the economic and financial aspects of production as they were the functionality and appearance of the product itself. While I found myself frustrated that my group members would not inform me of every dollar spent or component ordered, I had to remember that we were looking at the construction of our product through different lenses. Until I explained the importance of accounting for every single penny, they probably perceived me to be annoying and nitpicking. This diversity in our expertise forced us to consider the other members' perceptions and to figure out how to work together effectively and efficiently. We had to recognize when it was our time to take the lead and when it was time to take a backseat in order to prevent stepping on the others' toes and to keep our project moving smoothly.

The papers also described conceptual competencies (decision-making and innovativeness; Man, et al., 2002), particularly as was related to creating a product from a new technology. The students described learning to brainstorm and allow multiple ideas to percolate to the top in their ideation process. They described learning to trust each others' creative capacity. They described facing the challenge of applying their functional traininig to create a new product. They talked about the immense satisfaction derived from a prototype that actually worked and the dissapointment with multiple attempts at designing a working prototype. The quote below from a mechanical engineering student sums up learnings associated with conceptual competencies:

> For me the best was when the prototype was working. It was very satisfying to see that the actual idea was feasible. If I was to start over I would forget all the other ideas I had and would go with just this one. The extra time would have helped immensely. However I know that discarding bad ideas is part of the process and unavoidable….but the main problem was that you can't plan innovation. Sometimes our progress would be extremely fast, other times it would be slow and rife with problems.

Finally, the reflective pieces in this stage identified strategic competencies (setting and implementing strategies of the firm; Man, et al., 2002), particularly as was related to putting together a business plan and all the associated elements.

> A large amount of time has been given to the business side of this project as well. This gives me exposure to actual industry business practices such as creating marketing plans, creating financial plans, creating a management structure for our company, and making an overall comprehensive business plan for our company. This has forced me to work on my cross discipline communication skills. (A mechanical engineering student)

> The act of developing business plans, financial plans, production plans and so on forced me to think in areas that I had not thought about prior to this class. The scope of business is still beyond me at this point, but I feel that this course provided a culmination of skills that cannot be found elsewhere. (A mechanical engineering student)

Largely missing from the reflective pieces in the formulation stage were discussions of the things the students learned that could be classified as organizing and commitment competencies.

These findings are consistent with the activities the students were engaged in during the formulation stage. The students were primarily engaged in team building and innovating a new product and identifying a market for it. Thus, the reflection papers focused on activities that were classified as

opportunity, relational, conceptual, and strategic competencies. The students were not charged with putting together the organization that would support their product nor commit resources to moving ahead with the business venture. These activities would occur later once they had selected a product.

The reflection papers in the implementation stage described relational, conceptual, organizing, strategic and commitment competencies. The papers did not describe activities that could be classified as opportunity competencies. They also spent less time describing activities that could be classified as relational competencies as compared with the papers from the initial session. The papers focused primarily on conceptual competencies, particularly in relation to product modifications and improvements. This is inline with their experience in the implementation stage in which they had to modify their product and their plans along multiple lines. Ferrofluid, the main component of the initial design, was found to degrade after three months. This necessitated extensive product modifications and use of a new technology. Also, the students were required by the professors to re-incorporate ferrofluid into the product because they did not conduct sufficient testing before abandoning the technology. Again, this required additional product modifications. The schedule in the production plan had to be modified due to delay in the delivery of a major component of the product. The supplier had taken the order but failed to fill it, thus delaying production by three weeks! The marketing plan also had to be modified due to obstacles encountered in the implementation of the marketing plan. Contrary to their expectations, the students did not receive approval to broadcast the commercial they had created for their product on the TVs in the student center. This was an essential component of their marketing plan. They had to develop alternative broadcasting strategies in order to show the commercial.

The relational competencies were similar to those described in the initial session – they learned to communicate with teammates (particularly those of other disciplines), build consensus and negotiate. What was new in the final session was that they learned how to delegate and take initiative. In the initial session, the students had not created a structure to support the venture and as a result did not have specific roles. Once the structure was developed and roles were assigned, there was a need for the functional team leaders to learn how to delegate to teammates. This provided ample opportunities to delegate, on the part of the team leaders, and to take initiative, on the part of the team members. According to the Chief Technology Officer (a mechanical engineer):

> I realized that I needed to delegate more work to the other members. It is hard to communicate design concepts or assign tasks when the expectations are unknown; however, the amount of work was beyond my capabilities and required me to trust the other members. The outcomes have been satisfactory, however, and the project has progressed well.

The organizing competencies (organizing various tangible and intangible resources in developing market opportunities; Man, et al., 2002) described by the students focused on creating a functional organizational structure for the venture, assigning responsibilities and creating mechanisms for control and coordination. The students designed a structure and assigned roles consistent with their plan. They learned the importance of specialization, the efficiency of functional specialization, and the need to ensure mechanisms for coordinating the various functions.

> It is thoroughly important to divide up teams to work on sections in the business that they either specialize in or volunteer to work in. If there isn't organization into different functional groups, there would be an entire mess of work that would be overdone or maybe not done at all. Once the teams were split up through volunteering, it was easy to get feedback when work was assigned. Everyone knew the type of work they were getting into when they signed themselves up for their functional group. (A chemical engineering student)

As expected, the strategic competencies in the implementation stage were primarily focused on using the strategic plan as a means of guiding the activities of the venture.

It would be rather juvenile and naïve to think that you could start a business with a trial-and-error strategy. But instead, we were "forced" to write out these plans that were due every other week that encouraged us to write out the detailed steps of every one of our functional group. After seeing what each functional group came up with for the strategic plan and strategic objectives, I realized how set we were in actually carrying out the production of the business. It was entirely amazing how the work that was asked of us, forced us to implement things and push forward in progress in order to meet the deadlines to be ready to sell our product. (A chemical engineering student)

Commitment competencies (moving ahead with the business/venture; Man, et al., 2002) focused on the execution of the plan to move ahead with the business venture. Again, these results are consistent with the need to implement the plan that was formulated in the first stage.

I experienced that it takes a lot of research and preparation to market a new product. Marketing is a big aspect of trying to get the product known, which will ultimately drive sales for your product. The learning moment occurred by me joining the marketing team and actually going through the actions of preparing for the marketing of the product. Different tasks were spread up between the marketing team, but throughout the process, I was able to see all these tasks and also what it took to complete all these tasks. In order to complete most of our marketing plan, a lot of work had to go into it. (An entrepreneurship student)

How Did SPIEED Students Learn?

In evaluating the reflection papers for a description of how the students learned/developed these competencies, we identified three processes whereby these competencies were learned: problem solving, teaming, and working (that is, performing the functions necessary to accomplish the work of the organization). The processes were common in both sets of reflection papers – the formulation and implementation stages. The greatest amount of learning seemed to occur when the students encountered a problem for which they needed to develop a solution. As indicated in Appendix B, the types of problems the students faced in the formulation stage focused primarily on the products they were developing in their smaller teams. The problems in the implementation stage focused primarily on the degradation of the ferrofluid, a major component of the product they had chosen to commercialize, and the need to re-incorporate ferrofluid into the modified product design. The participants identified developing solutions to these problems as major learning experiences for them. According to one of the materials engineering students:

I had a really big issue at the beginning of the quarter when we found out the trouble we had with the ferrofluid breaking down after about 3 months. We had experienced the ferrofluid clumping in the tube when we worked with it last quarter, but we thought it was just a bad batch. But when we researched places to get the ferrofluid from, we learned firsthand that it was just a characteristic of the ferrofluid to lose its silica coating and let the nano-sized iron particles coagulate during the third month after the batch was made. The professor made it a requirement to reincorporate the ferrofluid because she felt we gave up on the technology too easily. It was really cool to see that the R&D Group really stepped up and acknowledged the insert and felt that it could work. I felt relieved that the group came up with a really easy and ingenious simple plan to incorporate the ferrofluid again.

The students also described the learning they obtained by working in teams. No individual had the requisite skills necessary to fully execute the plan; they had to depend on each other and trust each other. The multidisciplinary nature of the project provided the skills necessary to successfully execute the plan.

Combining students of multiple disciplines is an excellent way to learn about business and I feel as if I am better prepared for a future job or even starting my own company. Considering the number of first time business failures, I believe I still have a lot to learn before starting a company, however, going through the process of product development with the purpose of selling and making a profit really provides a realistic business experience. Engineering provides a lot of valuable tools, however, an engineer's job is only one part of a business and other disciplines play equally important roles. This realization was facilitated through the group work in the class. (A mechanical engineer)

We often needed to work on sections that didn't involve our current majors. I worked on some of the production sections, and my engineering teammates greatly aided me in the business sections. Of course, we all helped each other. I showed them some of the finance and operations management methodologies I had learned during my past few years at Cal Poly, and they taught me about the engineering techniques that they had learned at Cal Poly as well. For those reasons, I believe that the cross-functional structure of the class did facilitate learning. (A marketing student)

The students also described the process of doing the actual work of the organization as a learning opportunity. This quote exemplifies this point:

I learned so much about marketing and all that gets put into making a new product and trying to get the word out. Because I am a management major, I don't take many marketing classes and don't spend too much time on the subject. It has been a couple of years since I took the one marketing class required for my degree, and I didn't remember a whole lot from that class. Taking this class, I was able to actually get hands on experience to market a product. This is very valuable information for me because I want to own my own company and when it comes to the point that I do actually own my own company, I will have experience in marketing that I would have otherwise not had. (A management student)

How Did SPIEED Students Change?

An important finding of this paper is how SPIEED changed the participants. The students described in both sets of reflection papers the impact of the program on their preconceptions about each other's disciplines, about the business world, and in general. We provide sample quotes illustrative of these changes in Appendix C. The students described gaining the realization that their respective fields of study, be it engineering or business, is only one piece of the commercialization puzzle. While they may have known this mentally, they actually saw and experienced it.

I learned a little about engineers and the elements they think about when they are creating a product or project. Also all the tools they have to take into consideration when for example they have to seal a product. As a marketing student I think about all the aesthetic elements but I've never taken into consideration all the work that has to go into engineering that product for mass distribution. All the prototypes that have to be created until the final one is finally conceived. (A marketing student)

So far this class has been a learning experience like none other I have ever experienced. It gives us, the students, a chance to work on a project that is a representation of what life after school for an engineer might look like. We have to work with many different disciplines and be able to communicate to others our ideas so that everyone can understand. Even with a simple project like this, there is so much to be considered to be able to run a successful business that profits. I think that is what I will take away the most

from this project, to get work on something that is non-engineering related. This gives engineers another perspective of how it is not all about engineering; engineering is just part of the puzzle that makes a successful business. (A mechanical engineering student)

The students described developing an appreciation for the role of other disciplines in the creative process. One of the engineers described learning firsthand the impact of the product's design on production costs and the resulting change in the way he would approach the design process:

I learned that the marking department in a company is quite important, and that a good marketing team is invaluable. This aspect of the company sets the public opinion, and the ideas from the marketing group were interesting and unique. I learned that marketing requires a lot of creativity, which is necessary to capture the attention of our customers. Learning the financials provided several learning moments. Finances are extremely important, and the concept of 'making money on the buy' changed the way I approach the design process. The design process directly affects the financials of a company, and working with the finance department helped enforce this concept. Sharing numbers between officer members allowed group input to take place on reducing costs and allocating funds.

The students described experiences that were life affirming.

All in all this class has given me more hope about my future than any other class I have taken in my academic career. This class was more than I expected. I had trouble looking around for a senior project to jump onto, since none had enticed my interests. The only thing that I had wanted to do at Cal Poly, or for my future, was to work with other people of different disciplines, bring together our knowledge and creativity from our areas of expertise, to work together to solve a worldwide problem. This is what is important to me, and I feel that this class is a HUGE stepping stone to getting me where I need to be. (A materials engineering student)

I am a Management and Human Resources (MHR) major with an emphasis in entrepreneurship so it is very important for me to know what processes it takes in order to open a business and build it from the bottom up. I am working with many other people and we are learning this process together. There are going to be some hurdles to get over, but if I can learn about this process now, many of the mistakes I might make when I start my business might not be made. (An entrepreneurship student)

Conclusions and Implications

This study has demonstrated that the SPIEED program enabled the participants to develop the full range of entrepreneurial competencies by allowing them to not only formulate an entreprenrueial plan but to also fully impement the plan. During the formulation stage, the students, in their reflection papers, primarily focused on opportunity, relational, conceptual and strategic competencies. During the implementation stage, the student reflection papers mostly focused on relational, conceptual, organizing, strategic and commitment competencies. Experiences that could be classified as opportunity competencies were largely missing during the implementation stage while experiences that could be classified as organizational and commitment competencies were largely missing during the formulation stage.

For the competencies that were repeated in both phases (relational, conceptual and strategic), the focus of the reflection pieces differed. Relational competencies in the formulation stage emphasized learning how to communicate with individuals of different disciplines, learning how to negotiatiate ideas, and learning to trust team members and respect their expertise. While all of these elements were still

present during the implementation phase, the students also indicated learning how to delegate and how to take initiattive. Conceptual competencies in the formulation phase focused on ideation and prototype development; whereas in the implementation phase, the reflection papers focused on problem solving particularly as it related to design modifications. Strategic competencies in the formulation stage focused on developing a business plan, while in the implementation stage it focused on using the plan as a guide for organizational action. The results demonstrate the presence of "net new" learning for the participants during the implementation phase. Most engineering entrepreneurship programs provide training in the entrepreneurial planning process, including the development of viable prototypes and business plans, but do not give the program participants the opportunity to actually execute the plan by fully commercializing the new product/service idea. Although students do learn and develop entrepreneurial compentencies during the formulation stage, they would benefit by gaining greater depth in the competencies they developed in the formulation stage and acquiring additional entrepreneruial competencies such as organizing and commitment competencies through executing the entreprenurial plan they have developed.

The results also provide support for the efficacy of Problem Based Learning (PBL) in the context of entrepreneurial training. The results suggest that putting students in multidisciplinary teams to solve real world problems provides an effective learning environment. SPIEED participants seemed to indicate that they learned by having to actually solve a real problem (problem solving), by working in multidisciplinary teams (teaming) and by actually doing the work (for example, having to actually market a product enabling them to learn marketing skills). These are all important elements of PBL.

The results indicate that in addition to developing entrepreneurial competencies, SPIEED participants also experienced changes in their preconceptions. The students had preconceived ideas about each other's disciplines. While we did not collect data to identify what these were, their reflection papers indicated that whatever their ideas were about each other changed during the program. Engineering students developed an appreciation for the business disciplines while the business students developed a better understanding of engineering and the product design process. In addition the participants learned about themselves and whether or not they had the requisite skills to succeed as entrepreneurs. The program gave them confidence about their entrepreneurial capacity and their ability to work successfully in a multidisplinary team.

The results of this study have important implications for entrepreneurial engineering education. First, policy makers and educators agree on the need for future engineers to be able to work in multidisciplinary teams, respond to customer needs, and work with ideas and innovations in non-engineering disciplines (Kauffman Foundation, 2008; National Academy of Engineering, 2005; National Science Board, 2007). SPIEED provides a workable model to inculcate these skills and characteristics in engineering students, thus producing engineers with the necessary skill sets to compete in the twenty-first century. Second, educational institutions and enterpreneurship education researchers realize the need to develop more efficacious ways to instill HTDE entrepreneurial competencies in future engineers (Creed, et al., 2002; Ochs, et al., 2001; Polczynski & Jaskolski, 2005). The SPIEED model demonstrates an effective method of inculcating HTDE entreprenruail competencies in students who will become future engineers. Third, businesses value engineers with both technical and "soft" management skills (Ochs, et al., 2001). In SPIEED, students develop and apply both technical and "soft" management skills. The results of this study, by demonstrating the effectiveness of SPIEED in developing entrepreneurial competencies, will inform the design of entrepreneurial engineering programs that produce technically competent engineers with twenty-first century enterpreneurial skills and extend the body of entrepreneurship education research.

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APPENDIX A

ENTREPRENEURIAL COMPETENCIES IDENTIFIED FROM REFLECTION REPORTS SUBMITTED BY SAMPLE IN THE INITIAL AND FINAL SESSIONS -- WHAT STUDENTS LEARNED IN SPIEED

Entrepreneurial Competencies	Formulation Stage Sample Quotes	Implementation Stage Sample Quotes
[a]**Opportunity Competencies (recognizing and developing market opportunities)**	Each group has had to take their product from just a simple idea through all the engineering and business processes and have a marketable finished product at the end. This project has enabled me to more clearly see all the steps involved in taking an idea and forming it into something tangible. Even being a business major I didn't know all the steps and plans required to move a new product into the market because I have only ever read about them. We had no idea what we should come up with. We had three product ideas, and it was especially	

sad to see them end before we even got a chance to work on them. Once we found our snap tool idea though things became much more efficient. Everyone seemed to be more comfortable especially because we were all on the same page now. Once we got the idea down all of us started taking on roles and things started happening.

Relational Competencies (person-to-person and person-to-group interactions including persuasive ability, communication, and trust)	As for the course itself I found it to be excellent even though at first I felt out of place. It may sound sexist, but it was amazing enough that there were girls in my class. In mechanical engineering this was a rarity. But with introductions I got to know a little about everyone else and it helped when we first picked groups. The introductions definitely smoothed things over, got us talking about what we liked and what we cared about and it definitely got the ball rolling in terms of me meeting my teammates. I've learned how to communicate my engineering ideas, how to work in a non engineering team and the steps required to sell an idea. I learned so much about business and teamwork skills outside of engineering and I know all of this will be extremely valuable when I leave college. After all in the real world I won't be working in an insulated lab. Eventually, I will have to talk to people outside of the engineering discipline and plan with them and it's very helpful that I've learned how to do it early on. From an engineering standpoint there have been a number of things to be done on this project as well as learning how to effectively communicate these ideas with my non-engineering group members. Learning how to effectively communicate with non-engineering majors will be a huge advantage when it comes to being in the working world. The engineering side of this project, combined with the business side of things makes this project incredibly valuable due to the exposure to real world conditions and challenges.	I noticed that the production team's main goal was to develop the best product, while the finance team was more concerned with cutting costs and staying within the budgets. These differences forced each team to constantly communicate with one another and come to a consensus. The production team had to compromise some of the product goals they had established, and the finance team had to avoid being too cheap. Once we had reached this consensus, we found the best alternative for the organization, as a whole. I realized what was going on the whole quarter, and was grateful I decided to take initiative towards the middle of the quarter, and not sit back and wait for the officers to get me to do something. What motivated me was the knowledge that even though I wasn't an officer and others were, I was just as equally responsible as them in getting the project done, and we all technically should be doing the same amount of work.
Conceptual Competencies (decision-making and innovativeness)	The most valuable lesson I learned was to do as much brainstorming as possible in the beginning stages of design. Being as creative as possible is extremely important as it is one of the fastest ways to solve problems and allows for many options to develop simultaneously. It seems that it is better to have too many options than not enough, although it does require significant focus and diligence to narrow down ideas and assess their feasibility. Trusting others to develop creative solutions significantly helps this process and allows the group to function as a think-tank	We also overcame one last design change when we were tasked with re-incorporating the ferrofluid back into the design. More people in the group collaborated on this and we were able to find a feasible solution that added appeal to the clock without taking away from its fancy look. The other exciting thing is that the ferrofluid insert is actually located in the extension at the bottom of the clock which gives the clock its tilt. An extension that may not have been there, had I not suggested adding the feature, so that was satisfying. The design aspects of building and

throughout each phase of product development. The earlier group members trust each other to think creatively and welcome individual ideas, the better the group dynamics later on.

I have never created an entire Business Plan, and by going through the steps in this class, I was able to see how much work was needed to build a product from scratch and collect all the information needed to make sure the design, production, marketing, financial, and business aspects of this product in order for the company to run smoothly.

So far in my education we had learned a lot of technical aspects of engineering but we were barely challenged to bring our ideas to an actual market. This meant we could be wasteful, go over budget, and basically just guess whether customers would even buy our fake products. Actually making a product to sell and working with other non engineering majors seemed better than doing more experiments in the lab.

improving the prototype this quarter were very exciting and enjoyable to be a part of. I was able to work with people I enjoyed and stretch my creativity.

When we presented our clock to the marketing professor he was honest about it not being "worth $20". It gave us a reality check into putting more emphasis on the appearance and the materials used in the clock. The R&D group was able to redesign it and make it more presentable. With each prototype we were able to enhance it and at the end reduce the price.

I learned that there is never a set design when it comes to selling a product. A design can and always will be modified throughout the design process. This change can come at ease or can completely alter the business plan. I learned that designing a new product from scratch is a very difficult task and it takes a lot of specialists to do it, in our case engineers and business students.

Organizing Competencies (organizing various tangible and intangible resources in developing market opportunities)		A classmate stood up in front of the class to announce that we needed some sort of corporate structure and departments. We voted on what different departments/teams there would be, we nominated class members to be officers and we did not make an official decision until we had a consensus from the class. I think the way we assembled the company is part of the success we've been having. It was a good idea to have a CEO who is doing an excellent job making sure the company is running smoothly. Also, having a chief officer in different areas is more efficient, since they attend the chief officer meetings and then delegate tasks.
Strategic Competencies (setting and implementing strategies of the firm)	Since, everyone else volunteered to edit and rewrite the other plans; I was left with the marketing plan. Seeing that I'm an engineering major, and know nothing about marketing, this process was a task, and it got me to learn a lot. The marketing plan consisted of different segments where we described in detail what our plans would be. The segment on the product, pricing, promotion, and channel strategies were difficult. I did a lot of research online to see how other companies created their strategies, and saw how they would set up these plots describing their strategy, which could be complex at times. I also learned online the definition of each strategy and	Especially in this last quarter, I learned the importance of planning and having everything written out and edited before any physical action is taken...

what each strategy meant to the companies. I also asked my partners for help, and they encouraged that I come up with basic strategies, and not complex ones. All of this information was very insightful, and helped me know how to finish this segment. The other part of the marketing plan that gave me difficulty was the part that asked us to describe our goals for marketing our product. For this question I had to go online as well, and ask a partner in business to answer this question. Overall, I learned so much about marketing by completing this plan.

Commitment Competencies (moving ahead with the business/venture)		I experienced that it takes a lot of research and preparation to market a new product. Marketing is a big aspect of trying to get the product known, which will ultimately drive sales for your product. The learning moment occurred by me joining the marketing team and actually going through the actions of preparing for the marketing of the product. Different tasks were spread up between the marketing team, but throughout the process, I was able to see all these tasks and also what it took to complete all these tasks. In order to complete most of our marketing plan, a lot of work had to go into it. One specific example that describes this learning moment is the research done to figure out where we should set up the table and at what times. Though I was not assigned this task, the fact that somebody, or rather two people, had to sit at different locations and at different times during the day to determine this is time consuming work. It was a good experience to work with so many different, diverse people to get a product created and ready for production and distribution and all the other factors that go along with it.

[a]Six entrepreneurial competencies from Man, T., T. Lau, and K. Chan (2002). The Competitiveness of Small and Medium Enterprises: A Conceptualization with Focus on Entrepreneurial Competencies. *Journal of Business Venturing*, 17, 123-142.

APPENDIX B

PROCESSES THROUGH WHICH COMPETENCIES WERE DEVELOPED – HOW STUDENTS LEARNED IN SPIEED

Process	Formulation Stage Sample Quotes	Implementation Stage Sample Quotes
Problem Solving	The problem was that all of our materials and production processes were expensive, so we had to come up with a way of reducing those costs before we could think of lowering the price of our product. A team member was able to work with two plastic companies to reduce the price of the plastic and also	The 'aha moment' that I had, occurred when I realized that the ferrofluid had properties that could not be changed, at least in the time period that we had. The property of the water-based ferrofluid to break down made me realize that this material could not be used as such an integral part of our

the price of having the plastic itself cut down to 8½ by 11 inch sheets of plastic. By working with the two companies, he was able to work them against each other to keep lowering the price for each set of plastic. Another way we were able to lower the cost of the product was by lowering the cost of the water jet cost. Instead of cutting out the pieces of one sheet at a time, we were able to cut five sheets at a time. This reduced our costs substantially. All in all, we were able to reduce the cost of the materials and production for our product to get it down to a price we could work with.

My group is currently working on the mug that contains a phase change material pack. Challenges I've had to deal with thus far have been first designing a mug that would work as we wanted to. Then I ran into the challenge of working with a budget, causing us not to be able to design a cup and rather having to spec a mug that's currently available. This has caused me to have to communicate with various vendors, about materials used, cost per item, and dimensions of their product.

An "aha moment" that my group experienced was with the pop-up design of the snap tool idea. A teammate mentioned that the tools would fit tightly in the plastic sheet backing-sheet and that it would be difficult to get out. At that moment two other team mates mentioned to add a design of a lip in the acrylic sheet to make it easier to snap out. We all looked at each other confused at first, but when they explained the idea again we all laughed and nodded our heads. It was a funny moment but also a problem solving moment as well.

design. Even though the ferrofluid was innovative, the concept of a clock having a shelf life eliminated this appeal. Another 'aha moment' occurred when I realized that I had to provide a solution to the class. The pressure of the circumstances forced me to brainstorm and come up with a comparable design that took advantage of our previous efforts. The current design is the product of many 'aha moments' shared by the R&D and production team as well as the officers.

Because we had already finished the design of the clock along with the financial statements and budgets, we did not like the idea of having to go back and redo our entire business plan. Having just learned about the methods of accounting for product premiums in the previous quarter, I suggested that we just make the ferrofluid component a premium product and offer it for free with the purchase of the product. This way we were able to account for the component as an expense, change only the pro-forma income statement, and add a separate bill of materials for the premium rather than adjusting our entire financial plan.

While in the process of developing the marketing campaign for Bronco Time we decided to make a commercial to help create more brand awareness. While still currently in development the commercial was slightly side tracked due to the fact that the Bronco Student Center would not play it on their TV's. However, a teammate and I came up with a solution. We would use a projector to broadcast the commercial onto the side of buildings at night and during the day we could play it on the inside of our EZ-UP canopy at our selling locations.

Teaming	I have made new friends that I might not have met otherwise and I have learned to trust other students who are the experts in their respective fields. Consistent communication helped me understand that it is better to talk about the little details than to assume that those details will be taken care of otherwise. I think in the future I will be more open to ideas and will want to work with other business professionals in order to learn more about fields of study that I am deficient in. This class has taught me how the real world can be. In the sense that most of the time you will not be working with people of the same background and knowledge. I was able to see the different ways people think about the same problem based on their knowledge.	Working as a team, which sometimes doesn't feel like a team, but really feels like we're a business. And I've liked that a lot. I feel like we're accomplishing something more than just an assignment, because we are. We're a small business, engaged in a great work, lead by officers and hard working employees who are attempting to make this business successful. I really enjoyed the democracy we had as a class starting from the creation of an organization to deciding what size font to use on the different reports. I felt that the class had strong chemistry when we all voted on issues. The officers of the class such as CPO incorporated the same democracy when it came to issues in the production team. She really valued and respected

I think this class taught me a lot more responsibility and team work. I didn't particularly enjoy team work because sometimes group members aren't dedicated and then it just becomes harder on everyone. My group was great though and it made working in the group more enjoyable since everyone put in the same amount of passion for trying to create this product that we wanted to present. Group projects work well when everyone in the group puts in the same amount of effort to get it done. I learned a lot more responsibility because I didn't want to let my team down. I was constantly looking up more information on hot packs and things pertaining to it. I wanted to get as much information for my team as possible and do my part to contribute. After all, I couldn't contribute much in the financial plan and marketing plan, but I could find out different wants to make the product and different materials to use.

our views and opinions and took them into consideration when we wrote the production plan.

In fact everyone on my team did a great job. It made me realize how great it is to work in teams. It was especially beneficial because we all came from different educational backgrounds. So if one person didn't know the answer to something, someone else would know how to find that information. By the end of the quarter, we had a great media plan together. It took a lot of time and meetings and hard work to complete it. I think it was more work than people on my team expected it to be.

Working

I also really appreciate the exposure that I am receiving through this type of course. As opposed to doing traditional case studies or conceptual research, we are able to gain first-hand experience through the self-taught operation of a simulated business. I have the opportunity to propose objectives and actually work towards attaining those goals alongside my fellow organization members.

When we were putting together our final report, I had no idea what any of the income and balance sheet statements were supposed to look like, nor did I know where to start. By working side by side with other business partners, and compiling the final report together, I was able to learn what each financial statement was supposed to have in it. Now I'll understand what those statements will mean, and how to prepare them when I start working as an engineer.

As an Engineer I will be forced to deal with materials selection, strength of materials, product design, thermo dynamics, heat transfer, product assembly/manufacturing and engineering communication. I will also bear a somewhat heavy burden as a mechanical engineer because I am only one of four mechanical engineers in the entire class. Also, aside from engineering, I will be exposed to marketing, sales, financial planning and forecasting, creating a business plan, managing cross-disciplinary groups, web design, meeting break even goals, and the overall experience of starting a company.

This is the first time that I've had to single handedly work on a financial statement in this manner.

I was given the duty of being CFO for the company –something that I am very proud of! Since I haven't had experience as a CFO, I feel like I had a lot of learning to do, and this was just the right type of environment to do it in. Personally, I've always liked being on the go and having things to do to pass the day. But, because I was new to this CFO position and new to my work position, having a lot of things to do took more time than I originally thought. At the same time, I know that I had a team I had to lead. I think I could have done a better job at training the group members in the finance team about our financial statements.

My role on the Product Development and Commercialization Lab team became Chief Marketing officer. I was in charge of organizing a marketing team of four people. I think this was a real learning experience. Before this quarter, I didn't realize how difficult it would be to manage people. My learning moment occurred when I separated my team into smaller teams. I learned that many of them weren't prepared for the hard work required to be a marketer. At times, it became difficult to manage people because I didn't fully understand their skill sets. I think everyone felt that they might have worked better if they had more time to talk with one another and find out who would accomplish which task based on capabilities

Usually, I work together with my accounting group members because each of us has our strengths and weaknesses and when we work together we put out great group work, but I found that I really needed to be independent and figure things out on my own. This way, I would fully understand everything that I was doing.

My "aha" moment occurred very recently during one of our group assignments involving finance. Since our accounting teammate dropped the class, I knew that I would be next in line for "doing the numbers". Honestly, it really made me nervous. Up until the assignment, I never realized that I didn't know about accounting as much as I thought I did. I got good grades for basic accounting, but when I pulled up the assignment, I realized that I didn't really understand how to apply what I had learned. I pulled out my old finance book and went through a few chapters in order to write up and organize the requested financial documents. When my group got back our financial draft, I was excited that most of what I had done was correct. In many ways, I'm learning more here than I have ever learned in any of my "real world" internships.

APPENDIX C

IMPACT OF SPIEED – HOW STUDENTS CHANGED IN SPIEED

Formulation Stage Sample Quotes	Implementation Stage Sample Quotes
This class is definitely a great and helpful stepping stone from school to the actual business world. I feel much more prepared to take on real business challenges now than I ever have from just purely studying theory. So essentially it's not just the assignments and requirements of this class that have been informative but the process as a whole. From selecting our product to working with our groups to presenting, everything about this class has given me useful insight and experience that I can apply to my professional career. I know without a doubt that this class has prepared me better for the professional world better than anything else I have done in college.	The organization was too large for me to follow every detail but I trusted that all my group mates were getting everything done. I realized that in a large company I can expect to feel the same way. I had to rely on people I didn't know extremely well and hope they got the job done. In this case they did but I can see how in companies like Enron, people must have felt extremely betrayed that their fellow coworkers ruined their savings. Along these lines I've had adults suggest that I take an "every man for himself" attitude when I get my job and not trust anyone but again I see how this would destroy a company. If on Bronco Time I didn't trust my teammate to make the best decisions, I wouldn't put out my best work since I wouldn't be happy with the situation. I can see that if everyone feels this way in a large organization then that company will not be competitive since its employees will also be producing substandard work. Obviously this is all corporate culture and it taught me why it's so hard to get right and why it matters so much. The mood at our company is upbeat and the team members are supportive so the clock turned out well. I can see how if there was distrust between members that the clock would be much worse.

As a senior business student I feel as if business concepts are common sense, but since I have been working with other disciplines I realize my knowledge is not so second nature to others. This has been a new occurrence for me considering most of the people I talk to are business students.

I have to say that this quarter, the importance of a good team really hit me. I can also see how goal sharing is important too. If one employee wants a cheap final product and the other wants an expensive one, even if both are working hard nothing will get done effectively since they have opposing goals. The corporate culture is supposed to put everyone on the same mentality to get the same thing done. It just never really made sense to me before why one company with talented people would fail and another would do so great but it really makes sense now how you HAVE to have people who share the same ideals and don't cheat each other. Only then can you have a productive company that gets things done like we do.

I think that this aspect of working with other people and communicating is sometimes over looked. Something that I used to think is that "with good grades and understanding the concepts of accounting, you can go far", but it's not the case. It's not enough to simply understand rules and principles about accounting, it's also about working with other people and being able to communicate what needs to be done in order for you and your team to accomplish goals.