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CROWDFUNDING CAMPAIGN AS A DESIGN-BASED PEDAGOGICAL APPROACH FOR EXPERIENTIAL LEARNING OF TECHNOLOGY ENTREPRENEURSHIP

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ABSTRACT

Engineers are increasingly expected to master the knowledge and skills for entrepreneurship. Academic courses on entrepreneurship have been adopted in engineering schools around the world. However, the experiential learning of technology entrepreneurship remains challenging because it requires not only the experiences of ideation, design and prototyping in classrooms and fab labs but also broader engagement with users, manufacturers, marketers, and investors in business contexts. To conquer this challenge, we developed an approach to use an online crowdfunding campaign as a pedagogical approach to intensify the experiential learning of students in a technology entrepreneurship course. This approach, as part of a course module, provides a real-world context of uncertainty and resource constraints that characterize the entrepreneurship process, and it allows university students to discover and interact with actual users, investors, manufacturers and other stakeholders of their products around the world. We experimented with the use of a crowdfunding campaign as a pedagogical approach for experiential learning in the Entrepreneurship course at Singapore University of Technology and Design (SUTD). We found evidence of increased prototyping quality; learning intensity; empathy toward users, manufacturers, marketers and other stakeholders; and an increased interest in pursuing an entrepreneurial career.

INTRODUCTION

Entrepreneurship courses have been increasingly adopted in engineering schools around the world, due to the increasing uncertainty confronting our society, the growing innovation-driven economy worldwide and the growing demands for more entrepreneurial engineers in contrast to traditional ones [1,2]. Herein, our focus is on "technology entrepreneurship" and the social-technical process that integrates the conception, design, development and commercialization of novel and useful technology-based products, systems and services. The learning of technology entrepreneurship is naturally challenging because of its social-technical nature. It is not only requires the learning of design and prototyping methods [3-7] but also the knowledge and skills to emphasize and engage users, manufacturers and investors and other stakeholders [8-12]. Such activities as market research, user study, business plans and presentations in business entrepreneurship courses are also distant from real users and stakeholders and often based on imaginative products. However, university students lack the time, resources, and connections to discover, interact, experiment and learn with users and other stakeholders of an entrepreneurship process.

To conquer such challenges, we propose using an online crowdfunding campaign as a pedagogical approach to foster more practical, intensive and global learning experiences of the social-technical technology entrepreneurship process in an engineering undergraduate course. Crowdfunding is a recent but fast-growing phenomenon [13-18]. Increasingly more designers and entrepreneurs put their innovative designs and concepts on online crowdfunding platforms, such as Kickstarter.com and Indiegogo.com, to seek funding, concept validation and design feedback from early adopters. To launch a crowdfunding campaign, entrepreneurs need to work in teams, identify an entrepreneurial opportunity, design and prototype a minimum viable product that would appeal to early adopters around the world via the Internet, promote their campaign online and offline, and work on manufacturing and delivery. Therefore, when used as a course project, crowdfunding campaigns are expected to create a practical context for students to experience the holistic, social-technical global, and uncertain entrepreneurship process. As educators, our main focus is not on funding but on the entrepreneurial experiences that a crowdfunding campaign would offer to students' learning.

We have experimented the use of online crowdfunding campaigns as a pedagogical approach for experiential learning of technology entrepreneurship in the senior year elective course called "Entrepreneurship" in the Engineering Product

Development Pillar of Singapore University of Technology & Design (SUTD). In this paper, we will report our observations on students' intensified learning activities and the survey-based finding on their increased entrepreneurial career intention from the course. In the following section, we first review the crowdfunding campaign process and relate it to design and entrepreneurship.

LITERATURE: CROWDFUNDING FOR ENGINEERING DESIGN AND ENTREPRENEURSHIP

Howard Stevenson defined entrepreneurship as the pursuit of opportunity beyond the resources that a person currently controls [19]. Eric Ries considered a startup to be a human institution designed to create something new under conditions of extreme uncertainty, and entrepreneurship is the principle that deals with those situations of high uncertainty [11]. The established understandings of entrepreneurship have emphasized its characteristics as being uncertain and resource-constrained. The process to develop, launch and maintain a crowdfunding campaign embeds the key characteristics of entrepreneurship processes.

Literally, crowdfunding means raising relatively small amounts of financial contributions from a large number of online supporters (i.e., the crowd) typically via Internet. The financial contributions can take the forms of donation, reward, equity or lending [13,16,18]. Technology-based or product design projects usually use reward-based campaigns, where the entrepreneurs promise supporters early prototypes or a unit from the first batch of products as rewards [16,17]. Such funding can be viewed as advance payments. Herein, we focus on reward-based campaigns that are most relevant to technology entrepreneurship. Designers, engineers and entrepreneurs have increasingly turned to online reward-based campaigns to validate demands for their design concepts, raise funding for further development and manufacturing, and identify and build a community of early adopters and supporters [16,17]. For reward-based crowdfunding campaigns, Kickstarter.com and Indeigogo.com are the two most popular platforms [20].

On one end of an online crowdfunding platform, e*ntrepreneurs* develop campaigns to publicize their visions, designs and the state of project development through texts, videos, figures, and tables, and they communicate with the supporters. Entrepreneurs promise to use the pledged funding continue product development, manufacturing and delivery, if the campaign achieves its funding goal. On the other end, the potential crowdfunders browse through the campaign webpage and decide whether to make advance payments in exchange for the promised products to be delivered in the near future (normally 6 months). Crowdfunders are by nature "early adopters" [20,21] of novel technologies that usually do not interest normal investors or consumers. Compared to the mass majority of consumers, early adopters are more adventurous and intrigued by novelty to purchase, are more forgiving and are more likely to provide feedback on product designs; they also have abundant financial resources.

In brief, reward-based crowdfunding campaigns may offer the following benefits to technology entrepreneurs:

- Funding via advance payment for a pioneering product to be used for further development, manufacturing and delivery;
- Demand validation; and
- Community building with early adopters for feedback, learning and support.

Fig. 1 shows the crowdfunding campaign page of a typical live campaign from Kickstarter.com. On the campaign page, in addition to the information on the product, project and team, one can also find information on the funding goal, number and demographics of backers, days remaining before the campaign ends, pledging choices, and interactive page areas for campaigners to provide project updates and for backers to ask questions and provide feedback.

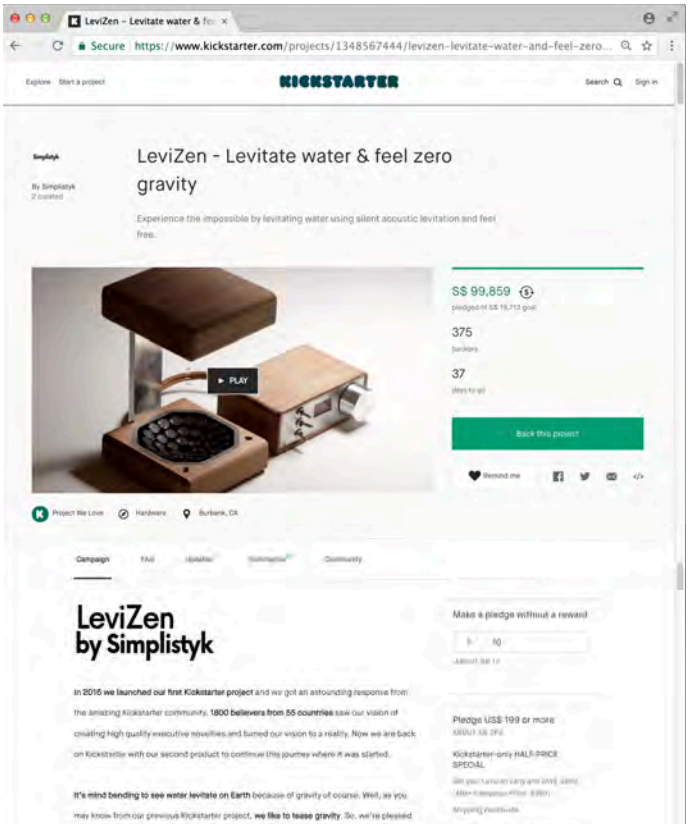


Figure 1. An Online Crowdfunding Campaign Page Example
(Source: https://www.kickstarter.com/projects/1348567444/levizen-levitate-water-and-feel-zero-gravity)

On crowdfunding platforms, many reward-based campaigns of innovative products have raised a considerable amount of funding from crowd supporters; examples include Pebble [22] on Kickstarter with $10,266,845 and Misfit Shine [23] on Indiegogo with $846,675. As shown in Fig. 2, on Kickstarter, campaigns in the technology category rank the highest among all categories considering the total live projects (i.e., the entrepreneurs' campaigns that are currently raising funding) and total live dollars (i.e., the supporters' pledges to the live campaigns). The most successful crowdfunding campaigns also appear to be technology-based. However, the technology campaigns' rate of success, i.e., the actual funding raised is greater than the preset funding goal, is the lowest among all categories. These figures combined suggest the popularity of technology-based campaigns, the great funding potential, and the small chance to successfully achieve funding goals.

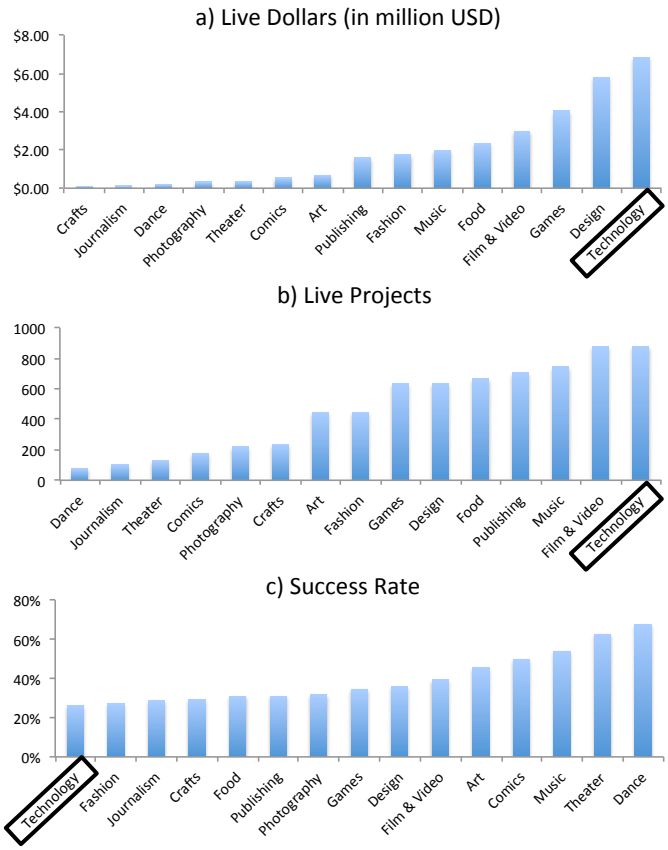


Figure 2. Live Dollars, Project Counts and Success Rates in Different Campaign Categories on Kickstarter.com

The story of Pebble demonstrates the benefits of crowdfunding campaigns. Eric Migicovsky developed an email notification device for Blackberry in 2009 with minimal funding from Y Combinator and angel investors. However, the startup failed to raise sufficient funding for mass production, because vague customer demands made it unfavorable to traditional investors. In 2012, Eric's venture team launched a campaign on Kickstarter.com, with a goal of $100,000 in a one-month pledging period and a promise to deliver in 6 months at the price of $125. The campaign raised $10.3 million on Kickstarter (Fig. 3). The success attracted an additional $15 million in Series A venture capital offline. With the validated demands for this type of innovative product at the time, not only startups but also incumbents such as Samsung and Apple followed in launching a series of smart watch products later. Note that Pebble was not the first to develop a smart watch. For instance, Microsoft's Smart Personal Objects Technology (SPOT) watch was launched in 2004. However, Pebble was the first to successfully validate user demand for such an innovative product (see Fig. 3). In particular, this validation was achieved via an online crowdfunding platform.

The Pebble case also suggests the relationship between crowdfunding and entrepreneurship. In particular, reward-based crowdfunding campaigns seamlessly synthesize the generic elements of the *lean startup* methodology [11,12] and the *design thinking* process [9,10] that recently gained popularity in the entrepreneurship and engineering design practices.

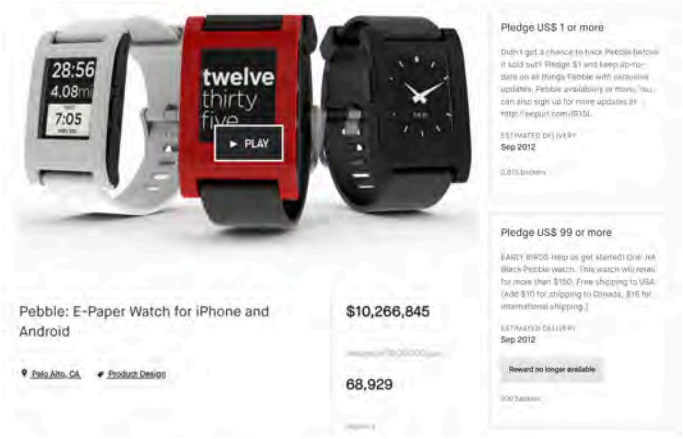


Figure 3. Screen Shot of Pebble's Kickstarter Campaign in 2012

The lean startup methodology was proposed to address the uncertainty and resource constraints confronting technology startups. This methodology emphasizes a *minimum viable product* (MVP) for paid uses of early adopters and validated learning from them [11]. MVP only includes the core features of the initial vision that allow the key assumptions to be tested but that are no longer. MVP is then used to validate demands before investing a large amount of time and money in product development and manufacturing. MVP should be deployed to early adopters, who are more forgiving and more likely to provide feedback. Similarly, crowdfunding requires a minimum viable product to be presented in the campaign. Crowdfunders are typical early adopters of innovation. Crowdfunders will pay for the minimum viable product a few months before it can be actually manufactured and delivered; therefore, demand validation is conducted before the product is mass-manufactured. Crowdfunders often provide questions, feedback and suggestions on the campaign websites, which are more meaningful than those from survey, interviews or market research with nonpaying persons. Traditionally, the discovery of early adopters is difficult. The reward-based online crowdfunding campaign is a *lean* methodology to discover and engage paying (advance payments) early adopters online for validated learning of demands and feedbacks.

Crowdfunding campaigns are also aligned with the design innovation and design thinking process [7-10,24]. The core elements of design thinking include *empathize*, *define*, *ideate*, *prototype*, and *test* [9,10]. These elements are not sequential but are looped in real-world design processes. Crowdfunding campaigns require a clear definition of the problem, ideating on solutions and the development of a working *prototype* for the campaign. The campaign is a *test* of demand and is meant to *empathize* with potential users, via their advance payments, based on the models or features they choose to fund, their questions, feedback or comments on the campaign website, and their demographics. Such learning and empathy will be useful for redesigns and adjustments of the original concepts and prototypes. Most importantly, a community of enthusiasts or early adopters for the new design concepts is built via the campaign and can be repeatedly engaged for feedback on new designs.

Combined, crowdfunding campaigns are highly related to entrepreneurship, as well as engineering design. Crowdfunding campaigns, if used in a course project, can provide an uncertain and resource-constrained context for students to experientially learn many fundamental elements of

the technology entrepreneurship process.

ENTREPRENEURSHIP COURSE AT SUTD

From 2015 to 2017, we have used the crowdfunding campaign as a pedagogical approach for experiential learning of technology entrepreneurship in the senior year elective course called "Entrepreneurship" in the Engineering Product Development Pillar of Singapore University of Technology & Design. SUTD has a unique curriculum that emphasizes multidisciplinarity, teamwork, hands-on and active learning [3,24] through a 4-Dimensional design learning framework [25] (Fig. 4). The 1st-D includes design projects within each subject, such as physics, chemistry and biology, to reinforce learning of the foundational knowledge. The 2nd-D design projects require students to integrate knowledge in different subjects in the same semester to solve a design problem. In the 3rd dimension, senior-year course projects (including the entrepreneurship course project) require students to utilize prior years' learnt knowledge and self-learn new knowledge to solve thematic design problems, such as medical device design and underwater robot design. As the 4th-D, students also self-initiate design projects with funding support and mentors or participate in research lab projects to explore their design interests outside the formal courses.

Figure 4. 4-D Design Curriculum of SUTD
(Source: SUTD Official Website)

The Entrepreneurship course is aligned with and embedded with SUTD's design-centric curriculum (detailed examples will be provided later). The Entrepreneurship course is designed for engineering students to develop systematic understandings of the social-technical factors and force that affect the entrepreneurship process; they also learn scientific principles and methods for making holistic product-process-people decisions under extreme uncertainty and resource constraints. Our eventual goal is to nurture holistic technical entrepreneurs. To achieve these learning objectives, the course is designed to synthesize theoretical and experiential learning. Fig. 5 summarizes the overall course design and structure, including the lectures, practitioner panel discussion and case readings with their topics matched with the project-based experiential learning stages and milestones.

The course is 14-weeks long and is organized in three stages for three milestones of the semester-long course project: 1) form a "company" by week 4, 2) launch a crowdfunding campaign by week 10, and 3) prepare and pitch to angel investors in week 14. In stage 1 (first 4 weeks), students work on forming a "company" (i.e., splitting roles and equity in a simulated way), developing a shared vision, and identifying an entrepreneurial opportunity. The lectures and classroom activities are aligned with the project stage and on the structure and dynamics of founding teams, entrepreneurial opportunity identification, innovative design idea generation skills, and methods and strategies. In week 3, a panel discussion with external entrepreneurs on entrepreneurial motivation, opportunity identification and team building are organized. At the same time, the homework involves reading and analyzing the cases related to founding teams and opportunity identification.

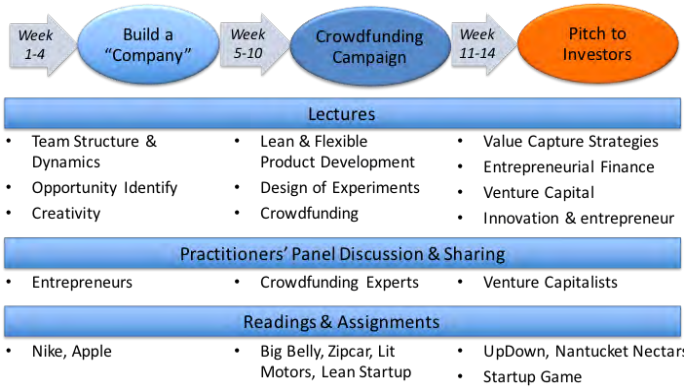


Figure 5. Matched Topics of Experiential Learning Stages and Milestones with Lectures, Panel Discussions and Case Readings

In stage 2 (weeks 5-10), venture teams focus on design prototyping and crowdfunding campaign development. Each team is provided a budget of SG$1,000. The teams can choose a design or prototype from their prior design projects or build new ones. Thanks to the 4-D design curriculum of SUTD [3-5, 24, 25], students entering the entrepreneurship course in the senior year have previously had approximately 20 design projects from their regular courses and extracurricular design projects at SUTD. At SUTD, most courses require team-based design projects to re-enforce the subject learning, such as electronics, thermodynamics and magnetism. Some teams will choose to work on new ideas and thus develop a new prototype for the crowdfunding campaign, while the other teams could further refine their prototype. To prepare for online campaigns, the teams also need to conduct user studies via market research, surveys, interviews and test uses, and develop a video and other materials required for the campaign. At the same time, the team needs to conduct precampaign marketing and to contact potential development, manufacturing and marketing partners.

In week 7 (recess week), we organize a one-week trip to Shenzhen, China for the hardware teams (at least one student from each team) to visit potential development and manufacturing partners and to understand manufacturing requirements and options. Shenzhen has the world's most comprehensive hardware design and manufacturing ecosystem. Currently, startups around the world are increasingly utilizing the Shenzhen ecosystem for not only mass production but also prototyping and actual manufacturing for crowdfunding projects (normally in small volumes). Some of the companies we visit are full-stack "product realizers" who can turn our students' functional prototypes into product prototypes considering design-for-manufacturing principles, agile manufacturers who specialize in low-volume high-mix manufacturing, and hardware startup incubators. The Shenzhen trip's objective is to help our students make connections with potential development and manufacturing partners, learn about a real-world manufacturing system, and collect information that will help

them better estimate development and manufacturing costs to set rational crowdfunding goals in the campaign. Once a campaign succeeds, student teams can return to the companies for manufacturing services with their funding raised from the campaign.

To ground the project activities at this stage, we deliver literature-based lectures on lean product development, design for flexibility, design of experiments, bootstrapping, crowdfunding strategies, tactics and critical factors. For instance, a lecture on the critical factors for crowdfunding success of innovative products was based on recent academic research [20] and aimed to guide campaign development directions. A panel discussion with entrepreneurs that had launched crowdfunding campaigns is organized for learning of their experiences and building connections with the like-minded communities. Some practitioners and students maintained the interactions during campaign development, launch and maintenance processes. In addition, case readings are assigned as homework for analysis in terms of lean experiments, minimum viable product, flexible product design, early adopter discovery, bootstrapping, and crowdfunding, matching with the lecture topics and project activities at the same stage.

The campaigns are launched by week 10 on an online crowdfunding platform, either Indiegogo.com or Kickstarter.com. Thereafter, the project enters stage 3. Each venture team needs to continue online and offline marketing and promotion efforts, generate and maintain momentum for new backers, address comments and feedback on the campaign website, and communicate with any people, organizations or stakeholders that discover the campaign or are discovered via their ledges on the campaign page. The campaigns normally last for one month. After their campaigns end, teams are expected to summarize the activities, outcomes and learning from the campaign and leverage these findings to develop manufacturing and delivery plans (if successful), business models, and investor pitches. In the end of the semester (week 14), when most of the campaigns are near conclusion, we invite a group of angel investors to the classroom, and students demonstrate their minimum viable products and pitch their projects to the investors for further feedback, comments and suggestions.

In this final stage (weeks 11 to 13), the in-class lectures and activities are primarily on business modeling, technology and innovation strategies, and entrepreneurial finance to support the students' development of a high-quality pitch to the angel investors in week 14. A panel discussion with venture capitalists is organized in week 12 to discuss such topics as business model and strategy, venture capital, valuation, and startup ecosystem. The homework case readings focus more on entrepreneurial finance at this stage.

Fig. 6 illustrates various experiential learning activities in and outside the classrooms across different stages of the course project. After the course ends, the successfully funded campaigners are expected to continue to work on design for manufacturing, actual manufacturing, and delivery to the crowdfunders. The teams that did not achieve funding goals may also continue venturing with their learning from the campaigns.

Note that the course projects are not evaluated based on the funding levels or the success or failure of crowdfunding campaigns. All teams receive the same portion of the total grade points for their crowdfunding campaigns, after their campaigns are successfully launched in week 10 after the investigation and approval of managers of the online crowdfunding platform that they use. Instead, the projects are evaluated in terms of the innovation, the market validation evidence, the business model, and the team efforts by the angel investors during the final pitch and demonstration session in week 14, and by the course instructor based on his observations throughout the 13 weeks. With intensified experiential learning by the campaigns, students are expected to enhance these dimensions of their course projects.

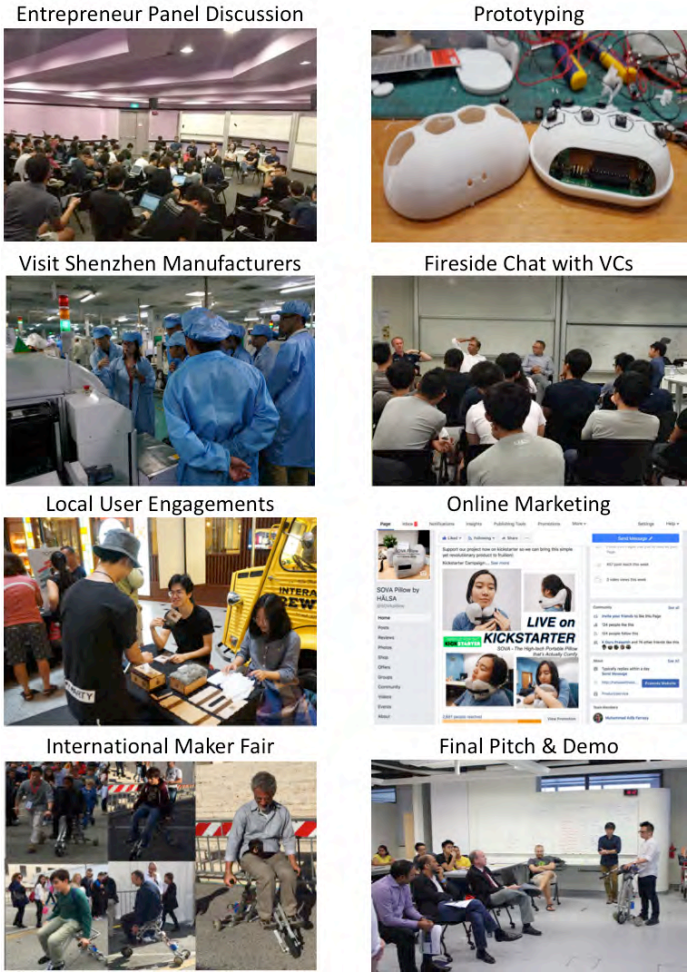


Figure 6. Experiential Learning Activities

RESULTS AND FINDINGS

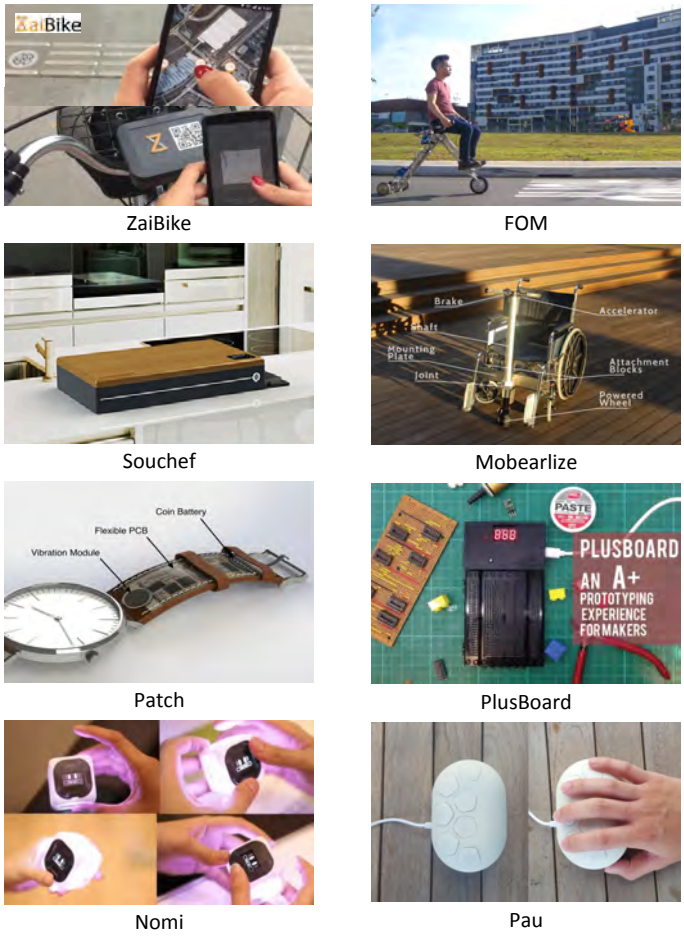
A total of 11, 16 and 11 crowdfunding campaigns were launched from the Entrepreneurship classes in 2015, 2016 and 2017, respectively; 1, 1 and 2 campaigns achieved their funding goals in the respective years. Indiegogo.com was used for all projects in 2015 when Kickstarter was not accessible in Singapore. Indiegogo.com is considered the second most popular reward-based online crowdfunding platform, only after Kickstarter.com. Thereafter, Kickstarter.com became accessible in Singapore and was used for all projects in 2016 and 2017.

In the following paragraphs, we will first report details on several course projects in different years, and then summarize the observations and findings. The minimum viable products from respective crowdfunding campaigns are shown in Fig. 7. Note that, herein, our focus is on the values of the

crowdfunding campaign experience for students' learning, instead of on the funding.

Project Snapshots

Zaibike was a project in the 2015 class. The team leveraged a bike sharing system concept they conceived from an extracurricular design project prior to the entrepreneurship course, and they developed a software-hardware integrated prototype system during the entrepreneurship course. The system allows users to find bikes on a map in the mobile app and unlock the bike by scanning a QR code on the bike. The team achieved the funding goal and launched a pilot operation with more than one hundred early adopters of their bike sharing service. Their crowdfunding campaign was widely reported by the online media (including Yahoo.com) and discovered by various government organizations interested in bike sharing systems. For instance, Jurong Town Corporation (JTC), which is a Singapore government-run industrial estate developer in Singapore, contracted Zaibike team to pilot their system in one of JTC's industrial parks, after discovering their crowdfunding campaign from media. After the class, the project received a grant from the SUTD-MIT International Design Centre to continue system development and venturing and was also admitted to an incubator run by a former director of the Land Transport Authority of Singapore. In this case, the campaign experience increased students' empathy toward users, media, funding agency and the government.



ZaiBike | FOM | Souchef | Mobearlize | Patch | PlusBoard | Nomi | Pau

Figure 7. Example Crowdfunding Campaign Projects from the Entrepreneurship Course at SUTD

The *Souschef* team started the Entrepreneurship class in 2015 without a specific design idea but a vision for food & beverage automation. The team first prototyped an egg breaker but failed due to technical difficulty. The team quickly pivoted to prototype a smart cooking ingredient dispensing device for another month and presold more than 30 units via a campaign on Indiegogo.com. The team found one-third of the preorders are from strangers from all over the world and primarily Indian; they also found a higher preference from Indian. Because of the exposure via the team's online crowdfunding campaign, Souchef's innovation was well reported by the media (e.g., Channel News Asia, TechInAsia, and Zaobao) and was invited to present at various innovation exhibitions and trade shows (e.g., InnoFest and CommunicAsia). At one of the team's later presentations, a Malaysian businessman who operates a bubble tea store chain approached Souschef for smart bubble tea making via automatic ingredient dispensing. With his funding and support, thereafter the Souschef team formed a company with him to develop automatic beverage mixing devices. After pivoting under the vision for food & beverage automation, the startup later raised SG$700,000 venture funding with a valuation of SG$3.5 million. In this case, the campaign experience provided students with the exposure, interactions and practical learning with early adopters, media and investors.

The *FOM* (meaning Future of Mobility) team in the 2015 class designed a novel affordable electric bike that eliminates the frontal area of conventional bike. The team was formed, and the prototype was developed before the entrepreneurship class from a project under the Undergraduate Research Opportunity Program (UROP). After their campaign was launched online, the students were approached by an Italian industrial designer for potential collaboration to improve the industrial design of the bike prototype and was approached by a British distributor for a partnership to distribute the bikes to Europe. In addition, the team received a purchase order of ~30 units from an American online shop of last-mile mobility devices. The students professionally responded and negotiated with these potential collaborators, partners and stakeholders. FOM was also reported on by various media and invited to attend maker fairs (including Rome Maker Fair in Italy) and innovation events. These engagements and learning prepared the team for later winning an award of $30,000 at a local design & business competition and a grant from SUTD Entrepreneurship Center to incorporate and develop a company. The campaign allowed the students to increase their empathy toward users, development partners, distributors, retailers, media and investors.

The *Mobearlize* team in the 2016 class designed a retrofit device to electrify and motorize a regular wheel chair in their earlier extracurricular design project before the entrepreneurship class. The team purposefully set a humble funding goal and planned to deliver custom-made devices to a small quantity of early adopters, because they learned about the impossibility to mass manufacture their product within 6 months during their Shenzhen trip. The team successfully achieved their funding goal of $5,000 on Kickstarter.com. Among the 6 backers, one is from the United States. The campaign was discovered by a local company, which did not back the campaign online but contacted the Mobearlize team to collaborate and codevelop 50-200 units for an existing group of customers locally in Singapore. Without the crowdfunding campaign, the team would not have been able to

link with the development partner and the lead to customers. One of the venture capitalists attending the final pitch and demo session also liked the project and team; he subsequently became an advisor of Mobearlize. With these steps arising from the campaign, Mobearlize won an award of SG$50,000 from the Create4Good Design Challenge. The company was incorporated and continued to develop the product within the SUTD incubator. In this case, the campaign experience provides students empathy toward users, manufacturers, partners, investors and media.

The *Patch* team designed a smart watch strap for analogue watches in the 2016 class. The team conceived the idea with the first few weeks into the semester and worked on the prototype for approximately one month. The team's company raised SG$29,644 from 106 backers on Kickstarter.com, with SG$18,000 raised in the first week of the campaign. However, Patch's project was ultimately not launched, because they set the funding goal excessively high at SG$50,000. Indeed, the team negotiated with two manufacturers in China and one in Singapore for a minimum order quantity production of SG$30,000, which is close to the amount they eventually raised on Kickstarter. The team learnt that, if the initial funding goal was set lower and achieved earlier, they could have attracted wider press coverage and publicity and thus more backers. The mainstream media refused to publicize the project when the team contacted them because the funding goal was not achieved, although a few online forums and blogs on smart wearable covered the Patch project. One of the team members later joined SPRING (Singapore government's agency supporting startups) after graduation. The team considered their learning experience to be successful, despite an unsuccessful campaign. In this case, the students developed empathy with users, manufacturers, development partners, and media.

The *NU Interactions* team in the 2017 class only began ideation after the semester began. The team explored many ideas, and the eventual idea of a physical emoji and interactive communication device (called Nomi) was inspired from the brainstorming sessions with the Head of Design of the Hax Hardware Accelerator (based in Shenzhen) visiting our entrepreneurship class as a mentor in week 3 of the semester. The team developed various prototypes rapidly and ran many user tests before the campaign launch in week 10. For instance, the team showcased the prototype at a local maker product shop to obtain feedback from consumers; they also pitched the project at Hax in Shenzhen to obtain feedback from other Internet-of-Things (IoT) entrepreneurs. The team seriously negotiated with manufacturers in Shenzhen and Singapore before setting the funding goal. With such exploration, the team decided to set a low goal and deliver 3D-printed maker products to crowdfunders. The campaign was successfully funded with $5,176 from 80 backers. The funding raised was not insufficient for later production and global delivery. However, the successful campaign garnered SUTD-MIT International Design Center's financial and technical support for the team to further refine their design, fabricate and deliver the products to crowdfunders from various countries. The campaign experience allowed the students to increase empathy with early adopters, development and manufacturing partners, suppliers, retailer, media, funding agencies, and investors.

The *PlusBoard* team in the 2017 class designed an integrated multifunctional breadboard for the ease of electronics prototyping; they targeted makers. The team brainstormed for approximately 6 weeks into the semester and delayed prototyping. However, the team managed to develop a high-quality prototype one week before the campaign launch. PlusBoard raised $10,008 from 275 backers, which was more than their funding goal of $8,000. In particular, the team found that the crowdfunders were primarily from the U.S. From the Kickstarter dashboard, they discovered that many backers were directed from online maker forums. Therefore, the team further conducted aggressive online marketing on these forums, in addition to offline marketing at local maker communities and technical schools. Despite a successful campaign, the team cancelled it because the funding was insufficient for the delivery to 275 backers from all over the world. The team purposely set a low funding goal to be fully funded quickly and to use that status for viral marketing. Despite failing to raise sufficient funding for delivery, the team had intensive interactions and learning about potential users, manufacturing partners, marketers, and media.

In the following section, we summarize the general findings from the observations of all 38 campaigns in the Entrepreneurship course offered in 2015 to 2017.

General Findings on Student Learning

1) Increased Practicality of Prototypes

The first finding is that all teams were actually able to develop a working prototype (i.e., minimum viable product) that meets the prototype quality requirement of Kickstarter within only 6~8 weeks of time for product development. Kickstarter rejects campaign submissions without fully functional prototypes. When the crowdfunding campaign was not required in the entrepreneurship class in 2014, only 2 of 11 teams developed functional prototypes, whereas the others remained with ideation and imaginative planning throughout the semester. This finding suggests that the crowdfunding campaign-based projects increase the practicality of learning about engineering design and prototyping under time and resource constraints. Thus, the class contributes to the 4-D design centric curriculum, particularly for learning engineering design in the context of entrepreneurship.

The crowdfunding campaign-based pedagogy also benefited from the 4-D design curriculum, the design culture and the systematic prototyping support available at SUTD as a design-centric university. At SUTD, students entering the entrepreneurship course have previously been prepared with various prior design projects and prototypes, rapid prototyping skills, familiarity with equipment, and 24/7 access to the fab labs, which, in turn, enable them to rapidly prototype and turn ideas into minimum viable products. Without these factors, the crowdfunding-based pedagogy that requires a functional prototype in 6 to 8 weeks would be impractical.

2) Increased Practical Interactions with Stakeholders

The second common finding is that all teams discovered and interacted more or less with early adopters that are crowdfunders from all over the world, and with many local and international, online and offline media presses, distributors, and retailers to and promote their campaigns and market their innovations. The students all had realistic negotiations with manufacturing companies for price quotes for different production volumes. Representatives from all teams visited Shenzhen, China. The companies in Shenzhen shared practical business information with our students because they knew our students would launch crowdfunding

campaigns; thus, they treated our students as potential clients if the campaigns are successfully funded.

The fact that students are developing crowdfunding campaigns also incentivized local entrepreneurs and venture capitalists to come to the classes, share their experiences and insights, and advise the campaign projects. Such engagements, in turn, offer real-world learning to our students. In the past 3 years, approximately 100 entrepreneurs, venture capitalists, design and manufacturing experts visited our classes at SUTD, not for a "guest speech" but for practical engagement with our students' crowdfunding campaigns. In contrast, in the entrepreneurship class in 2014 when the crowdfunding campaign was not used, the students had no practical interaction with the actual external stakeholders of their entrepreneurship projects.

3) Increased Entrepreneurial Career Intention

In addition, we also found clear shifts in students' career intentions toward entrepreneurship before and after the learning experience, based on a repeated survey in the classes of 2016 and 2017. At both the beginning and end of the 14-week course, we asked the students to choose one of the four career intentions listed in Table 1. The results reveal an obvious increase in the interest for a more entrepreneurial career after taking the entrepreneurship course. Furthermore, of the total 38 projects and teams in the classes in 2015-2017, 9 (32%) grew into real startups and incorporated companies after graduation. Crowdfunding campaigns may have intensified the learning and accelerated the maturation of students' venture projects and thus prepared them for a startup career after graduation.

Table 1. Career Intention Survey Results

Career Intention	Year 2016 (66 Students)		Year 2017 (57 Students)	
	Before Semester	After Semester	Before Semester	After Semester
A) Definitely plan to start a new venture upon graduation	5%	19%	10%	11%
B) Considering starting a new venture	31%	42%	24%	29%
C) May start a new venture later on after gaining experience in an established organization	27%	34%	57%	50%
D) Do not foresee being an entrepreneur	37%	5%	9%	11%

In sum, via crowdfunding campaigns, all teams discovered crowdfunders and early adopters from all over the world and interacted with them for feedback and suggestions. In the SUTD entrepreneurship course, most teams practically interacted with suppliers, development and manufacturing partners, marketers and media. Some teams attracted venture capital investors and relevant government bodies for support or collaboration. In contrast, the projects in traditional engineering design courses often only involve the instructors or are only exhibited on campus. Such experiences allowed the students to develop systematic empathy with the real-world stakeholders of the entrepreneurship process (as summarized in Fig. 8).

It is also noteworthy that many of the student teams experienced significant positive cash flows; this is attributed to the pledges of their early adopters. Such an experience contrasts with those of students in traditional engineering design courses who only manage a prototyping budget of a few hundred dollars and do not have real users and payments. In traditional business school courses, students often analyze imagined cash flows and have no opportunity to experience real sales to users.

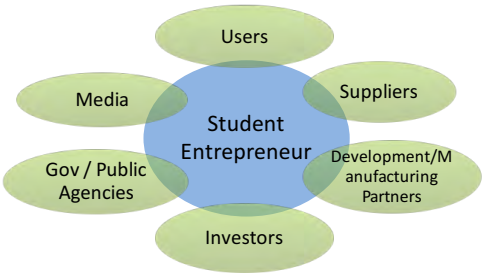


Figure 8. Stakeholder Discovery and Engagement

Combined, such practical, social-technical, intensive, and global exposure and stakeholder-engaged experiences allow the students to develop systematic understanding of the entrepreneurship process. This experience would be impossible for university students, without using the crowdfunding campaign as the entrepreneurship course project. Such learning experience may have increased the intention of students toward an entrepreneurial career.

The Support Ecosystem

The effective experiential learning via the crowdfunding campaign requires multifaceted support and engagements. Through the continual efforts of the students and faculty in the entrepreneurship classes in the past three years, a design, manufacturing and business support ecosystem has emerged around the course. Fig. 9 summarizes the key elements of the crowdfunding-based experiential learning support ecosystem.

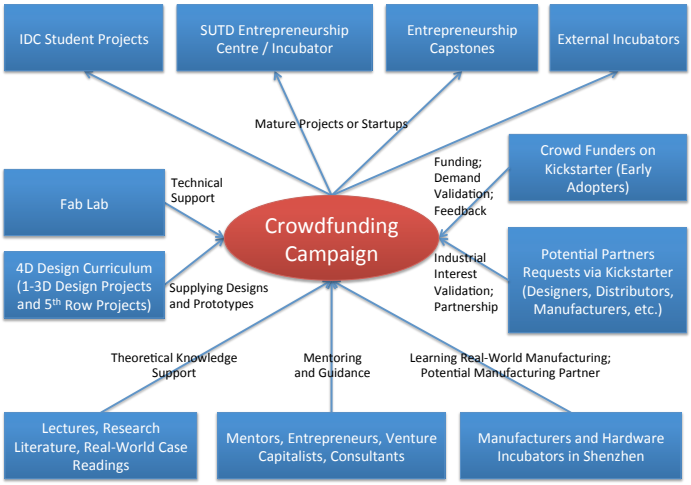


Figure 9. The Ecosystem to Support Crowdfunding Campaigns for Experiential Learning of Technology Entrepreneurship

For example, the 4-D design curriculum and fab labs at SUTD supplied the design projects, relevant skills and technical support for product development and rapid prototyping for a crowdfunding campaign as part of a semester-long academic course. A crowd of external entrepreneurs (including those who had crowdfunding experiences), venture capitalists, prototyping and manufacturing companies (including those in Shenzhen) is

engaged. The practicality of our students' crowdfunding campaigns intrigued the external parties to interact with our students. Consequently, our students learn more. The mentoring-learning relationships have been continuing informally after the classes. SUTD-MIT International Design Centre, SUTD Entrepreneurship Centre and external incubators have provided continued support to some of the projects rolling out of the Entrepreneurship course after it ends in 14 weeks.

In addition, we have built a website, http://www.tech-entrepreneurship.com, to document various activities, mentors and guests, and project information from the classes in recent years. In particular, the website deposits all the crowdfunding campaigns from past years, as well as the crowdfunding campaigns launched by the involved entrepreneurs, mentors and collaborators of the Entrepreneurship course. Because the campaigns will be permanent on Kickstarter.com or Indiegogo.com, the expanding collection of campaigns collected on the course website will serve as a growing design repository and precedent database to support the learning of students in future classes.

CONCLUDING REMARKS

In the paper, we demonstrate the use of online crowdfunding campaigns as a pedagogical approach to intensify the experiential learning of technology entrepreneurship in a formal academic course. The crowdfunding campaign-based course project is expected to provide a practical context for students to experience and learn the social-technical, global, uncertain and resource-constrained entrepreneurship process, which traditional engineering design pedagogies do not offer. This paper contributes to engineering design education and learning in the context of entrepreneurship.

Our experiments in the entrepreneurship course at SUTD from 2015 to 2017 have shown evidence of the increased practicality of the designs and prototypes, and the global engagement of students' projects with the design, manufacturing, business and government stakeholders increased the students' career intention toward entrepreneurship. We hope this paper and our preliminary findings can be viewed as an invitation for the university-based technology entrepreneurship courses around the world to adopt the crowdfunding-based pedagogical approach for experiential learning.

However, a few factors may condition its effective implementation.

1) Knowledge foundations on the phenomenon and benefits of reward-based crowdfunding and rigorous understanding of crowdfunding strategies, tactics and success factors for campaign development;
2) A local design and prototyping support ecosystem, such as the 4-D design-centric curriculum, fab labs, design expertise and culture at SUTD, is crucial for the high caliber product development required by crowdfunding platforms and the rapid prototyping in 6-8 weeks required by the regular course schedule;
3) Seamless connections and engagement with a crowd of product realization companies and low-volume-high-mix manufacturers; and
4) A supporting local community of crowdfunding practitioners, marketers, entrepreneurs, and venture capitalists.

In conclusion, our proposition on the pedagogy and the enabling factors needs to be further tested via formal structured education research. Controlled experiments and quantitative data collected in future classes may allow us to develop a more nuanced understanding and ideas for a pedagogical evolution in such courses and curricula.

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