Technology and Innovation, Vol. 22, pp. 41-54, 2021
Printed in the USA.

ISSN 1949-8241 • E-ISSN 1949-825X
http://dx.doi.org/10.21300/21.4.2021.5
www.technologyandinnovation.org

LESSONS LEARNED: RESEARCH BENEFITS AND BEYOND ASSOCIATED WITH PARTICIPATING IN THE NSF I-CORPS™ CUSTOMER DISCOVERY PROGRAM

Lisa Bosman and Jose Garcia-Bravo

Purdue Polytechnic Institute, Purdue University, West Lafayette, IN, USA

The purpose of this study is to communicate lessons learned and benefits (which go beyond assessing commercial viability) from faculty principal investigator participation in the National Science Foundation (NSF) Innovation Corps (I-Corps™) Customer Discovery National Teams Program. The NSF I-Corps Customer Discovery National Teams Program markets itself as a program that "prepares scientists and engineers to extend their focus beyond the university laboratory and accelerates the economic and societal benefits of NSF-funded, basic-research projects that are ready to move toward commercialization." However, there is so much more to be gained by program participants. Unfortunately, researchers wouldn't know this unless they personally participated in the program or received insights from someone who has completed the program. This study aims to respond to the following research question: How does participation in the NSF I-Corps Customer Discovery Program benefit faculty principal investigators? This study integrates both secondary data, using VentureWell's data file and code book, which was developed as an assessment tool for the NSF I-Corps National Teams Program, and autoethnography, whereby the authors use a qualitative research approach to self-reflect upon their own experiences conducting customer discovery on energy-focused technologies. Findings show there is much to be gained by program participants, including improvements in overall career success attributes, such as learning, mentoring, and research capabilities. In addition, the results show faculty researchers how they can recreate the process on their own.

Key words: Authentic learning; Ethnography; Interviews; Experiential learning; Entrepreneurship education; Training

INTRODUCTION

Energy generation and distribution methods have been evolving rapidly over the last few years. Current research and innovation efforts have explored energy storage, alternative energy conversion methods, micro-grids and artificial intelligence, energy blockchain and the internet of things, and cybersecurity for critical grid infrastructure and optimization, to name a few.

However, in industry, new product development, marketing research, and project management tend to work differently than they do in academia. CEOs, project managers, and design leads are less concerned with how new theories or data analysis techniques can be applied and where good ideas come from and, instead, are more concerned with the effective implementation of new product development efforts. This means that the successful discovery, evaluation, and

Accepted: March 1, 2021.
Address correspondence to Lisa Bosman, Purdue Polytechnic, Institute 401 N. Grant St. West Lafayette, IN 47907, USA. Tel: +1 (765)-496-0267. Email: lbosman@purdue.edu

exploitation of opportunities in industrial settings require a more collaborative and convergent approach to research and development than in academia. The National Science Foundation (NSF) Innovation Corps (I-Corps™) program provides just that environment.

The NSF I-Corps Customer Discovery Program offers two major types of learning experiences: the NSF I-Corps Sites Program and the NSF I-Corps National Teams Program. The NSF I- Corps Sites Program is a five-week course offered through an approved U.S. academic institution (there are about 100 throughout the U.S.). Participating teams (typically groups of two to three faculty and/or students) gain knowledge to take the first step in understanding the industry and whether or not the research technology is able to address an industry-validated need. Teams typically receive $2,400 to cover travel costs (e.g., local travel and/or entrance to a tradeshow) associated with interviewing a minimum of 35 potential industry customers. The NSF I-Corps National Teams Program is a seven-week intensive, immersive, and real-world learning experience where the participating team (typically including a faculty researcher, student, and industry mentor) join a cohort of 20 to 30 teams to explore the commercial potential of the research technology. Teams receive $50,000 to cover travel costs associated with interviewing a minimum of 100 people, including potential customers, partners, and competitors. In both programs, the goal is to determine if the research idea is actually desired by industry and to assess the associated commercial potential by considering the various components of the business model canvas.

In this paper, two faculty, both engineering assistant professors within the Purdue Polytechnic Institute (formerly, Purdue University's College of Technology), provide lessons learned related to their participation in the NSF I-Corps Customer Discovery National Teams Program. Both faculty members participated in the Summer 2019 Midwest cohort. The guiding research question is as follows: How does participation in the NSF I-Corps Customer Discover program benefit faculty principal investigators?

BACKGROUND

History and Motivation for the NSF I-Corps National Teams Program

The I-Corps program was launched by the NSF in 2011 with the mission of translating academic research to the marketplace. More than 1,450 teams have participated in the program, including members from over 230 universities. As a result, more than 600 start-up businesses have been created and close to $210 million has been raised from private investors. Over its eight years of existence, the I-Corps program has provided an accelerated path to commercialization for worthwhile business propositions and educated entrepreneurs about the existing sources of funding to pursue their ideas. One such path to commercialization is through NSF, in particular with the Partnerships for Innovation (PFI), Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR) programs, which will be discussed below.

Starting with either participation at a local I-Corps site or through an existing NSF-funded project, an entrepreneur becomes eligible to participate in the NSF I-Corps National Teams program. Upon completion of the program, a team can use the results to make an informed decision about continuing to pursue commercialization and may choose to solicit a grant from the NSF's PFI program to help translate research and technology developed in a lab into a viable commercial product. Two tracks exist under the PFI program: 1) technology transfer and 2) research partnerships. The end goal for each path is the same—to move the discovery or technology from the laboratory to the marketplace. However, each individual path addresses the specific needs of the product or process before it can be commercialized. In the technology transfer track, funds are given to a team to develop prototypes or a conceptual demonstration for the technology, while in the research partnerships track, the goal is similar but aims at the creation of a team between academic researchers and third-party organizations.

Lastly, the SBIR and the STTR programs are congressionally mandated programs intended to spur innovation and help create businesses and jobs in the U.S. Figure 1 depicts a possible path for attaining federal funds from an initial research discovery, technology, or idea. It is important to note that researchers can bypass participating in the local site program if they have NSF lineage.

Upon completion of the NSF I-Corps National Teams Program, program participants are informed

Figure 1. The federal funding path for entrepreneurs.

of these potential paths to commercialization for beginner entrepreneurs.

NSF I-Corps Assessment Literature

The literature has several manuscripts assessing and evaluating the NSF I-Corps program. Huang-Saad, Fay, and Sheridan (1) published an article explaining the growth of the University of Michigan's (one of the first two NSF I-Corps Nodes funded) entrepreneurial ecosystem. The article concludes with lessons learned and provides a summary of recommendations for administrators and policy makers to increase entrepreneurial initiatives at universities throughout the U.S. Swamidas (2) conducted case study research to compare and contrast the successful commercialization and start-up policies associated with three universities (Massachusetts Institute of Technology, University of Colorado, and Auburn). The research concludes with policy recommendations for a university's Office of Technology Transfer (OTT), including a focus on pre-license seed funds, increasing skillsets of OTT staff, deploying a process to for early evaluation of start-up potential, and leveraging the NSF I-Corps program to establish pre-license training. Youtie and Shapira (3) completed a study to better understand pubic values and perspectives. Using the context of nanotechnology, the study assesses the role of public opinion on nanotechnology commercialization. Specifically, the study explores public views related to potential nanotechnology risks, such as environmental, health, and safety, and the influence those views have on the rapid commercialization process. Smith et al. (4) wrote a manuscript providing an overview and assessment of the NSF I-Corps L program, which focuses on learning technologies for educational initiatives. The authors conclude by persuasively arguing the potential for I-Corps L to drive science, technology, engineering, and mathematics (STEM) education transformation by sustaining and scaling NSF-funded education research centered ideas. Bozeman and Youtie (5) evaluated the societal outcomes associated with NSF-funded efforts. In particular, the research offered a case study comparing four NSF-funded programs, one of which was the NSF I-Corp program, assessing the socio-economic impacts of the research. With respect to the NSF I-Corps program, the researchers highlight two main criticisms. First, I-Corps tends to equate economic impacts with social impacts but fails to consider or assess uncontrollable factors in the economy, such as delays, supply chain influences, and regulatory changes. Second, the I-Corps perspective of equating economic impacts with social impacts is narrow and fails to consider other potential broader impacts, such as quality of life, environmental benefits, and safety impacts to name a few examples. Finally, Duval-Couetil, Huang-Saad, and Wheadon (6) conducted a study using the four-level Kirkpatrick Model to assess faculty experiences with the NSF I-Corps program. The researchers interviewed 26 faculty working at three large public research institutions. Among other takeaways, they highlighted faculty behavioral changes related to research and teaching as a result of participating in the program. The paper concluded with recommendations for I-Corps program administrators to enhance its value for future faculty participants related to broadening participating, post-participation support, time commitment, and improvements to the I-Corps assessment process.

The previously mentioned literature provides a great foundation for understanding the NSF I-Corps process and its implications for university administrators, policy makers, STEM education researchers, and the general public. Yet, Duval-Couetil, Huang-Saad, and Wheadon (6) are the first researchers (to the best of our knowledge) to focus on better understanding the experiences and perspectives of faculty participants. However, the researchers focus more on generalizability then providing the rich context, deep understanding, and specific nuances associated with autoethnography and personal narrative. Thus, the purpose of this study is to qualitatively go deeper into two faculty participant experiences while offering quantitative generalizability by considering the experiences of all faculty participants through the VentureWell dataset by considering the guiding research question: How does participation in the NSF I-Corps Customer Discovery program benefit academic faculty principal investigators?

METHOD

Data Collection and Analysis

This study uses a mixed-methods approach including quantitative and qualitative data collection and analysis. First, the quantitative data incorporates VentureWell's data file and code book developed as an assessment tool for the NSF I-Corps National Teams Program (7). This secondary data source provides a cumulative summary of pre- and post-survey data collected by program participants. Additional details about the VentureWell data set are provided in the next section.

Second, the qualitative data employs autoethnography, a type of author self-reflection, to explore anecdotal and personal experiences (8,9). In this study, the authors apply autoethnography, taking into consideration their own personal experiences participating in the NSF I-Corps National Teams Program and the resulting outcomes stemming from participation in the program. Using a collaborative autoethnographic approach allowed the two participants reported in this study to discuss their experience, coming together to make sense of their situation, context, and experiences.

VentureWell, a nonprofit organization with a mission to drive innovation on university campuses, is the third-party evaluator charged with assessing the NSF I-Corps National Teams Program. VentureWell provides an assessment related to both immediate outcomes and long-term impact (by considering outcomes from the program's start in 2011). VentureWell cleans, analyzes, and formats the data to allow program participants, administrators, and evaluators to 1) identify areas for improvement, 2) determine how to better assist participants, and 3) better understand which factors influence the commercialization of academic research (1).

Participants complete three evaluations: 1) pre-course, 2) post-course, and 3) longitudinal outcomes. All three surveys take a mixed-methods approach, using both quantitative and qualitative questions. The pre-course survey is administered prior to the seven-week intensive program and takes about five minutes to complete. It includes questions related to team demographics (e.g., quantity of time working together, type of technology, etc.), prior knowledge related to course content, and program expectations. The post-course survey is administered on the final day of the seven-week intensive program and takes about twelve minutes to complete. Questions focus on knowledge gains, program satisfaction, post-program intentions, and program accomplishments. The longitudinal outcomes survey is administered every year in the fall and includes all participants who have previously participated in the seven-week intensive program. Longitudinal questions include commercialization-related questions (e.g., legal business creation, quantity of employees, financing obtained, licensing established, and revenue earned) and individual questions (e.g., program influence on career, utilization of knowledge, new collaboration development, and entrepreneurial-focused curriculum development).

Full survey details can be found in *Impact of NSF's I-Corps™ National Program on ndividual Participants* (Release 2.1) (7).

NSF I-Corps National Teams Program Design and Intervention

The NSF I-Corps National Teams Program has three key components that run in parallel (Figure 2): 1) viewing Steve Blank videos, 2) conducting interviews, and 3) summarizing findings and obtaining feedback. For the purpose of accountability and tracking, all components are hosted and accessed using Launchpad Central, an online portal that can be thought of as a learning management system (for the purpose of this paper).

For the first component, knowledge transfer is gained through watching the entertaining and interactive Steve Blank videos. Steve Blank, who is widely recognized for creating the Lean Sartup movement, teaches at Stanford and is the author of several books, including *The Startup Owner's Manual*. In the videos, Steve Blank provides an introduction to the business model canvas, the primary tool used for documenting the nine key descriptors of a start-up or any well-run company, going into details about how to hypothesize, measure, and validate each of the descriptors. For the purpose of accountability and tracking, the videos need to be watched using the Launchpad Central portal. However, fortunately, the videos can be watched for free through Udacity's massive open online course, How to Build a Startup.

The next step is the interviews. Over the course of the seven-week NSF I-Corps National Teams Program, a minimum of 100 interviews must be conducted. The goal of interviewing, a qualitative approach, is to obtain saturation; this occurs when additional interviews no longer provide any new insights. Anecdotal evidence suggests this takes a minimum of 100 interviews. This way, even if saturation isn't obtained, completing 100 interviews increases the likelihood that participants will begin to see a path and potentially realize they've reached the tip of the interview and information iceberg. The first week of the program requires a minimum of ten interviews (for participants to get their feet wet), and then every week thereafter requires a minimum of 15 interviews. The interview information is logged and stored using the Launchpad Central portal.

The third key component is to summarize findings and obtain feedback. Each week, the team comes together to summarize findings with respect to the learning goal (and videos watched) for that week. The team creates a PowerPoint presentation that reflects on the key takeaways and next steps for moving forward. This is done virtually in a group setting with multiple teams so that constructive feedback can be offered and obtained by other teams in addition to the instructors. During the final week, each team is required to reflect back on the entire seven-week process. This more cumulative approach allows the teams to see from a "big picture" perspective how far they've come in such a small amount of time.

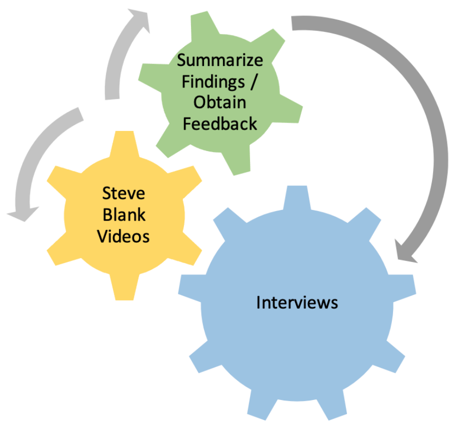

Figure 2. The three key components of the NSF I-Corps National Teams Program.

METHOD APPLICATIONS

The two cases presented in this section are exemplary and display two possible outcomes of the participation in the program. In one example, the participating team decided to continue its path to commercialization after conducting and analyzing the results of the 100+ interviews. The second team decided to revise its value proposition and the nature of its business after reviewing the data. In both cases, the procedure was the same. The teams needed to conduct more than 100 interviews and decide if the proposed business was worth pursuing. This section describes the nature of the proposed businesses. Although the technical details are less important, the purpose of providing an overview of the two research technologies is to offer readers context for better understanding the results.

Research Technology #1: Solar Swami Customer Discovery Hypothesis

Small-to medium-sized solar energy system owners need a predictive maintenance and quality assurance monitoring tool to minimize electricity generation downtime and expedite time to warranty claim.

Problem Identification

Within the U.S. solar energy industry, there is a general motto of "set it and forget it" with solar energy. This notion is derived from much of the research and reliability studies around the photo-voltaic (PV) panels themselves and not necessarily based on the PV system as a whole (including the inverter and other components). Yet, many things can go wrong to cause the actual performance to deviate from the expected performance (10-13). First, design and/or installation could be flawed. Second, the life expectancy for each component varies. PV arrays are typically warrantied at 20 to 25 years, inverters (which convert electricity from DC to AC) are typically warrantied at five to 10 years, and batteries are typically warranted for one to two years. However, exact optimal component replacement times vary with every system due to variance in degradation. Third, if an individual cell gets damaged, the power output and efficiency of the entire system lowers. Unfortunately, without taking continuous weather and power readings, it is difficult to assess issues with the naked eye. In summary, it is important for all of the PV cells and components to work together to maximize solar energy generation. If failures and/or unanticipated degradation issues go undetected, this will lead to loss of energy generation (and associated electricity credits) and/or potential loss of component warranty due to time or manufacturer turnover.

Current Approaches to Problem

There are three main approaches to the problem. First, a small percentage of PV system owners decide to pay extra for individual-level component monitoring up front. For example, Enphase Enlighten monitors the output of their microinverters. In addition, SMA Sunny Portal monitors the output of their central inverters and add-on weather sensors (when purchased and installed separately). These online portals allow solar energy system homeowners real-time access to energy production. Second, another smaller percentage of PV system owners might invest in a maintenance plan or contact an installer as needed if they sense an issue exists. In either case, the installer/electrician will conduct a manual diagnostic on the individual components, which costs an average of $500 per visit. The electrician will likely conduct this data collection and analysis on a sunny afternoon to avoid drastic changes in incoming solar irradiation (which could further limit the accuracy of the results). Finally, the large majority of PV system owners do nothing. This choice is taken under the guidance of installers and researchers alike and assumes that a lack of combustion, fuel consumption, or moveable parts should result in minimal maintenance costs (17).

Gaps in Current Approaches

In all three cases mentioned above, gaps exist. With respect to individual-level component monitoring, there are three major downfalls. First, monitoring occurs at the individual component level and not at the system level. The second downfall is that the individual component monitoring is limited to production outcomes and not necessarily warranty outcomes (actual vs. expected). The final downfall is that the individual component manufacturer's number one priority is the success of its own company, which brings bias into the picture. With respect to installer check-ups, there are also three major downfalls. First, real-time data collection is limited. Second, there is no standard process or quality of care for installer check-ups. The final downfall is that the installer's number one priority is the success of their own company, again bringing bias into the evaluation. To make matters worse, there is a shortage of skilled manpower to meet maintenance, inspection, and repair needs (18). With respect to doing nothing, there is only one potential downfall: The PV system may not be operating as intended. By the time the PV system owner figures it out, it could be too late to recoup lost costs.

Proposed Solution

Given the size of the problem and gaps with current solutions, the proposed solution for PV system owners is a third-party, commercially available, system-level PV system predictive maintenance tool to optimize return on investment and minimize time to warranty claim. Figure 3 shows how this product works.

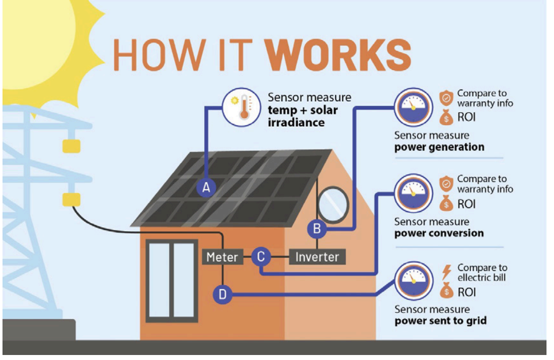

Figure 3. An infographic illustrating how the Solar Swami works.

Research Technology #2: Electro-Hydraulic Hybrid EH2 Customer Discovery Hypothesis

Class 5 and higher vehicles dissipate a large amount of energy during repetitive braking. The proposed technology will lead to the improvement of energy efficiency and reduced maintenance cost in vehicles with high start and stop duty cycles by reusing the energy that would be wasted during braking.

Problem Identification

The adoption of electrical vehicles (EVs) in urban environments must be considered a priority given the increasing amount of tailpipe emissions and the corresponding deterioration of the air quality in major cities such as New York, Beijing, Los Angeles, and Mexico D.F. The efficiency of current EVs and hybrid vehicles is influenced by the entire drivetrain (power electronics, electric motor, mechanical parts, and air/road friction). An EV's capability to recover energy is influenced by the size of the battery pack and the rate at which energy can be converted from kinetic to chemical form. This conversion has two stages: mechanical to electric (motor/generator) and electric to chemical (battery). The second stage, along with the dynamic response of the DC/DC converter, forms a bottleneck that can limit the regeneration capability.

Current Approaches to Problem

Although there is an increasing trend in electrification and hybridization, the traditional original equipment manufacturers (OEMs) are less active in pursuing high-risk activities that would lead to a complete redesign of their powertrains. These OEMs have preferred to optimize systems and components to reduce the risk. Fast charging is a significant challenge in electrification, especially for battery packs serving as energy storage systems. Conventional vehicles using gasoline or diesel spend only a few minutes getting the tank filled, and because of the ease of transporting fuel, users do not worry about the driving range or hours of operation. The battery pack dominates the energy storage system of an EV, but it usually takes six to eight hours to be fully charged, which makes people anxious. Most applications use permanent magnet machines because of the high torque density and efficiency. An induction motor is still being used by some manufacturers. For transportation applications, automotive manufacturers want to increase the DC bus voltage to obtain a low current, which will reduce the losses. High voltage power semiconductor switches or multi-level inverters are used to drive motors. Other options include the flywheel battery as presented by Beaman and Rao (19), where they described the potential usage of a hybrid battery with the flywheel battery energy storage system for an aerospace application to reduce the size of the other components. The flywheel battery has the characteristics of uncertain parameters and nonlinearity. Thus, a combined fuzzy proportional-integral control strategy may be adopted during the charge mode, and during discharge, a slide mode controller could be developed to control the discharge voltage of the flywheel battery due to the characteristics of the variable flywheel speed and load (20). The last alternative is the ultracapacitor regeneration battery, where the battery plus an ultracapacitor conform a hybrid energy storage system, which is the most popular solution for transportation electrification applications. To achieve an acceptable driving range for transportation applications, a high-energy battery system is necessary. However, the advanced battery available often does not allow sufficient power densities to meet the demand of large power pulses at relatively low monetary, volumetric, and weight costs.

Gaps in Current Approaches

Weight is the foremost challenge for an energy storage system. In order to recycle energy from braking and repetitive events, the battery would have to absorb high current peaks. The electronic components and battery have limitations, and the peak current will decrease the usable life of the battery (21). Energy density provides the ability to perform a job for a long time, while power density refers to the rate at which the job is performed. Electric storage in batteries leads to high energy density but low power density. Even though there is much ongoing research and development, high charging rate technology is not mature, and the battery pack cannot absorb a high charging current, which may pose a potential thermal issue or shorten the life cycle. The high temperature in an electric traction drive is also a major challenge. Moreover, limited charging stations and the supporting infrastructure for operation electrification are required, hindering the penetration of such technology. Without a charging standard, it is hard to build and distribute charging stations in a short time. For special vehicles, such as buses or delivery trucks, it is relatively easier to build the infrastructure. They can be arranged at stations or terminals where they make their regular stops, but cost and space are largely an issue for their adoption. Lastly, the end of the lifecycle is also affected by the recycling and disposal provisions that are indispensable for the viability of electricity storage systems, primarily referring to batteries that contain hazardous chemical elements. After thousands of charging and discharging cycles, the battery will degrade and an appropriate disposal method should be used to avoid pollution.

Proposed Solution

The proposed system couples the benefits of a traditional ICE-mechanical [internal combustion engine] or an electro-mechanical drivetrain (Figure 4) with a hydrostatic drivetrain for increased energy efficiency, improved performance, and extended driving range. This concept is fundamentally different from the existing approaches, as it is based on the design of a non-OEM compact kit to hybridize an existing drivetrain for large transportation vehicles used in cities (greater than six tons). This novel method is a radical improvement because it effectively captures larger amounts of kinetic energy from a moving vehicle compared to existing and other proposed methods (electric battery, flywheel, and supercapacitor; see Figure 5).

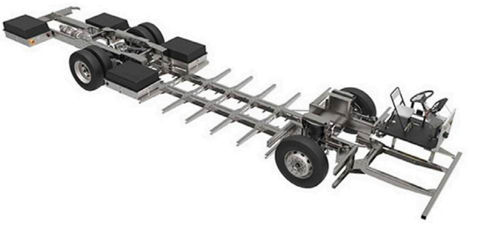

Figure 4. Electric drivetrain for passenger bus by Equipmake (15).

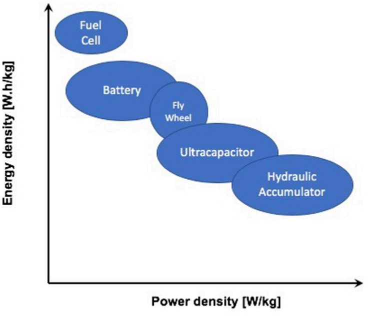

Figure 5. Energy vs. power densities of various storage device (22).

A hydraulic accumulator will be compactly coupled to a hydraulic pump/motor to conform to a regenerative hydrostatic transmission mounted to the front axle of the vehicle. The proposed technology will lead to the improvement of energy efficiency in vehicles with high start and stop duty cycles. The proposed technology has been tested on a scaled-down vehicle solely powered by batteries. The research team's most recent results (21) used a computer simulation of an electric-hydraulic hybrid bus with three hybridization levels. The study evaluated the effect of the accumulator size on battery performance. It was found that utilization of a larger accumulator leads to a large energy storage capacity but also an increase in the required volume for operating in various urban cycles.

RESULTS AND DISCUSSION

Quantitative VentureWell Dataset

This section provides survey questions and responses with key takeaways relevant to providing an overview of the NSF I-Corps National Teams Program experience and outcomes for the participating cohort (Summer #3, 2019).

"Overall, how would you rate the I-Corps course?"

- 5 Excellent = 55.0%
- 4 Very Good = 29.9%
- 3 and below = 15.2%

Key Takeaway: The vast majority of participants (84.9%) rated the course as excellent or very good. This implies credibility for the quality of the program.

"Indicate your level of agreement with the following statements about the current status of your technology and future plans. [I have adequately assessed my technology's readiness for commercialization.]"

- 5 Totally agree = 24.0%
- 4 Agree = 51.8%
- 3 and below = 24.2%

Key Takeaway: Almost three-quarters of participants (75.2%) totally agree or agree that they have adequately assessed readiness for commercialization. This implies that the majority of participants had a clear answer on the potential for commercialization at the end of the program.

"Are you currently pursuing a new venture?"

- Yes = 38.9%
- No = 61.1%

Key Takeaway: The majority of participants are not considering a new venture, primarily because the results of the interviews suggest the potential for commercialization does not yet exist. This could be due to a technology pivot, team makeup, insufficient or limited access to interviewees for conducting customer discovery, or limited self-efficacy of commercialization skills.

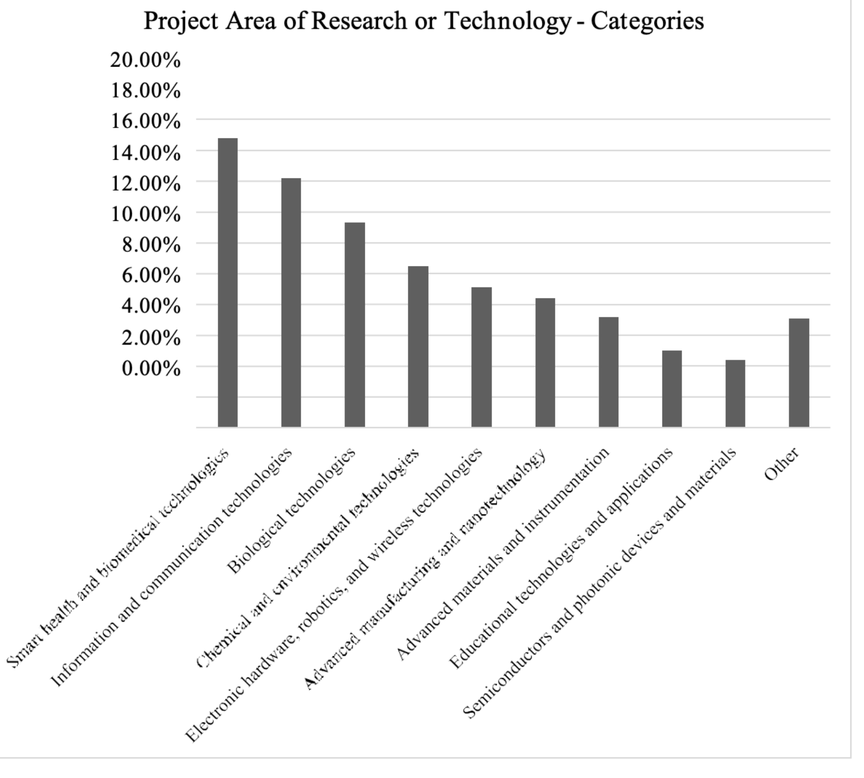

Figure 6. Results from the survey question "At the end of your I_Corps Course, which of the following categories best described your project's are of research or technology?"

"Did the experience with original technology and I-Corps result in spin-offs?"

- Yes = 17.1%
- No = 82.9%

Key Takeaway: For a small minority, participating in the NSF I-Corps program results in a new company or spin-off.

"At the end of your I-Corps Course, which of the following categories best described your project's area of research or technology?" (Figure 6).

Key Takeaway: NSF I-Corps National Teams Program is for everyone regardless of industry or technology focus area.

"Did the I-Corps award lead to any collaborations between the university you are currently affiliated with and the external community?"

- Yes = 30.4%
- No = 57.0%
- Unsure = 12.6%

Key Takeaway: About one-third of the teams participating in the NSF I-Corps program are able to create collaborations with the external community, primarily due to the high quantity of community contacts and networking completed through the 100 interviews.

"After the I-Corps course ended, did you seek any additional funding (e.g., an SBIR award, equity financing from a venture capitalist, state grant, or personal investment)?"

- Yes = 73.7%
- No = 26.3%

Key Takeaway: Whether or not a new spin-off was created or if community collaborations were established, the vast majority of participants applied for additional funding related to the NSF I- Corps project. For some NSF programs, such as SBIR/STTR and PFI Technology Transfer (PFI-TT) or PFI Research Partnerships (PFI-RP), applicants are highly advised to complete the NSF I-Corps program prior to submission.

"Participation in I-Corps influenced my approach to my […]." (Figure 7).

Key Takeaway: Although the NSF I-Corps program markets itself as a program that "prepares scientists and engineers to extend their focus beyond the university laboratory and accelerates the economic and societal benefits of NSF-funded, basic-research projects that are ready to move toward commercialization," there is so much more to be gained by program participants. Participation in the program improves overall career success attributes, including learning, mentoring, and research capabilities.

"How useful is the 'Value Proposition' component of Osterwalder's Business Model Canvas in your current work?"

- 5 Extremely useful = 78.6%
- 4 Useful = 15.6%
- 3 and below = 5.8%

Key Takeaway: The 'Value Proposition' component of the of Osterwalder's Business Model Canvas is the number one reason why a customer should buy a product or service. It encapsulates the perceived and actual value offered to a customer or market segment by a company or organization. It can be argued that the 'Value Proposition' is the most important element of one's marketing message. About 94.2% of participants rated the usefulness of the 'Value Proposition' component as extremely useful or useful. This is promising, as the implications extend beyond research and new technology development to applications within one's personal life as it relates to jobs and value creation.

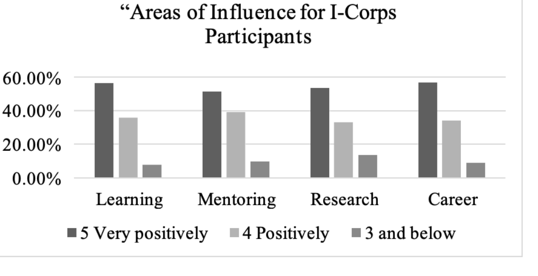

Figure 7. Survey results for the question " Participation in I-Corps influenced my approach to my…?"

Qualitative - Anecdotal Findings and Unexpected Benefits

Research Technology #1: Solar Swami (Go!)

At the end of the seven-week program, Solar Swami was validated as a "Go!" with respect to technology readiness for commercialization. In addition, several benefits came from participating in the program. First, during one of the interviews, the CEO of a state-wide rural electric cooperative umbrella agency advocating on behalf of its 38 members showed great interest in our problem statement and value proposition. He passed along his business card and requested a university-industry collaboration to pilot a prototype and work toward a solution. Second, we found a great example of our problem statement, which, when summarized, can clearly justify the problem and clarify the need for finding a solution (especially when used within a grant proposal). Figure 8 provides an image of bad solar panels and microinverters (placed next to the garbage bin so that they can be removed during the next trash pick-up).

This organization (who wishes to remain anonymous) purchased a 984kW system eight years earlier. Two years ago (six years after the PV system had been installed), a new employee (who we interviewed) was hired to focus on innovation efforts within the company. The young engineer was right out of college and just happened to have some knowledge related to PV systems due to a class project completed. The new employee conducted some basic analysis, estimated the PV system was not working as intended, and proposed hiring an installer to come out and perform an official analysis of the system. Once all of the paperwork was submitted, approvals were granted and the installer was brought on-site. It was determined that 15 panels (and their individual microinverters) were bad. Unfortunately, the original installer and the component manufacturers had gone bankrupt four years earlier, so the warranty claim was no longer an option. The equipment was replaced on the organization's budget at a cost of about $50,000. The organization estimated the panels had been bad for about five years, which resulted in another $5,000 in lost electricity credits.

Figure 8. Example of bad solar panels.

Third, through participating in the program, we learned about additional funding opportunities through networking events, mentors, and other teams within the cohort. Specifically, we learned about additional accelerator start-up programs, such as Argonne National Laboratory's Chain Reaction Innovations (located just outside of Chicago, Illinois, this is first tech incubator targeting energy-focused technology innovations and start-ups), the Clean Energy Trust (a nonprofit seed-investing organization focused on high-impact cleantech start-ups in the Midwest), and Elevate Ventures (a combination venture capital firm and entrepreneurial development agency located in Indianapolis, Indiana). In addition, we learned about additional NSF programs targeted as "lineage" programs to follow the I-Corps program, such as the SBIR and STTR programs and the PFI-TT and PFI-RP programs. Fourth, we were able to learn about other problems and research areas to work on next. While not all interviewees expressed interest and/or validation of our original problem, many brought to our attention other problems they are facing that our team is capable of tackling.

Research Technology #2: Electro-Hydraulic Hybrid EH2 (No Go!)

At the end of the seven-week program, the EH2 value proposition was invalidated and identified as a "No Go!" business model. Although the technology is viable from a technical perspective, the EH2 working team learned that there is no market to commercialize the product. Although this may seem discouraging at first, there was a tremendous amount of benefit that came from participating in the program. As a first lesson, the team learned that hydraulics systems, although very difficult to match in power density, are perceived as noisy, old, and leaky. This means that very few transportation companies are interested in pursuing this technology. More emphasis has been given to electrified powertrains and in other cases to natural gas conversions. The market is set on investing in those two technologies because they can be fitted without major modifications to the existing vehicles. Second, there seems to be a lack of knowledge in the area of hydraulics, and, more interestingly, fuel or energy efficiency is less of a concern for the market segment (urban transportation for Class 6 vehicles, with high duty cycles). Reducing the maintenance costs and projecting a green image seemed to equal or exceed more important factors for the implementation of energy regeneration of these types of vehicles. Third, during the customer discovery process, the team found that a very select fleet of utility vehicles may actually benefit from the use of hydraulic regeneration. Interestingly, this benefit seems to arise from the need to satisfy safety and regulation needs for vehicles using telescopic arms, such as man lifts, bucket trucks, and truck cranes. All of these vehicles are already fitted with hydraulic components and have customers who don't seem to mind the noise and leaks of this technology. On the contrary, they seem to recognize that no other actuation system would work for their applications.

The EH2 is currently focusing its effort on two main fronts: 1) further investigating the telescoping utility vehicles (Figure 9) and 2) improvement of the hydraulic systems to produce a solution that is compact, quiet, and leak-free for expansion into the continuously growing EV segments. More importantly, after participating in the program, the Technical Lead, who is also a professor, has recognized the importance of questioning the intrinsic value of his research products. In other words, he is motivated to challenge his own research agenda to serve a purpose beyond advancing the science in his field and has the intention of making his research products usable by and understandable to non-academics. In summary, this case study team learned about the importance of acknowledging the ubiquity of the existing technology—meaning that customers don't want a great sudden change in their technology—and also how the perception of a technology plays an important role on commercialization. This team had to change their business strategy and target an audience that already accepts and uses the technology (hydraulics). New paths for product implementation were identified thanks to the networking activities carried out during the I-Corps program.

Summary of Benefits (Unexpected and Otherwise)

In summary, the guiding research question was as follows: How does participation in the NSF I-Corps Customer Discover program benefit academic faculty principal investigators? Some unexpectedted benefits of participating in the NSF I-Corps program found are as follows:

- Networking and relationship building for the purpose of seeking mutually beneficial grant or company-sponsored funding
- Understanding the differences of an academically successful product that may or may not be a commercially successful product
- Recognizing and learning how unique aspects of a new product are not easily discovered in an academic environment
- Case examples to be used in proposal descriptions for securing future grant funding
- Opportunity to learn about additional NSF-funding available because of faculty participation in the NSF I-Corps program
- Opportunity to improve research focus based on public and market perceptions

Although not specifically highlighted in the examples, the two faculty participants also benefited by gaining a different perspective on mentoring their graduate students (e.g., entrepreneurial leads) to allow for greater student independence and autonomy while increasing expectations related to public speaking. In addition, the two faculty participants have a greater understanding and appreciation for the term "value proposition" and its implications across

Figure 9. Examples of telescoping utility vehicles.

all three pillars of academia (research, teaching, and service); because of this, they are more intentional when thinking about who determines value and the need to modify your communication of the value proposition depending upon the audience. Finally, the two faculty participants have also made changes to their teaching to incorporate an NSF I-Corps-like experience to include design thinking and customer discovery within the engineering classroom and undergraduate research experience.

CONCLUSIONS

In conclusion, this study aims to respond to the following guiding research question: How does participation in the NSF I-Corps Customer Discovery Program benefit faculty principal investigators?

This study contributes to the body of knowledge in three important ways. First, this study is one of the first studies to provide first-hand experience on participating in and outcomes related to the NSF I-Corps National Teams Program. The NSF I-Corps Customer Discovery National Teams Program markets itself as a program that "prepares scientists and engineers to extend their focus beyond the university laboratory and accelerates the economic and societal benefits of NSF-funded, basic-research projects that are ready to move toward commercialization." However, there is so much more to be gained by program participants. Thus, this study provides an "insider" perspective that can be beneficial to other faculty researchers considering participating in the program. Second, this study shows positive survey outcomes and real-world examples of benefits resulting from participation in the NSF I-Corp National Teams Program. These outcomes go beyond assessing the technology readiness for commercialization to include lessons learned related to mentoring, research focus areas, and additional funding opportunities. Third, it provides the resources and methodology used by the NSF I-Corp National Teams Program, which can be used by faculty instructors and researchers interested in making improvements to their own research agendas to increase focus more toward what customers want rather than what can be designed from an engineering perspective.

Future research and training should consider integrating a similar process (videos + interviews + summary/feedback) into research experiences for undergraduates, classroom projects, capstone and design courses, and even as a pre-requisite for onboarding new graduate research students.

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