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Impact of a Biomedical Engineering Undergraduate Research Program on Student and Faculty Perceptions of Creativity

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Abstract

Immersive research experiences have been shown to significantly improve the research and communication abilities of students who participate in them, as well as increase the likelihood that these students will pursue higher education after the completion of their bachelor's degrees. While Research Experiences for Undergraduates (REU) programs are widespread, the Cardiovascular Research: Engineering a Translational Experience (CREATE) REU program is unique in that it emphasizes the parallels between the creative process and research. Creativity, an attribute that most feel is important for aspiring engineers, is typically not emphasized in research programs or in the undergraduate curriculum. This study describes the impacts that emphasizing the creative process in the CREATE REU had both on student and faculty perceptions.

Background and Literature Review

The National Academy of Engineering (NAE) emphasizes that creativity is one of the important characteristics that engineering students should possess. As stated in the pivotal *Engineer of 2020* manuscript, "Creativity…is an indispensable quality for engineering and given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, creativity will grow in importance" (p. 55).[1] However, creativity is not typically emphasized in the traditional engineering curriculum and, rather, is relegated to design courses or entrepreneurship minors. Few core technical courses incorporate elements that require students to demonstrate aspects of the creative process in their assigned work. In fact, research has shown that both faculty and students feel that creativity, "is not valued in contemporary engineering education" (p. 762).[2]

This lack of focus on the creative process in the engineering curriculum has been hypothesized to be a factor in the retention of engineering students. Results of a cross-sectional study of students' creative self-perceptions showed that senior students tended to feel that creativity was less expected of them in their engineering courses as compared to first-year students.[3] In addition, seniors tended to identify themselves as being less creative than first-year students. The results of this study suggested that more creative students could potentially migrate out of engineering towards majors that better allowed them to utilize the creative process. These results were supported by Atwood and Pretz who demonstrated that students' creative self-efficacy negatively correlated with students' persistence in engineering. As the authors noted, "until engineering students see creativity rewarded in their grades and emphasized in their curriculum, the engineering field will miss the opportunity to retain and develop more creative engineers" (p. 555).[4]

Embedding creativity into the technical curriculum and courses can be challenging as course content can be restrictive, focusing on specific ABET outcomes. In addition, faculty may not feel comfortable integrating elements of the creative process in their courses if they do not feel trained to do so. This paper focuses on a National Science Foundation (NSF) funded REU program in biomedical engineering which emphasized the parallels between the creative process and the scientific method. While outside of the core engineering curriculum, REUs can afford students the opportunity to enhance skills that may be helpful in their professional careers, such as increasing their creative capacity. In addition, the creative process has some strong parallels with the scientific method. Emphasizing this parallel may be more appealing and intuitive to faculty.

Research Experience for Undergraduates (REU) Programs

The National Science Foundation (NSF) identifies REU programs as being, "…a major contributor to the NSF goal of developing a diverse, internationally competitive, and globally-engaged science and engineering workforce."[5] These programs aim to increase the involvement of undergraduate students, particularly underrepresented minorities, in research-based experiences. Among the reported benefits of REUs are increased recruitment of underrepresented groups, gains in research-based skills, clarification, refinement, and reinforcement of career and educational goals, an increased understanding of the research process, increased student retention in science and engineering, and an increase in students' self-confidence of ability and self-esteem.[6,7,8,9,10]

Prior work shows that students who have participated in REUs often describe their experiences as being a very important part of their undergraduate careers. These students perceived increases in their ability to understand scientific findings, communicate the results of their research, and understand scientific literature after completion of the REU, and were also more likely to pursue graduate education.[11] Faculty perceptions of REU experiences have also been reported as reflecting significant educational benefits for students and the graduate students who serve as their mentors.[12]

Grimberg et al. found that students participating in the last four years of a seven year REU program reported greater levels of satisfaction when the program coordinators began to emphasize a broader theme, environmental sustainability, as compared to implementations of the program without the emphasis of the sustainability theme. In the context of the REU described by Grimberg, the students reported that the inclusion of the environmental sustainability theme made them more aware of the "value and greater context of their work."[13] Similarly, the REU being described in this paper emphasizes the creative process and its relationship with the scientific method as a broad theme of the program. To our knowledge, creativity has not been previously studied in the REU literature. We hypothesize that the incorporation of this theme has the potential to impact both student satisfaction and perceptions of the REU program.

Parallels between Creative Process and Scientific Method

Creativity was implemented into the REU described in this study by describing creativity to the students and faculty in the context of engineering research problems. The creative process used for this training was a model described by Mumford, and can be compared in parallel to the traditional scientific method. The processes included in Mumford's model of creativity are described in Table 1.

Table 1. Description of processes included in Mumford's model of creativity.[14]

Process	Description
Problem Construction	Defining the problem. This includes identifying goals, constraints, outcomes, key steps towards a solution, and important information that needs to be considered.
Information Gathering	Determining which information might contribute to solving the problem.
Concept Selection	Identifying which information you have gathered will be the most pertinent in constructing a problem solution.
Concept Combination	Combining and reorganizing the information chosen in the concept selection step to move towards generating novel ideas.
Idea Generation	Formally determining potential problem solutions.
Idea Evaluation	Determining the efficiency and appropriateness of the proposed solution.
Implementation Planning	Testing the chosen problem solution.
Monitoring	Searching for evidence to determine the problem solution's level of success.

By emphasizing the parallels between the creative process and the scientific method, faculty who had previously thought of creativity as being outside the bounds of technical engineering may now see how the creative process is used in research. Table 2 shows the alignment of the two processes, as mapped by the principal investigators for the proposal. The authors noted that there are some differences in the two processes, such as the level of detail relating to certain steps. For example, in Mumford's creative process, individuals go through three processes relating to coming up with new ideas: concept selection, conceptual combination, and idea generation. While some of these steps may occur during scientific research, the model identified by Crawford and co-authors uses a broader category of forming an explanatory hypothesis. Similarly, the creative process refers to "idea evaluation," while the scientific method breaks this down into how the hypothesis would be evaluated through experimentation, data collection, data analysis, and interpretation.

Table 2. Parallels between the Creative Process and the Scientific Method.[15,14]

8 Stages of the Creative Process		**8 Steps of the Scientific Method**	
1	Problem Construction	1	Define the question
2	Information gathering	2	Gather information and resources (observe)
3	Concept Selection	3	Form an explanatory hypothesis
4	Conceptual Combination		
5	Idea generation		
6	Idea evaluation	4	Design and Perform an experiment and collect data (test the hypothesis)
		5	Analyze the data
		6	Interpret the data and draw conclusions
7	Implementation Planning	7	Publish results
8	Monitoring	8	Retest

Context of Study: The CREATE REU

The first year of this NSF funded Biomedical Engineering REU program was held over 10 weeks during the summer of 2016 at a large Mid-Atlantic university. The formal title of the program is Cardiovascular Research: Engineering a Translational Experience (CREATE). . Cardiovascular Disease was chosen as the program's primary emphasis, because of its imminence in American culture and the ingenuity required to approach treating the disease. Research in this area requires training the students on an interdisciplinary level to be proficient in materials, mechanobiology, and multi-scale phenomena. Additionally, the research focus provides a natural opening for the implementation of training in creativity. Creativity was the second unique emphasis of the REU program, intended to be an integral part of the program to foster students' growth as scientists.

The CREATE REU program's objectives are to help students: conduct research on multi-scale problems to improve the understanding and treatment of Cardiovascular Disease, apply the creative process to solve engineering problems applied to Cardiovascular Disease treatment or intervention, be able to describe the process of translating research into marketable technology, and be able to identify requirements for success in graduate and professional schools.

To achieve these goals, several forms of training were provided to the students. These included technical workshops, hands-on research experience with a designated mentor, and practice presenting research findings before a professional audience. The scope of the workshops provided to the students over the course of the summer included training in scientific research, communication, creativity, and careers (see Appendix A). In addition to the workshop series, students were also taken on guided tours of the Artificial Organs Lab at a nearby medical center and a local company that designs and manufactures medical devices.

Students' research experiences with their mentors were diverse, with several of the faculty involved in the program holding joint appointments in the Biomedical Engineering Department, Mechanical and Nuclear Engineering, and the Engineering Science and Mechanics Department. Additionally, some work was done in collaboration with the Surgery Department in the College of Medicine. In their collaboration with the research groups involved in the CREATE REU, students were exposed to all aspects of graduate research. They worked on individual projects under the supervision of a graduate student mentor and were immersed in the culture of their particular lab, performing literature reviews, experiments, and disseminating their progress in both one-on-one meetings with their PI and the group as a whole. The following are a sampling of the projects that were explored by students who participated in the REU: clot fracture mechanics with applications in the surgical therapy of acute stroke, nanoscale dynamics of kinesin motor domains during processive stepping along microtubules, and additive manufacturing of biomechanically anisotropic hydrogels for tissue engineering.

Creativity was heavily woven into the program. The students were trained early in the summer in how to view the creative process as being parallel to the scientific method. Before the start of the REU, the participating faculty members received a similar workshop. The faculty were presented with a model of creativity and asked to find parallels to the scientific method. They also discussed how they could incorporate elements of the creative process into their work with the REU students. Students participated in three subsequent workshops on specific parts of the creative process to help them make intentional connections tying engineering and research to creativity. The workshops were titled: “What is the problem? Identifying problems and stating a research question;” “What does it take to have a winning idea? Ideation in Research;” and “The iterative loop: Evaluating your design and your data.” Two additional workshops provided information on skills needed to be successful in research: developing a literature review, titled “What do we already know? Learning to find and search references” and scientific communication, titled “Tell me about it – how to communicate your results and success.” The training the students received in creativity was also intended to be reinforced through the individual mentoring each student received from the assigned faculty member.

Program evaluation was conducted by a member of the College’s teaching and learning center and a graduate student from the College of Education. The evaluation focused on whether or not the REU was meeting intended program objectives as well as explored the impact on student and faculty perceptions of the creative process as it relates to research.

Research Questions

Three research questions were explored to examine the impact of the CREATE REU and its emphasis on creativity, on both students and faculty. These research questions follow:

1. What impact did the CREATE REU have on students’ creative self-concepts, in particular creative identity and creative self-efficacy?

2. How did participation in the CREATE REU impact student perceptions of creativity and the research process?

3. How did faculty incorporate the creative process into the work with their REU students and what were their perceptions of the effectiveness of their approach?

Methods

Instruments

As part of the overall program evaluation, students were administered pre- and post-surveys. These surveys consisted of five scales: three scales measuring students' creative self-perceptions and two scales measuring the impact of the program on students perceived research skills. The latter scales were the Experience with Research Activities Scale (EWRAS) that measures broad research experiences and the Undergraduate Research Student Self-Assessment (URSSA), which is an NSF-funded survey measuring specific scientific research skills.[16,17] Given that the purpose of this paper is to explore students' creative self-concepts, the results of the EWRAS and URSSA are not discussed here, but were used for overall program evaluation.

The three remaining scales included measures of creative self-efficacy, identity, and expectation. Creative self-efficacy refers to the "belief that one has the ability to produce creative outcomes" (p. 1138).[18] Creative self-identity refers to the "overall importance that a person places on creativity in general as part of his or her self-definition" (p. 248).[19] Creative self-expectation refers to students' perceived expectations that they need to be creative within the academic setting, in this case the REU. Descriptions of the items included in these scales are given in Table 1. All three instruments used Likert-type scales. The number of anchor points corresponded to the initial development by the scale authors. Responses were coded numerical with "Strongly Disagree" coded as a 1 and "Strongly Agree" coded as a 5 (or 6 for the self-efficacy scale). Scores were calculated by summing up the coded values for each scale.

Table 3. Description of Creativity measures.[20,18]

Measure	# of Items	Scale Type	Scale Anchors/Response Type
Creative Identity	10	5-point Likert	Strongly Disagree - Strongly Agree
Creative Self-Efficacy	4	6-point Likert	Strongly Disagree - Strongly Agree
Creative Expectation	8	5-point Likert	Strongly Disagree - Strongly Agree

Faculty and student interview protocols were developed by REU evaluators. The protocols included questions relating to the overall evaluation of the program and to perceptions relating to creativity. The questions in the student protocol that relate to creativity and are aligned with the paper's purpose follow:

1. How did learning about the creative process and its relationship with the scientific method impact your understanding of research?
2. How has your conception of yourself as a creative person changed as a result of participating in the REU?

Questions on the faculty interview protocol that related to creativity follow:

1. How did the REU's emphasis of the creative process impact the way in which you mentored your REU student(s)?
2. Do you feel that the REU's emphasis of the creative process impacted the REU student's experiences?
3. Did the REU's emphasis of the creative process impact your personal view of the research process?

Procedures

The pre-survey was administered to the students the week prior to the start of the REU, and the post-survey was administered at the conclusion of the program. Surveys were administered online using the Qualtrics program.

Student interviews were held within the span of one week towards the end of the program. Interviews of the faculty took place over a two-week period of time following the conclusion of the REU. Each interview lasted no longer than one hour. The interviews were conducted by a graduate student in the College's teaching and learning center. The interviews were audio-recorded and were later transcribed. The responses were analyzed by question using NVivo software. For each interview question, broad themes were identified first, and then these themes were analyzed for more specific sub-themes. All interviews were then coded using the coding scheme developed.

All participants were asked to complete informed consent documents in accordance with the university's policies from the Office for Research Protections.

Participants

A total of 11 students participated in the REU program. Of these students, 4 out of 11 identified as female and 6 out of 11 identified as being part of under-represented minority groups. Four participants were recruited from the REU's home institution. The students were all within 19-21 years of age (as reported on the post-survey); 4 were classified as sophomores, 2 were classified as juniors, and 5 were classified as seniors going into the Fall 2016 semester. Two of these students had previously been part of an REU. A summary of this information is given in Table 4.

Table 4. Summary of demographic information for the participants.

Number of Participants	% Female	% Under-Represented Minority	% Fr, So, Jr, Se	Average Age in Years
11	36.4	54.54	0, 36.4, 18.2, 45.5	20

All 11 REU students completed the pre-survey; 8 of these also completed the post-survey. All 11 students participated in the interview.

There were 11 faculty mentors who participated in the REU, all of whom run active research labs and received federal funds for participating in the summer program. Eight of these faculty have their primary appointment in the Biomedical Engineering Department, 2 held joint appointments in the Biomedical Engineering and Engineering Science and Mechanics Departments, and one held a joint appointment in the Biomedical Engineering Department and the Department of Surgery in the College of Medicine at the university Medical Center. All 11 faculty members were male. A total of 8 faculty participated in the interview.

Results

Research Question #1: *What impact did the CREATE REU have on students' creative self-concepts, in particular creative identity and creative self-efficacy?*

Summaries of the descriptive statistical data for the pre- and post-survey scales are given in Tables 5 and 6.

Table 5. Descriptive statistics for the composite pre-survey scores.

	Minimum	Maximum	Mean	Std. Deviation
Creative Identity	32.00	42.00	37.09	3.21
Creative Self-Efficacy	15.00	24.00	19.27	2.41
Creative Expectation	26.00	34.00	31.55	2.30

Table 6. Descriptive statistics for the composite post-survey scores.

	Minimum	Maximum	Mean	Std. Deviation
Creative Identity	34.00	46.00	39.88	4.19
Creative Self-Efficacy	19.00	24.00	20.88	1.81
Creative Expectation	31.00	40.00	34.13	2.80

The pre- and post-survey data were compared using dependent t-tests to determine significant changes pre- to post-REU in the students on each summed scale score. No significant changes were found between the pre- and the post-scores for any of the creativity scales (Creative Identity: Creative Self-Efficacy t=1.361, p=.216; Creative Expectation t=1.879, p=.102; t=1.469, p=.185).

We also performed an item-level analysis (Wilcoxon signed-rank test) for the creativity scales to determine if there were any significant changes pre- and post-REU by item. We saw significant changes in two items on one of the creativity scales (Creative Identity): "In general, my creativity is an important part of my self-image" (t=2.000, p=.046); "I am confident that I can be creative in my coursework" (t=2.121, p=.034).

Research Question #2: How did participation in the CREATE REU impact student perceptions of creativity and the research process?

Student participants were asked to reflect on how learning about the creative process and its relationship with the scientific method had impacted their understanding of research. While 4 of the 11 students did not feel that the training impacted their understanding of research, the remaining 7 did feel that there was an influence.

Four subthemes were identified among the student responses coded as having impacted their understanding of research: changes in perceptions of creativity in engineering, changes in understanding of the creative process, increased ability to use the creative process, and increased awareness of their use of the creative process. These are detailed further below.

Two of the 11 students reported that their perception of creativity in engineering had changed positively. As one student noted, "I thought that was the coolest part of this because it's kind of unique in that. You don't really think of creativity with engineering and the sciences as much." Another student noted that creativity helped to alleviate the difficulty associated with the technical nature of engineering, as the student noted, "It was nice to know that there is creativity that goes into engineering and not just like the hard stuff."

Four of the 11 students reported that the REU had impacted their understanding of the creative process and its relationship with the scientific method. These 4 reported that the REU helped them to understand and use the creative process. For example, one student stated, "…a lot of the different activities we did, it made me think about things outside like my stereotypical do this, this, this, and this. It made me think of different factors that would go into it. It made me be more creative and, obviously, in the ways that I do things in the lab."

One of the 11 students reported that their awareness of their use of aspects of the creative process had increased as a result of the program. As this student said, "I didn't realize I'm actually brainstorming initially, and then thinking about it. And that 'aha' moment, everyone calls it, it was actually an accumulation of stuff that I was doing that I didn't realize. So, the CREATE program more made me more conscious originally of what processes I'm going through to get to a solution."

In the second creativity interview question, students were asked to reflect on their conception of themselves as creative individuals and whether this had changed as a result of the REU. Eight of the 11 students reported that they did think their perception of themselves as creative individuals had changed positively. As one student stated, "It made me feel that I actually am creative, because I could have sworn that I wasn't creative at all. But it's helped me realized that I am creative."

The other 3 of the 11 students did not feel that their perceptions of themselves as creative individuals had been altered at all by the program. For example, one student did not feel that he or she was not particularly creative beforehand and did not feel the program impacted creativity: "I don't really feel any more or less creative. I didn't feel like I wasn't creative before and so I guess it's enforced that?" Another student noted that he or she already felt creative and did not feel like the program resulted in an increase in creativity: "…I don't think I'm insanely creative, but I do think I'm creative. I still think I'm creative, I don't know, but not crazy creative."

Research Question #3: How did faculty incorporate the creative process into the work with the REU students and what were their perceptions of the effectiveness of their approach?

The most common theme found in the faculty responses regarding how they incorporated creativity into their mentoring process was the encouragement of creative work through the use of open-ended projects. Five of the 8 faculty interviewed had responses that demonstrated this type of approach. For example, one faculty member said, "So, for example the project that [the student] was working on. So, he was pretty much given the project, but we only outlined some approach or strategy on how to make the scaffold of the vascular graft. But we didn't give him very detailed instruction. So, he figured out how to make the materials, and also make them mimic native blood vessels."

In the completion of these projects, 2 of the 8 faculty reported having the students pursue their own ideas despite the possibility of failure. As one faculty member noted, "I think the thing that changed is I sort of encouraged [my student] to try things that have a low probability of working - high-risk projects. So, that would probably be the main thing. And if she had an idea, I would encourage her to follow it."

Another described the encouragement of design on the part of the student.

> "We try to encourage creativity. In particular, the micro-forensic device, we actually encouraged [the student] to think about how to implement it, how to decide. At the end, the device was actually come up with by the student, so we didn't take the drawing and say, "Make it." He actually came up with that."

Some unique methods of implementing creativity into their mentorship were also described by the faculty. One faculty member reported that they would point out creative achievements made by scientists in the field during regular group meetings. This activity was intended to give their student a reference point for what creativity may look like in the professional world.

> "What she [a senior graduate student] did early on was to just tell them, "I want you to test this idea." And didn't tell them how to do it and let them figure it out…But what we did is we emphasized a couple of experiments that were open-ended to do that, and then… I also would highlight in our lab meetings where there was real ingenuity - which is basically the result of creativity in the creation of this method. They could see, "Wow, how did somebody ever think about that?" And then we would point that out. So, we emphasize the importance of creativity throughout the process."

Another faculty member described deep discussions he had engaged in with the student in order to convey principles of the creative process.

> "So creativity is a thing that is a concept, and not entirely for me, not easily defined and not easily teachable. But I was trying to convey to my student that there isn't a single way

> to accomplish something, and that creativity really went into making specific choices as to how to achieve your objectives or—so long as you have a sense of the big picture. The idea was that all the intermediate choices, those were all also creativity, to some degree."

Two of the 8 faculty reported that they did not feel that they had been entirely successful in their implementation of creativity for the duration of the REU, and one faculty member reported that he did not attempt to implement creativity at all into his mentoring of the student. As one stated, "I think it was a bit of a challenge…But along the way, I think we sort of fell back into the scientific method more than sort of focusing on the creative method. So, I would say I didn't do necessarily a great job of really promoting the creativity part, in the sense of saying, "Always go back to those workshops." I think lesson learned."

When asked if they felt that the REU's emphasis on creativity had impacted their students' experiences, 4 of the 8 faculty responded that they did not know. For example, one stated, "I'm not very sure, but at least I can tell that this student showed a great interest in biomedical engineering field. And he got some experience in research." Another said, "Actually I don't know. I'm aware there are some activities in the REU program, the CREATE program encourages them to be creative and do things. But I'm not sure exactly what they have done and I don't have really a comparison."

There were four of the 8 faculty who believed that their students had been positively impacted by the program's emphasis on creativity. As one said, "I think it did [have an impact]. In having actually some sort of side conversations with some of the students through the summer, I think they thought it was really cool trying to think of science and research in a very different way, and so I think it did have an impact."

Another faculty member reported that he believed the program had been successful in helping cultivate interest in his student in the field of his project. A quote from this faculty member follows:

> "I think so. I think so. I have an underlying—I don't know what to call it - anxiety that—it is a lot easier to involve students in science if you bring them into a laboratory, and they actually make experiments and things of this kind. I'm essentially a mathematician when everything is said and done, and so it's hard—I feel that pulling people into the math and showing how that relates to science is not as easily done and so I think that he, somehow, bought into it. And in fact, he may even continue doing what he was doing. So, it seemed to me that the whole thing was successful even in cultivating a certain interest that it's often harder to cultivate."

When asked if the program had impacted their own conceptions of research and creativity, 5 of the 8 faculty members reported that it had not. As one stated, "Not significantly. I've been a faculty for ten years. I think I've mentored maybe 20 students of similar nature. We always try to encourage the student to do creative research."

Three of the 8 faculty reported that the REU program had altered their conception of the research process. As one stated, "Yeah. First of all, I bought into the idea early on because we worked together on the proposal. I liked how it synced up with the scientific method, and design method, and things like that. You could really see that the creative process had elements of all those things. In that case, it showed me that in science—even when it fails—a method can be creative."

Discussion

This study explored the impacts that emphasizing the parallels between creativity and the scientific method had on the students and faculty involved in a summer REU program. We saw no statistical differences in the pre- and post-scores of students on the three creativity measures included in the surveys, but item-level differences were found for two specific questions on the creative identity scale: "In general, my creativity is an important part of my self-image," and "I am confident that I can be creative in my coursework." These findings suggest that participation in the REU program impacted students' images of themselves as being creative individuals, a theme which also reflected in the interview data.

The student interview responses provided a more comprehensive picture of how the creativity emphasis impacted students' perceptions. Many of the students reported that learning about creativity had impacted their summer experience in a positive way. Student comments suggested a revelation that creativity is an important component of biomedical engineering, and in many of the students', re-evaluation of their own creative potentials. The REU program showed the students that they could conceptualize creativity in a different way rather than thinking about it in terms of art. Most of them reported that they now feel more capable of being creative than they once believed they were.

Of particular interest to us, were the interview responses received from the faculty who were asked about creativity in the REU program. These faculty were offered a workshop before the start of the REU discussing the model of creativity that was to be presented to the students. At that time, they also participated in a collaborative discussion of ways they could help emphasize creativity through their mentorship activities with students. Despite this training, some faculty did not feel that they had a high level of understanding of the creative process and did not feel comfortable implementing aspects of the creative process in interactions with students.

Faculty responses to the interview questions revealed that while the faculty approached mentorship of their students with the intent of inspiring creative work, they did not always feel that they were successful or did not know whether or not the students were receptive to their efforts and those of the REU coordinators. The most common method utilized to encourage students to think more creatively was to assign them with projects that were open-ended. Many faculty reported that they did not discuss creativity directly with their student much, if at all. They also reported little change in their own conceptions of creativity. However, a few of the faculty received feedback from their students leading them to believe that the creativity component of the REU was having a positive impact.

Further responses from the faculty indicated that they felt more communication with the REU coordinators would be helpful. In particular, they felt that knowing more details about the programmatic activities might assist them with making connections to the research activities happening in the lab. This suggestion was provided to the REU coordinators to improve the program for future years.

The study did have some limitations, including the size of the participant pool and reliance on self-perception data. Due to the small sample size of this cohort, we were unable to determine significant improvement statistically in the pre- and post-scales measured. While significant differences were found for two items, none of the summated scale scores were found to be statistically different between the pre- and the post-scale administrations. The average scores for all three scales did increase, suggesting that there may be a trend for increases in students' perceptions of themselves as creative individuals. In future years, data from each new cohort will be analyzed independently and in combination with previous years to increase statistical power for these analyses. A second limitation is the reliance on student and faculty self-report data. No direct measures of creativity were used to determine if students' performance or research skills were impacted as a result of participation in the REU. Future research may consider additional measures of creativity as well as collecting longitudinal data to see if the REU program had long lasting impact on students' perceptions. We may also consider linking of the student's and faculty mentor's perceptions of the program in future years.

Overall, the assessment of the CREATE REU allowed us to examine the impacts that emphasizing the creative process and its parallels to the scientific method had both on student and faculty experiences. Additionally, teaching the students and faculty about creativity and the scientific method led to perceived positive outcomes for a majority of the students.

In future years, we will seek to improve the design of the program to further emphasize creativity to the faculty. We intend to highlight the alignment of the creative process with both the scientific method and the engineering design process to assist in this. Additionally, we may include periodic creativity workshops or brainstorming sessions for the faculty, and we will send out notes with updates on student activities that are being held weekly.

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Appendix A

Workshop Title	Presenter	Summary	Resources
Engineering and the Creative Process	Tom Litzinger, Assistant Dean for Educational Innovation and Accreditation, Director of the Leonhard Center, Professor of Mechanical Engineering	This workshop presented the current understanding of creativity with respect to engineering and the disconnect between its value and how/if it is taught.	Available upon request.
What is the problem? Identifying problems and stating a research question.	Maggie Slattery, Assistant Professor of Biomedical Engineering, Interim Assistant Dean for General Education	This workshop presented common challenges with problem definition and has students practice defining problems in way that did not presuppose a solution from photographs	https://psu.box.com/s/ps2p6f272z27iaqurb62eoho3rbfzlhs
What do we already know? Learning to find and search references. (Engineering Librarian)	Vanessa Eyer, Engineering Librarian	This workshop presented resources that are available via the Penn State library system and ways to effectively search for primary scientific literature	http://guides.libraries.psu.edu/biomedicalengr
What does it take to have a winning idea? Brainstorming in Research	Scarlett Miller, Assistant Professor of Engineering Design	This workshop presented common roadblocks in brainstorming and ways in which good ideas are sometimes passed up.	http://www.engr.psu.edu/britelab/resources.html
The iterative loop: Evaluating your design and your data	Matthew Parkinson, Associate Professor of Engineering Design, Learning Factory Interim Director	This workshop presented the value of iteration and demonstrated to students the value of repetition through hands-on exercises.	http://www.mattparkinson.com
How to communicate your results and success: Effective Technical Presentations	Michael Alley, Professor of Engineering Communications	This workshop presented an overview of the assertion evidence model of presentations and asked students to critically consider how they present technical content so that it is communicated in the clearest way possible	http://www.assertion-evidence.com/