Exposure of undergraduate research students to entrepreneurial activities to motivate future research careers

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Introduction

The potential that materials-based solutions hold for global challenges such as in biomaterials, energy, environment and aerospace is undisputed. Therefore, it is imperative to groom undergraduate engineering and science students with a broad-based materials science and engineering back-ground, in order to maintain technological leadership position of developed and developing countries in the 21st century. At Oklahoma State university (OSU), we have established a Research Experiences for Undergraduates (REU) program that is based on the premise that interdisciplinary research training including entrepreneurship is essential for a complete research experience in Materials Science with most of the students coming from a broad background. Our objective was to expose undergraduate scholars to a variety of materials research with applications in energy, aerospace, defense, environment and agriculture. Undergraduate scholars were (1) provided hands-on materials research experience in multidisciplinary engineering projects, (2) introduced to cutting-edge materials characterization methods through a 2-day national workshop on Advanced Materials Characterization webcast for easy access, (3) exposed to entrepreneurial routes to commercializing materials research in collaboration with the School of Entrepreneurship by leveraging the Oklahoma State University's Innovation Corps site program, and, (4) educated students about graduate programs and careers.

This hypothesis was tested by including two students with an innovation and entrepreneurship background with undergraduate scholars performing research and conducting multiple customer discovery interviews to evaluate if the research is needed and if it has commercial potential. It was observed that including entrepreneurial activities such as customer discovery and the Innovation Corps program in the research experience changed the way in which the students viewed the research question. The scholars were more enthusiastic about their research and were able to communicate their findings and goals in a clear fashion at the end of the REU program. Participation in the REU program has resulted in three graduated scholars accepting jobs at start-up companies and two of those scholars to participate in proposal writing activities. Further, several REU scholars have started graduate programs in materials science and engineering nationwide, with two scholars starting their research at OSU and another scholar applying to our graduate program for Fall 2020. One of the significant impacts of this program was in grooming undergraduate engineering and science students to pursue interdisciplinary research with a strong-base in materials science and engineering. We believe that this is critical for developing a workforce to address global grand challenges in energy, aerospace, medicine, environmental sustainability and maintain technological leadership position of developed and developing countries in the 21st century.

Research Experiences for Undergraduates in Materials Science and Engineering program and goals

As indicated above, the REU program at OSU is based on the premise that interdisciplinary research training is essential for a complete research experience in Materials Science. As the

only materials science and engineering program in the state of Oklahoma, the associated research center was established to educate students from the state as well as to help create new enterprises based on the research conducted in our research center. The REU program objective was to expose undergraduate scholars to a variety of materials research with applications in energy, aerospace, defense, environment, health and agriculture with an emphasis on real-world applications and how the research conducted could be assisted in transitioning to the real-world. It was established to increase our exposure to graduate students from non-traditional fields to be recruited into our graduate program in materials science and engineering. This exposure was most important for our program that is just a few years old and to increase the number of domestic students from Oklahoma as well as from neighboring states. Our experience was that only a small number of students with an undergraduate background in materials science and engineering were applying to our graduate program and most applicants were students with an undergraduate background in mechanical, electrical or chemical engineering as well as physics, chemistry and engineering physics. It was believed that the REU program would help to expose our program to motivated students with a good idea about the research that they would be conducting as graduate students. In the first two years of the REU project, even though we observed that the undergraduate research scholars were interested and motivated about the research projects, they had no idea about the applications of those technologies or if they wanted to take these ideas to the market. Further, very few of the REU scholars from the initial years were interested in applying to our graduate program. Therefore, it was decided to revamp and modify our approach to the structure of the REU program during the third year of the project.

REU project student statistics

Students were recruited from colleges and universities (including Langston University, the only Historically Black College/University or HBCU) in Oklahoma and neighboring states that have limited STEM research facilities and large populations of underrepresented minorities. The 2-year and 4-year colleges in Oklahoma do not have research intensive programs, and have a large body of Native American students and were focal to our recruitment efforts. The Louis Stokes Alliances for Minority Participation (LSAMP) Program at OSU also assisted the REU program to recruit students. During the application process, the applicants' academic performance, leadership, and professional interests were evaluated, with particular emphasis on their personal essay rather than their GPA. Ten to eleven undergraduate scholars per year were selected to participate in a nine-week summer program. Preference was given to underrepresented minorities (Native Americans and African-Americans in particular), females, persons with disabilities, and U.S. Armed Services veterans.

A total of thirty-two (32) REU scholars were selected from 116 applicants (76 male, 40 female applicants with a ~28% acceptance rate) in three years between 2016-2018. During the third year, 48 applications were received, eleven REU scholars were selected that also included two REU scholars with an innovation and entrepreneurship background. Their academic backgrounds varied from bio-medical engineering, materials science, mechanical engineering, chemical engineering, chemistry, physics, innovation and entrepreneurship, bioengineering and biotechnology. Approximately 28% of the scholars were underrepresented minority candidates, 28% were female scholars, and 22% were from 2-year colleges. Two graduate students were hired as dedicated mentors during year 3, who happened to be REU scholars from previous

years. The recruiting efforts for the REU program evolved and improved over the three years. More focused recruitment through the LSAMP and one-on-one presentation at various schools in and around Oklahoma, especially with Langston University, the only HBCU in Oklahoma and Tulsa community college with a high Native American population, were two aspects that were identified for future recruitment.

Entrepreneurial activities in the REU project

Oklahoma State university (OSU) currently has an on-going NSF-funded Innovation Corps project, which provides an opportunity to all students with a STEM background to evaluate the commercial potential of their research projects. In these projects, the I-Corps site program encourages the students to form teams of engineering/sciences students with the school of entrepreneurship and school of business and to conduct customer discovery of their technology. OSU has had success in initiating student start-ups based on technologies initiated in the university including our research center by leveraging the I-Corps site program. Since the REU project encourages REU scholars to conduct research in existing projects at our research center under the direction of graduate student mentors, it was believed that leveraging the I-Corps site project and conducting customer discovery as one of the activities of the REU project would make the most sense and assist the REU scholars to understand the commercial potential as well as the product/market fit of their technology. However, since the REU program is designed to be a research-intensive program, in the third year of the REU program, two separate students were recruited from an innovation and entrepreneurship undergraduate program. The qualifications of the scholars who were recruited and their responsibilities is listed in the following section. These students were teamed with two REU scholars each and asked to prepare a business model canvas and conduct the associated customer discovery activities for each of the REU scholar projects. A list of REU projects that the scholars selected to include in the I-Corps program is listed in Table 1, along with their recommendation for their project continuation as a “GO” or “NO GO”. In the case of one project, the REU scholar was also the I-Corps site entrepreneurial lead. The I-Corps site program paid for any necessary customer site visits and customer discovery activities. A detailed case study of one project from year 3 is described for demonstrating the benefits of combining research projects with I-Corps activities. It should be pointed out that the REU program at OSU is one of a few REU programs in the nation with an innovation and entrepreneurship aspect to it.

Table 1. List of selected REU projects included as I-Corps site projects and GO/NO GO decision

#	Project description	I-Corps site student activities	GO/NO GO
1	Bulk metallic glass by Spark Plasma Sintering	Customer interviews, present project to I-Corps teaching team, assist REU student to understand customer needs	NO GO – has limited potential due to sample sizes that can be manufactured
2	Qualification and certification of additively manufactured (AM) parts	Customer interviews, present project to I-Corps teaching team, assist REU student to understand customer needs	GO – has commercial potential

3	Infra-red organic LED high resolution screens	Customer interviews, present project to I-Corps teaching team, conduct research to fabricate devices with high photon-photon efficiencies	GO – has commercial potential
4	Harvest-to-harvest: Novel clay-based adsorbents for poultry litter	Customer interviews, present project to I-Corps teaching team, assist REU student to understand customer needs	GO – has commercial potential

Background of I-Corps site entrepreneurial leads and their career goals

As indicated above, two scholars with an innovation and entrepreneurship major background from Clarkson University in New York was recruited to work with the REU scholars. One of the students had a business and entrepreneurship background, while the second student had a chemical engineering and entrepreneurship background. Clarkson University in NY with an innovation and entrepreneurship major was approached to recruit these students, culminating in a Skype interview with those students. Based on this interview, we were convinced that these students were focused on commercializing innovations in the field of materials science engineering. The students indicated that this internship would allow them to expand their knowledge of commercializing innovation that was being developed in the lab by working with engineers. By working on the REU projects, we became convinced that it would further the interests of these students in engineering and their understanding of how innovations can be advanced into commercialization more rapidly. Both these students had experience in working with clients from different disciplines, helping them to develop their products and bringing them to the market place. This background gave them experience with commercializing innovations from many different disciplines. It was also our goal that this inter-play between innovation, entrepreneurship and research would expand the possibilities for the REU scholars and motivate them to conduct meaningful research.

Customer discovery process

The REU scholar was adopted as the research lead (RL) and the I-Corps site scholar was adopted as the entrepreneurial lead (EL). The REU project is 9-weeks long, while the I-Corps site project is 4 weeks long. During the remaining 5 weeks, the EL studied the research project, identified the potential customer segments, prepared the initial business model canvas and the pitch to the I-Corps site teaching team. The RL was responsible to conduct the research, while the EL was responsible to identify the potential customers and conduct the customer discovery. During each week of the I-Corps site program, the EL presented a 10-minute pitch to the I-Corps site teaching team. The goal was to conduct approximately 30 customer interviews over 4 weeks. The RL also attended these meetings. This pitch consisted of:

- a problem statement,
- the number of interviews conducted during the week with a split between in-person and phone interviews,
- what the research solution was,
- the business model canvas,
- the hypothesis tested in the customer interviews including what problems the customer has,

- whether any changes were required in the research approach based on the customer feedback, and,
- what difficulties were faced by the team in reaching the goal of 8-10 customer interviews per week

The I-Corps site teaching team handles the team in a supportive and encouraging manner, which is helpful in helping the EL and the RL to understand the impact of their research. Even though there is an expectation of at least 10 interviews per week, the teaching team works with the EL and RL in helping them identify additional potential customers in case the team is unable to meet the expectation. In contrast, the I-Corps team program is an extremely intensive and stressful program, with very clear expectations of having to exceed 15 customer interviews per week and compared with other teams.

Projects and associated entrepreneurial activities

Bulk metallic glass by Spark Plasma Sintering: Spark plasma sintering (SPS) is a pressure and electric current assisted sintering technique that is being used to sinter materials ranging from metals, ceramics, and composites [1]. Fully dense compacts can be manufactured by SPS at lower temperatures as compared to other pressure assisted sintering techniques such as hot pressing (HP) and hot isostatic pressing (HIP) [1]. There is considerable interest in developing SPS methods for Fe based amorphous alloy powders in order to utilize their excellent mechanical and electrochemical properties [2]. The REU project was set up to analyze the effect of systematic increase in heating rate on the densification characteristics of a recently developed Fe-based amorphous alloy and to evaluate the commercial potential of the process and the materials. However, due to the requirement of large samples from customers from such alloy compositions and due to the inability of the SPS process to progress beyond 25 mm diameter x 25 mm height samples, the REU student and the I-Corps site student were unable to identify any customer interest in the project. They also could not manage to arrange any customer interviews, due to which the project was not continued as an I-Corps site project, resulting in “NO GO”. This convinced the REU student that it was not sufficient to adopt an interesting research problem but it was necessary to identify commercial potential and applications if the research project had to move forward.

Qualification and certification of additively manufactured (AM) parts: The simulation and qualification of AM parts are essential so that these are accepted by the industry and customers as a valid manufacturing approach. Technical challenges related to materials, equipment, machine/ process variation and application continue to be major factors to be considered in producing quality parts and to establish the predicted lifetime of components under specific conditions based on material properties. The key challenge is that any simulation or prediction methodology is specific to one type of equipment, material or process [3], [4], [5]. The REU scholar fabricated AM parts and measured the micro hardness of the AM parts and correlated the same to the elastic modulus in different directions to predict the performance of such parts under actual service conditions and accounted for the part anisotropy. The REU scholar worked with the EL to identify commercial potential for this approach and conducted customer discovery, with 20 interviews (all over the phone). The customer segments consisted of companies manufacturing additive manufacturing equipment as well as end users in the aerospace and

automotive companies. As indicated in Table 1, customer discovery suggested that this project should be continued, with a "GO" recommendation.

Infra-red organic LED high resolution screens: Near-infrared up-conversion devices have promising applications in imaging, night vision, machine vision systems, and other displays [6]. These devices convert invisible, infrared light into visible light. However, while OLEDs are considered for a low-cost high-resolution and high-contrast displays with a long-life span, there are still performance gaps. In this REU project, the goal was to synthesize organic LED up-conversion devices using various materials and test their efficiencies. Devices with various colors were also synthesized. Various customer segments such as large research universities (with over 20k students), stadiums & arenas, audiovisual integrator companies, advertising agencies, and casinos were identified and contacted during the 4-week program. A total of 37 interviews were conducted, with 17 over the phone, 18 in person and 2 over email. Based on the customer feedback and analysis of the research results, it was decided that the project was a "GO". In this project, the EL and the RL were both the same person, since the EL had a background in chemical engineering. The additional experience of customer discovery assisted the RL in tailoring the research objectives and taught the faculty and graduate student mentor about the commercial potential of this project.

Case Study of the effects of combining REU research activities and I-Corps site customer discovery activities:

Harvest-to-harvest: Novel clay-based adsorbents for poultry litter: The REU students processed and evaluated the efficacy of natural clay-based adsorbents to harvest phosphates and ammonium ions from poultry litter, and explored its application as a fertilizer. Besides turning a waste into a useful product, this waste management solution is expected to help poultry producers reduce the levels of ammonia in chicken farm houses, thereby reducing energy requirements [7], [8], [9]. Additionally, it is also expected to help in mitigating contamination of ground water by inadvertent leaching of these chemicals into the ground when chicken and pig manure is discarded injudiciously. This project was an exciting one for the students first, because of the environmental benefits and second, due to the customer discovery process, they clearly understood the benefits to the customer, who were the chicken and pig farms in the state. A typical chicken farm is shown in Figure 1, while the clay-chicken manure combination is shown in Figure 2. The technical solution was to make natural clay-based adsorbents of various compositions under the guidance of a graduate student, while the entrepreneurship student conducted customer discovery, with special emphasis being placed on not telling the customer about the solution, but rather, finding the customer problem and tailoring the solution to solve the problem. Based on the discussions, the student team was able to determine that it was important to prepare the adsorbents as lightweight discs that could easily be spread inside the farm house. They also discovered that making these adsorbents from a low thermal conductivity natural polymer would enable the adsorbents to keep the heat inside the farm house, which would be important in chicken farm houses in the winter, especially in the northeast.

Figure 1. A typical chicken farm house in the state

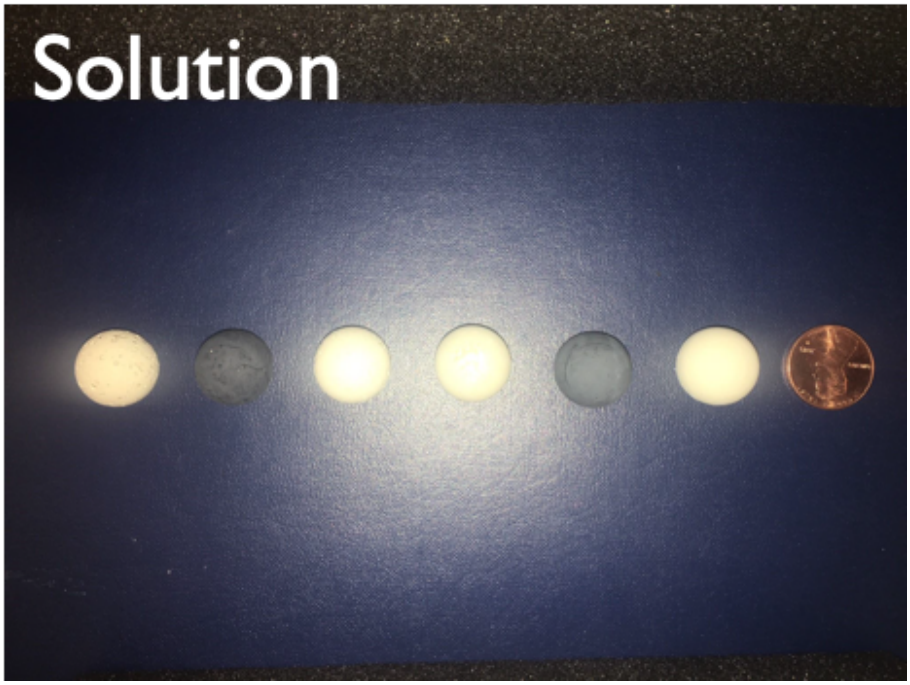

Figure 2. Natural clay-based adsorbents for poultry litter

A preliminary business model canvas was created and constantly modified based on customer interviews. A total of 36 customer interviews (22 phone and 14 in-person) were conducted. The final business model canvas is shown in Figure 3.

<table>
<tr>
<td rowspan="2">Key Partners
• Farmers owning chicken farms
• Companies buying chicken from farmers
• Fertilizer companies that could buy the product</td>
<td>Key Activities
• Complete research
• Define customers wants and needs
• Test the ability of product to remove ammonia and phosphates to acceptable levels</td>
<td rowspan="2">Value Propositions
Growers
• Eliminating ammonia completely would benefit health of chicken
• Reducing ammonia would reduce days between flocks
• Lowering ammonia levels would reduce energy costs
• Improving air quality can improve company image

Corporations
• Increase revenues
• Less risk of damage to chicken feet increasing profits</td>
<td>Customer Relationships
• Get: Teach the companies how the product works
• Keep: requiring them to have to buy new balls after so many flocks
• Becoming a mandatory regulation of the companies
• Grow: referrals to other farms</td>
<td rowspan="2">Customer Segments
• Chicken Farmers
• Specifically commercial broiler farmers
• Broilers for deboning
• Northern farms
• Companies that don’t require farmers to remove litter between every flock
• Farms that use manure as fertilizer to sell
• Turkey Farmers
• Northern Farms</td>
</tr>
<tr>
<td>Key Resources
• Research facilities
• Raw materials needed
• Testing equipment</td>
<td>Channels
• License through a manufacturing agreement
• Sell through corporations</td>
</tr>
<tr>
<td colspan="3">Cost Structure</td>
<td colspan="2">Revenue Streams</td>
</tr>
</table>

Figure 3. Final business model canvas based on customer interviews and hypothesis

A set of hypothesis and conclusions based on the customer interviews are listed below.
Hypothesis #1 – eliminating ammonia completely would benefit the health of the chicken. This hypothesis was not valid, since ammonia only needs to go below 25 ppm, as it was not noticeable below those levels.
Hypothesis #2 – reducing ammonia would reduce days between the changing of the flocks. This hypothesis was valid, as it saves on poultry litter treatment, days between flocks, saves money for farmers, and it reduced the need for companies contracted to clean the farms.
Hypothesis #3 – lowering ammonia levels would reduce energy costs. This hypothesis was valid, as reduced ammonia reduces the use of fans to remove ammonia, which is advantageous in winter, especially in northern states when heating is needed to maintain the temperature.
Hypothesis #4 – improving air quality can improve the company’s image. This hypothesis was not valid, as the customer does not know or care about air quality, and the average product buying customer only cares about if they are grown as cage free birds, whether the chickens are inhumanly slaughtered and if any chemicals or antibiotics are used during their growth.

The customer interviews led to a better understanding of the research problem for all students. It also helped to improve the quality of research and gave students an idea about the needed research and product development direction. Additionally, it provided the graduate student with an understanding of the market and the customer. It has further allowed the current graduate student and the faculty to submit for a patent disclosure for commercialization with the assistance of the technology development center at OSU. The REU scholar's poster at the end of the REU program was selected for presentation at the National Council on Undergraduate Research annual meeting in October of that year. This further has motivated the REU scholar (who is female and African American) to apply to our graduate program for Fall 2020, where she has already been admitted. It is evident that without the entrepreneurship aspects of the project, this REU scholar may not even have considered attending graduate school or our graduate program. With additional funding, we will be able to support the incoming graduate student to continue the work initiated in the REU project. We were also able to attract two other REU scholars to apply to our graduate program, both of them being female and one of them being Native American.

Results from completed project evaluation

Several elements of the REU program design, execution, and impact were evaluated through comprehensive surveys of participants at the onset, midterm, and at the conclusion of the annually. An example of the assessment is presented in the figure below, where knowledge about materials science (Figure 4), knowledge about experimental design (Figure 5), and how to make a research presentation (Figure 6) was evaluated. It was clear that the students had come in with less knowledge about these aspects that are vital for pursuing careers and or academics in the STEM fields. The activities and interactions that the participants experienced during the 9 weeks in the program did influence both their knowledge and skills positively, especially the entrepreneurship aspects during year 3, as these scores were all better in year 3 than in year 1 and 2. It was clear that students grew in these areas based on our interviews with the students. While these results are from a small set of participants (total 32 over the three years) they do provide some insight into areas to improve in future offerings of such a program or how such approaches may be followed at other REU sites. For example, the significant improvement in all three categories in the midterm evaluation of the 2018 program offering was a direct result of introducing two graduate student mentors in the program. These mentors worked with the REU students hands-on, interacted with the scholars for more than at least 20 hours every week, and guided them in all aspects of conducting research.

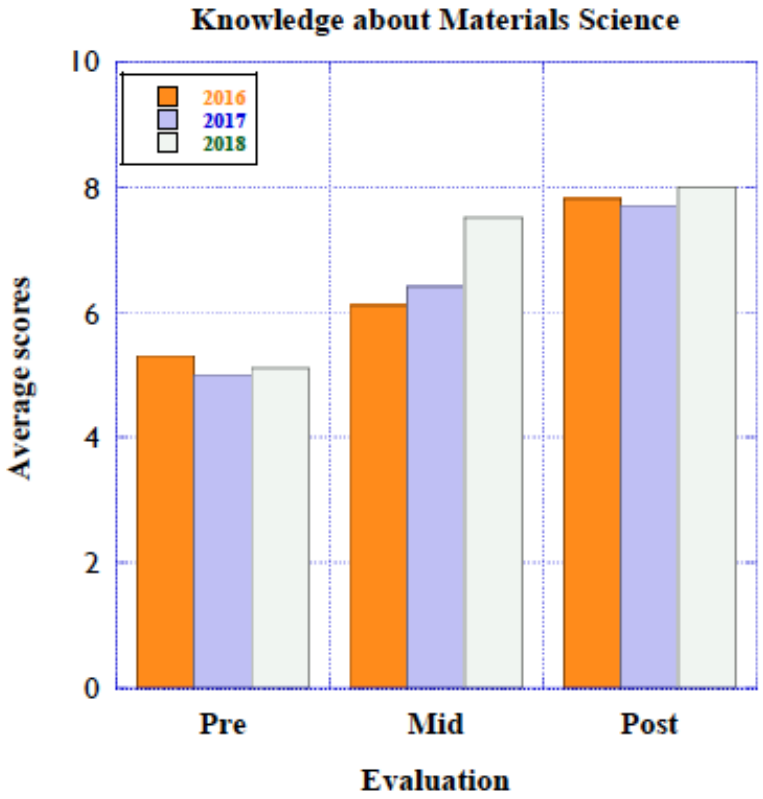

Figure 4. REU Survey results of knowledge about materials science

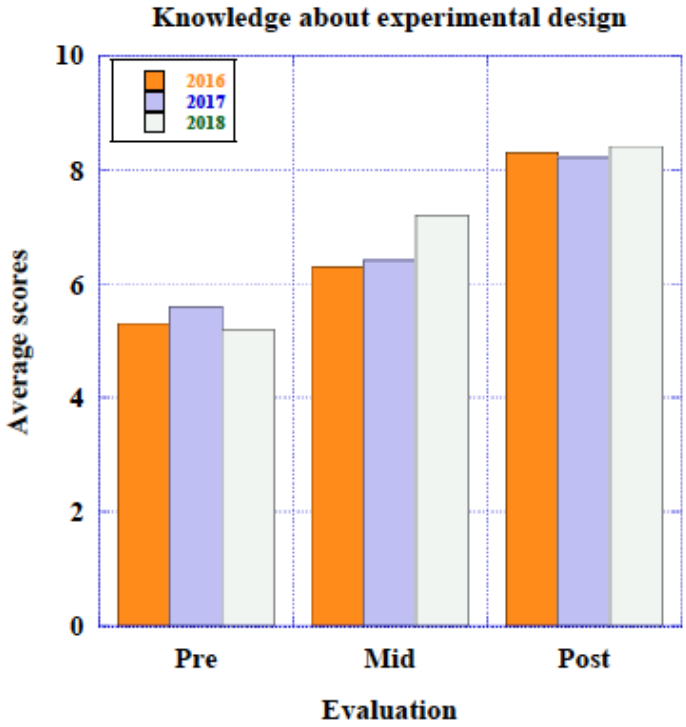

Figure 5. REU Survey results of knowledge about experimental design

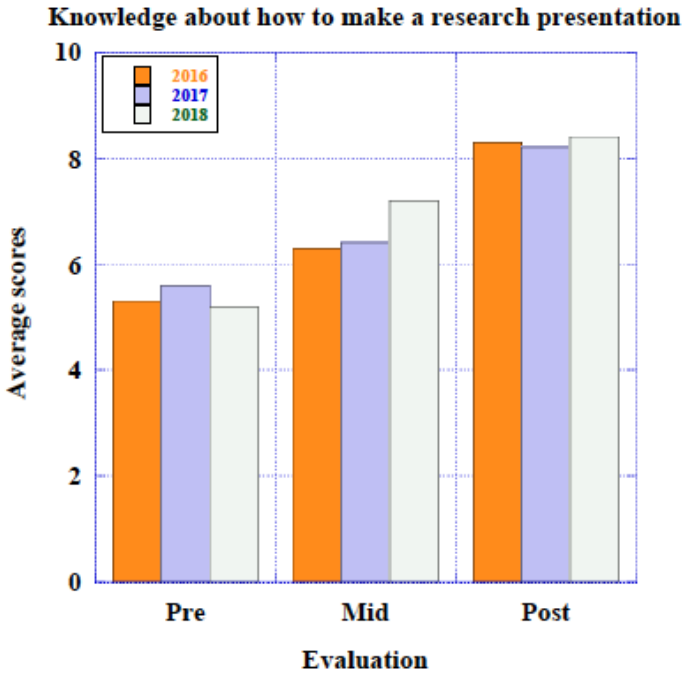

Figure 6. REU Survey results of knowledge about how to make a research presentation

It should be noted that in 2018, the REU students' knowledge about experimental design and materials science in general increased at the mid-program level itself through the assistance of the graduate student mentors who themselves were REU scholars from the previous year. This suggests that graduate student mentors who were REU scholars themselves could be a critical factor for the success of an REU program. We believe that this was also improved through the addition of the entrepreneurship aspects of the project. The REU scholars also had an opportunity to meet with student entrepreneurs from OSU, which further enhanced the REU scholar's understanding of the importance of working with students with interdisciplinary backgrounds.

Typical comments from students after the REU program

Student #1: Allowed me to see firsthand the role materials science plays in the commercial world. I'm considering going to graduate school – never thought about it before this summer.
Student #2: This changed the way I thought about graduate school. I wanted to get an MBA only but now I want to get an advanced degree in Materials Science and Engineering and an MBA and work for a start-up.
Student #3: It gave me an idea of what I should do before I go to graduate school and what skills I need to make my research fruitful before I graduate.
Student #4: Taught me how to define a research objective and understand how to look for information.
Student #5: Helped me realize the importance of the teaming of business and research. I will go to graduate school to earn an MBA and Masters in Material Science and work full time.
Student #6: I plan to transfer to the undergraduate program at this university to continue working on my research project from thus summer.

Significant results from the REU program

Approximately 28% of the scholars were underrepresented minority candidates, 28% were female scholars, and 22% were from 2-year colleges. 100% of students who graduated from their undergraduate programs are employed in STEM related fields or in graduate school while all students pursuing graduate school are enrolled in MSE programs; of the remaining, 95% are planning to pursue advanced degrees at various institutions, whose interest in graduate studies was enhanced due to their involvement in the REU program. Three students have accepted jobs in start-up companies – their response was that their REU experience gave them the confidence to work with a start-up. Our graduate program at OSU has been able to attract two female graduate students pursuing their Ph. D in Materials Science and Engineering (one student being a female Native American) and another female African American has just applied for admission to the Master's program in Materials Science and Engineering in Fall 2020. Yet another Hispanic student has transferred to the undergraduate program in Mechanical Engineering from Cameron University, which is a two-year college in the Southwest part of Oklahoma.

How can combining research and entrepreneurship benefit?

Most of the challenges in the future need new materials and products to be developed, which can only be accomplished by a new generation of young scientists who are yet to be developed and trained. The reality is that not all of those scientists will come from a purely materials science and engineering background nor will they all come from big cities. Therefore, universities such as ours have to take the lead in training students from backgrounds other than materials science and engineering and to recruit from rural parts of the country. Collaboration between engineers, scientists and entrepreneurs and their understanding of product/market fit for each of these products will assist in the accelerated development of new products to address these grand challenges. According to recent National Academies of Engineering reports, active engagement of undergraduate scholars has been proposed as an opportune way to actively engage students and may be a key strategy for broadening participation in STEM [10,11].

Challenges to the Materials Science and Engineering community to develop the new generation of materials scientists

These challenges include – (i) How do we convince peer researchers in MSE about the importance of understanding the customer needs to tailor their research? (ii) How do we attract a big pool of applicants to smaller graduate programs that combine materials research with entrepreneurship? (iii) How do we set up activities other than just research in a college town that has very few students staying back in summer? (iv) How do we convince faculty the importance of motivation and aptitude rather than just GPA and recommendations? And, (v) How do we convince REU scholars to apply to the graduate program at our university when they have finished graduation? Some of these challenges are critical, since many NSF reviewers of REU proposals do not easily accept combining entrepreneurship and REU programs, believing that an REU program should retain a singular focus on research activities alone.

Conclusions

Including the entrepreneurship and customer discovery components improved the research aspects of the REU project at OSU. The understanding of the students about how to conduct research, their knowledge about materials science, and how to make research presentations all increased from the time they started to the time they finished their program. The REU students learnt how to work in teams, improved their communication skills and gained confidence in their research capabilities. All students who graduated are working in STEM related fields and all graduate students are working on graduate degrees in Materials Science and Engineering. Those who are yet to graduate are planning to go to graduate school in Materials Science and Engineering and/or business.

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