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Multidisciplinary "Boot Camp" Training in Cellular Bioengineering

to Accelerate Research Immersion for REU Participants

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Abstract

Research Experience for Undergraduate (REU) sites widely serve as the first major research gateway for undergraduates seeking a structured research experience. Given their lack of prior research skills, and the highly compressed duration of the REU programs, these students frequently encounter barriers to a seamless transition into a new laboratory environment. We hypothesized that the design of a unified short course on laboratory and analysis techniques could serve as a pivotal orientation experience. Our goal was to rapidly align student expertise to their summer research goals while also integrating the student participants into a cohesive learning community. This article discusses the design and outcomes of a Cellular Bioengineering Boot Camp, which is offered at the outset of the 10-week REU site at Rutgers. The Boot Camp provides hands-on, supervised training for techniques and procedures that are common among projects. The training establishes a common language and baseline for the REU students and allows their first laboratory experiences to be with each other, and creates an immediate network of peers and mentors. Surveys before and after the Boot Camp and at the end of the summer indicated a significant improvement in student proficiency in the techniques that was retained throughout the summer. We believe that the Boot Camp approach can be tailored to the specifics of each REU site and its associated projects and research foci.

Introduction

Research Experience for Undergraduate (REU) programs can provide invaluable opportunities for undergraduates interested in science and engineering to experience research on a full-time basis for an extended period of time. Independent research has become a complementary but critical component to traditional lectures and teaching laboratories for education and training in science and engineering. At most institutions that include research in their mission and offer significant education and training at the graduate level, undergraduates have a number of formal and informal opportunities to engage in research, although during the academic year this is often limited to 8-12 hours per week because of a typical course load. There are no such opportunities at many institutions that focus on undergraduate education, where the faculty do not regularly engage in scientific research. In an increasingly competitive climate, students without undergraduate research experience are clearly at a disadvantage for entry into graduate programs, particularly at the doctoral level. Indeed, published studies indicate that research experience is the best predictor of success as in STEM graduate studies [1, 2], and emphasize how programs use research experience as a deciding factor in granting admission.

REU programs, which usually operate over the summer and can be financially supported by internal programs and/or by external granting agencies, address this gap in training. Externally supported programs, especially those from the National Science Foundation (NSF) and the National Institutes of Health (NIH), are typically focused around a specific research area and include elements for professional development in that field. For example, we have operated an NSF-sponsored REU site in Cellular Bioengineering since 2010. Our REU program is a 10-week immersive research experience for rising juniors and seniors. Research projects span areas from biomaterials to stem cells, and include topics such as tissue and cellular engineering, drug delivery, metabolic engineering, and gene delivery. Most of the Cellular Bioengineering REU projects involve engineering design and/or analysis of a material, surface, or system, but also require strong laboratory skills. A representative sampling of projects is provided in Table 1. Professional development activities include mentoring in fellowship preparation, career panels, GRE preparation, and workshops in innovation and entrepreneurship.

Table 1: Representative summer research projects for the REU in Cellular Bioengineering

Project	**Description**
Electrospun nanofiber scaffolds for controlling astrocyte behavior	Students culture astrocytes on nanofiber scaffolds of different polymers, fiber size, and fiber density and relate the response of the astrocytes to the biophysical properties of the scaffold.
Electroporation “on-a-chip”	Students develop a continuous flow microfluidic system that delivers controlled, dynamic electric fields to cells to optimize molecular delivery while minimizing cell death.
Metabolic engineering of liver cells for translplantation	Students design, evaluate, and model the influence of soluble and insoluble environmental factors on the metabolic function of liver cells, with a goal of “defatting livers” to increase the donor pool for liver transplantation.
Label-free microscopy for analysis of subcellular structural dynamics	Students use a novel non-invasive approach to quantitatively analyze subcellular structures within a living cell that is based on optical Fourier processing with Gabor filters and examine changes in these structures that occur with cancer, growth, and differentiation.
Interactions of lipid-based nanocarriers with vascular endothelia and macrophages	Students design and engineer lipid nanocarriers that are loaded with therapeutic agents for treating cancer to be taken up by endothelial cells while avoiding detection by macrophages.

Externally-sponsored REU programs are usually open to students from outside the host institution who are from other colleges and universities. In fact, in the program description, the

NSF places specific emphasis on offering REU opportunities to students from schools that have traditionally lacked research opportunities:

> "REU Sites are an important means for extending high-quality research environments and mentoring to diverse groups of students. In addition to increasing the participation of under-represented groups in research, the program aims to involve students in research who might not otherwise have the opportunity, particularly those from academic institutions where research programs in STEM are limited. Thus, a significant fraction of the student participants at an REU Site must come from outside the host institution or organization, and at least half of the student participants must be recruited from academic institutions where research opportunities in STEM are limited (including two-year colleges)."[3]

The Cellular Bioengineering REU at Rutgers has especially focused on these NSF-derived criteria during recruitment of summer scholars, with over 50% of participants attending primarily undergraduate institutions (PUI), and significant enrollment from other under-represented groups including females, traditionally under-represented minorities, and first-generation to college (Table 2).

Table 2: Cellular Bioengineering REU Demographics

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
Total Scholars	10	10	9	10	12	**51**
Under-represented Minorities	4	3	5	4	4	**20**
Females	3	4	4	6	6	**23**
First-Generation to College	3	4	5	4	6	**22**
Primarily Undergraduate Institution	5	3	4	7	7	**26**

It is difficult to transition anyone who is new to research on to an established, cutting-edge research project in cellular bioengineering. For intra-institutional research experiences conducted during the academic year, these difficulties are usually addressed with slow but thorough training that provides experience and improves the students' confidence in their research abilities. Course-based undergraduate research experiences have also been implemented to attempt to standardize experience and training [4-6]. However, for short immersive REU programs, where students are inter-institutional and there is not sufficient time for a transition into the project, the problem is particularly challenging. If thrust immediately into a participating laboratory, the REU student will likely have a highly deficient skill set and experience and feel the most vulnerable. Studies have demonstrated that perceived self-efficacy is an important determinant of attrition in STEM including in research, especially for under-represented groups [7-12]. In an educational environment, initial experiences have a strong effect on self-perception and influence long term performance, outcome, and attrition. Early interventions that improve this state can have significant long term effects [11].

The goal of this work was to accelerate the integration of REU scholars into their first critical research immersion experience by improving their proficiency and confidence in laboratory and research skills. To achieve this goal, we have developed a Cellular Bioengineering Boot Camp. REU students attend the Boot Camp during the first week in the program. It introduces and provides hands-on, supervised training for techniques and procedures that are common among Cellular Bioengineering REU projects before the students enter into their host laboratories. The training establishes a common language and baseline to the REU students and allows their first laboratory experiences to be with each other.

Implementation

The Boot Camp runs during the first week of the REU program, and is comprised of two half-days with three sessions each day. The incoming cohort of 9-12 REU students is split into 3 groups that participate in a rolling sequence of ~60 minute, hands-on training sessions. The sessions are led by graduate students, post-doctoral associates, or other technical personnel from the host laboratories. In the past, we have formally partnered with graduate student training programs, such as NSF-sponsored Integrative Graduate Engineering and Research Training Programs (IGERTs), and drawn upon IGERT fellows as hands-on instructors and “near peer” mentors for the Boot Camp.

Session topics for the Boot Camp were chosen in consultation with the participating faculty and especially with the graduate student and post-doctoral “near peer” mentors. These “near peer” mentors most often partner with the REU students to provide day-to-day mentoring and supervision. Six procedures and techniques that were judged as fundamental to the majority of laboratories and projects were ultimately selected. Activities were designed to introduce these procedures and techniques, each within an hour training session. The six session and the specific activities associated with each session are described in Table 3, and photographs of students participating in some of these activities are shown in Figure 1. We emphasize that the Boot Camp was not designed to provide exhaustive training in any of the topics, but rather to familiarize students with foundational techniques in biotechnology and bioengineering. In doing so, we expect to establish a common baseline for the laboratory technical skills as well as to standardize expectations for the "near peer" mentors. Follow-up and specialty training are provided in the individual host research laboratories.

Table 3: Boot Camp sessions and activities. For assessment, students were asked to rate their confidence and proficiency in each activity on a scale of 1 (lowest) to 5 (highest).

Session	**Activities/Techniques**
Dispensing solutions with laboratory pipettes	Electronic pipettes Micropipettes of different volumes
Preparing chemical and biochemical solutions	Molarity/Normality Serial dilution Weight or volume percentage
Aseptic technique and cell culture	Working in a biosafety cabinet Aspirating solutions Handling tissue culture flasks
Trypsinization of cells and cell counting	Using a hemocytometer Trypsinizing and labeling viable cells

Digital Microscopy	Bright field microscopy Phase contrast microscopy Epifluorescence microscopy Approaches to label cells for microscopy
Image analysis	Using image analysis software Filtering and thresholding an image Identifying and measuring features

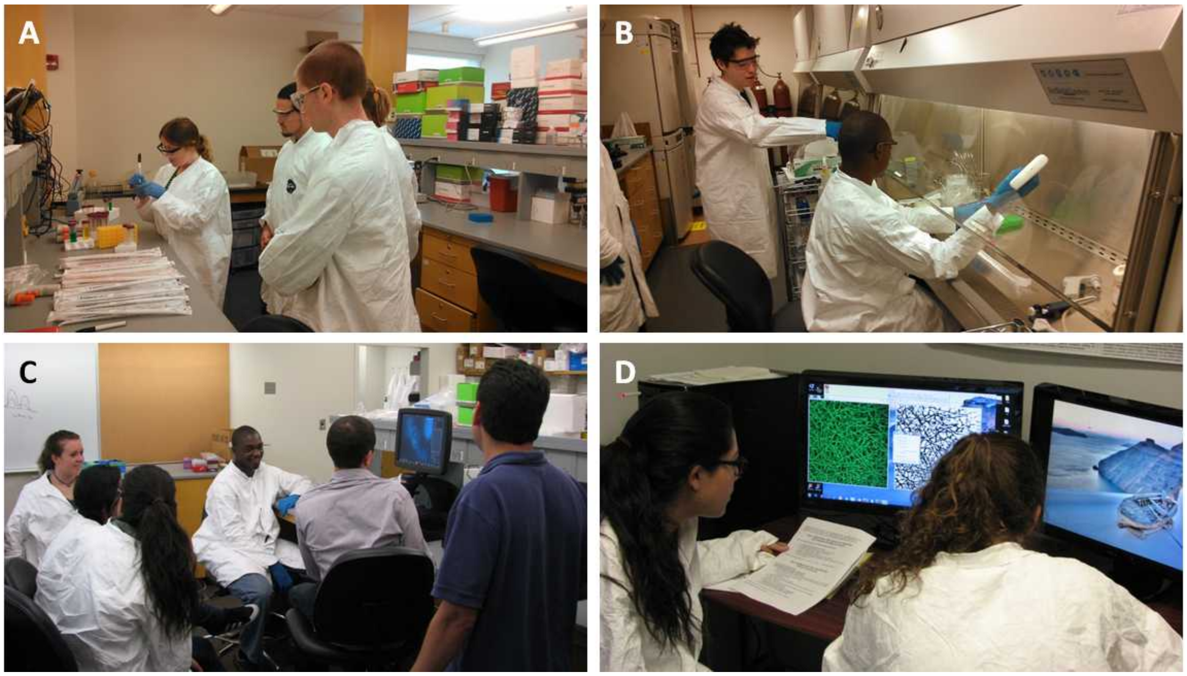

Figure 1: Students and mentors at Boot Camp Sessions. A) Dispensing solutions with pipettes; B) Sterile technique; C) Digital microscopy; D) Image analysis

Program Assessment

For the past two summers we have collected data to assess the effectiveness of the Boot Camp. An anonymous questionnaire was used to evaluate the influence of the Boot Camp on the perceived training level of the REU students. Students rated their confidence and proficiency level with the techniques introduced during each session (Table 3) on a scale from 1-5, where for a given technique, 1 represents no experience or proficiency whatsoever and 5 represents that the technique can be performed confidently and independently. The REU students were asked to fill out the questionnaire three times during the summer: after admission but prior to the Boot Camp to evaluate their entering level of experience; immediately after the Boot Camp to assess the success of the specific Boot Camp activities; and at the end of the REU program to determine the extent to which the selected activities were appropriate and their confidence was retained. We believed that students who routinely used and built upon the training provided in the Boot Camp in their research projects would demonstrate an increase in their confidence level throughout the summer. However, if a student did not use techniques or skills introduced in the Boot Camp during the 10-week program, there would be no significant uptick in the student confidence level. Similar approaches have been used in other Boot Camp settings [13, 14]. Student confidence levels were statistically compared across the three administrations of the questionnaire. Comparisons were made for each topic by lumping the scores for each activity within a topic, as well as for each individual activity.

Results

Data were collected for consecutive cohorts of ten and twelve students participating in Summer 2013 and Summer 2014 sessions, respectively. As shown in Figure 2, in general, students entered the program significantly lacking experience and confidence in the techniques and procedures covered in the Boot Camp. The results of the Pre-Boot Camp surveys indicated that students had "no experience" and "no confidence" in almost 52% of the activities, and only had "some exposure, but no experience" and "little confidence" in 12% of the activities. Student confidence improved markedly after the Boot Camp, and increased further by the end of the summer. The Post-REU survey results demonstrated that, across all activities, students gained "significant experience" and were "fully confident" in their proficiency and ability to work independently in about 55% of the activities. Students gained "good experience" and were "confident" in an additional 24% of activities.

Figure 3 displays the average confidence level for each of the Boot Camp thematic sessions for 2013 and 2014. Entering students had higher levels of confidence in their ability to pipette and prepare solutions than in sterile technique for cell culture, cell counting, digital microscopy, and image analysis. However, the confidence level significantly increased from pre-Boot Camp to post-Boot camp cohorts and pre-Boot Camp to post-REU cohorts for all of the sessions in both years ($p < 0.0001$, ANOVA followed by pairwise comparisons with Tukey's test). Student confidence also increased significantly from post-Boot Camp to post-REU in several of the areas. In both cohorts, this improvement was observed for sterile techniques (max $p = 0.0007$) and microscopy (max $p = 0.0038$). The 2014 cohort also demonstrated increased confidence in cell counting ($p = 0.04$) and image analysis ($p < 0.0001$) from post-Boot Camp to post-REU cohorts.

As shown in Figure 3, while the confidence level increased significantly for all topics from pre- to post-Boot Camp in 2013, students expressed below-average levels of confidence in Digital Microscopy following the Boot Camp. The activities and approach in this session were revisited prior to the 2014 program. Specifically, fewer examples of labeled tissue and cells were included, which allowed more time for each of the REU students to control the microscope and capture images. Special care was also taken to engage the REU students in the session and to involve them in the discussion by explicitly connecting the different activities to their research projects. As shown in Figure 4, which compares results from 2013 to 2014 for the Digital

Microscopy activities, these small changes appeared to have a significant and positive impact on the average confidence level. For each microscopy activity, the raw average was greater in 2014 than 2013 post-Boot Camp and post-REU. The averages were normalized to the pre-Boot Camp average for the respective year. Normalized averages from 2014 were then compared statistically to those from 2013. Significant increases were identified for: (A) average confidence levels in bright field microscopy post-Boot Camp (P=0.007) and post-REU (P=0.005); and (B) average confidence levels in cell labeling techniques post-Boot Camp (P=0.006) and post-REU (P=0.035). After normalization, differences for phase contrast microscopy (P=0.160 and 0.48) and epifluorescence microscopy (P=0.062 and 0.189) were not significant for comparisons between 2013 and 2014 post-Boot Camp and post-REU confidence levels, respectively.

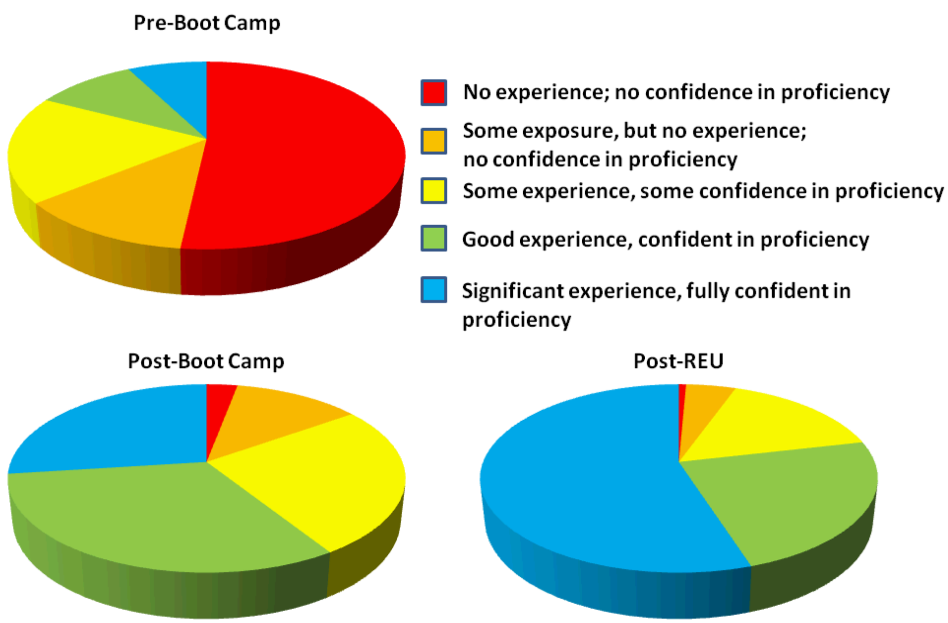

Figure 2: Average distribution of student confidence level Pre-Boot Camp, Post-Boot Camp, and Post-REU for both summers across all of the Boot Camp topical sessions.

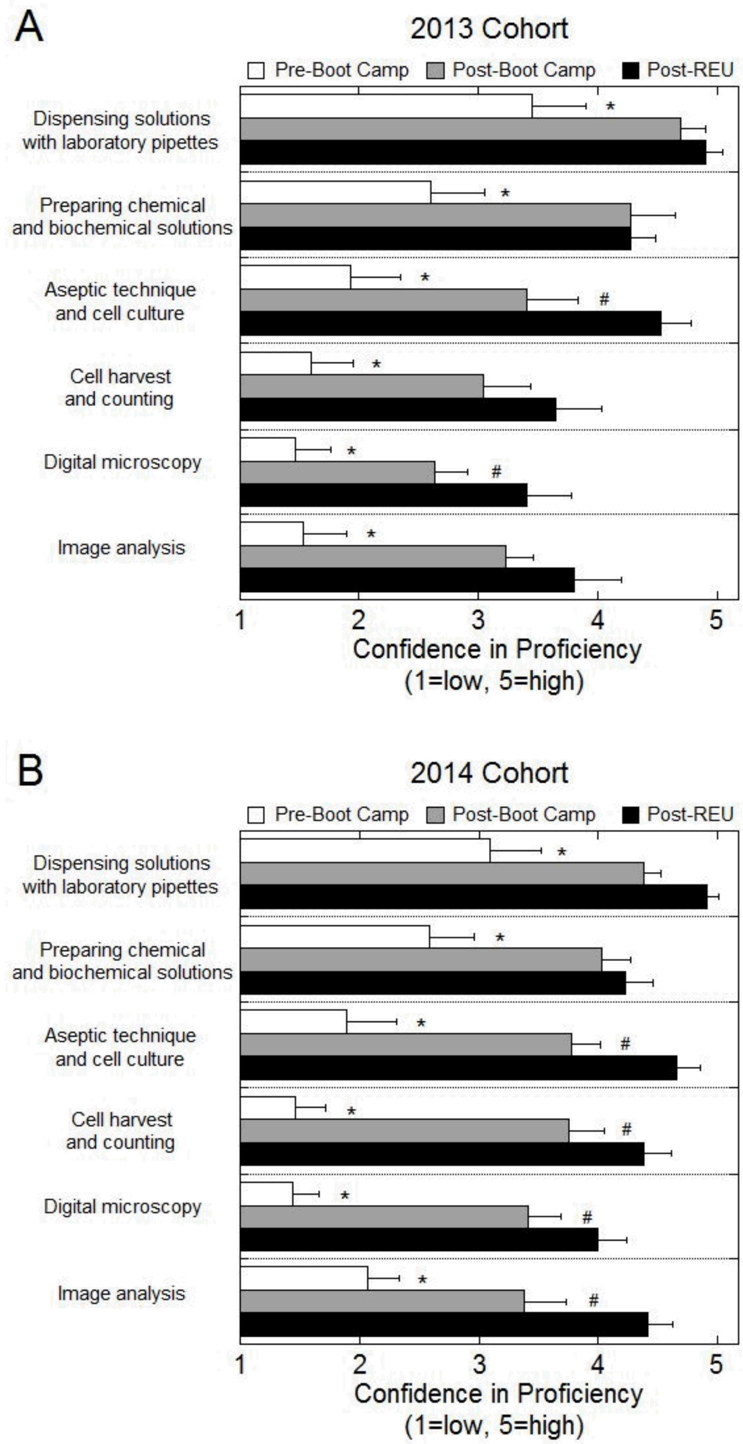

Figure 3: Average confidence level (+/- standard deviation) for each of the sessions for (A) the 2013 cohort and (B) the 2014 cohort of students. Student confidence increased from pre-Boot Camp to post-Boot Camp and post-REU in all activities (*, $p < 0.05$). For two of the sessions in

2013 and four of the sessions in 2014, confidence also increased from post-Boot Camp to post-REU (#, $p < 0.05$).

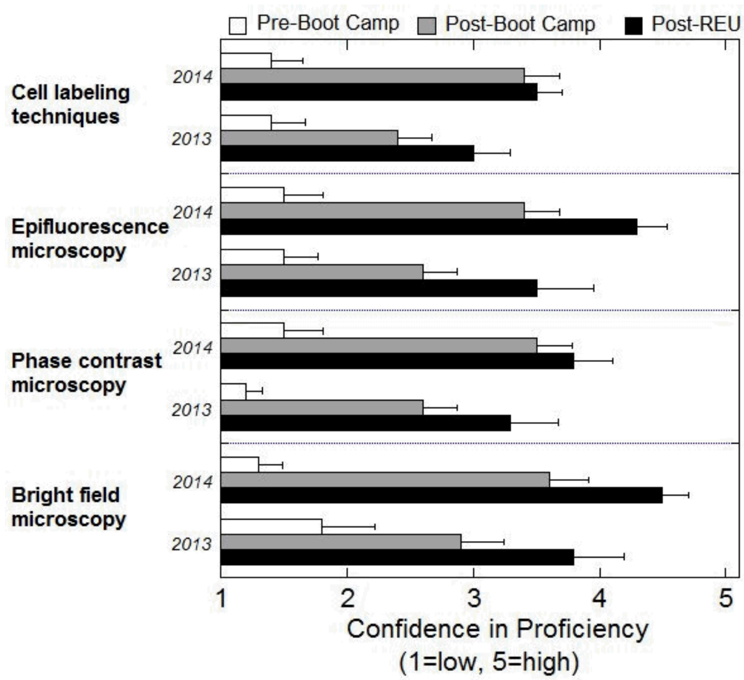

Figure 4: Student confidence in the four activities/techniques covered in the *Digital Microscopy* session for the 2013 and 2014 cohorts. Based on the relatively low improvement in confidence following this session in 2013, activities were re-visited and modified to be more hands-on. The raw confidence level in each of the activities improved for 2014 cohort. After normalizing each activity to its pre-REU level, differences in confidence between 2013 and 2014 post-Boot Camp levels and between 2013 and 2014 post-REU levels were statistically significant for Cell labeling techniques and for Bright field microscopy ($p < 0.05$).

Discussion

Introducing new students to laboratory research – or technical research of any kind – can be a slow and difficult process. Boot camps can be an expedient approach to introduce new techniques and skills to a group over a short period of time. In medical education, for example, boot camps have been effective in developing certain clinical [15-18] and professional skills [19-23]. In engineering education, they have been particularly popular and useful for engaging students in innovation and design [24-26].

In an REU program, where a group of research novices is expected to launch into an immersive, 10-week experience, the challenge is amplified. According to program websites, several REUs include boot camp training among their activities, including boot camps in molecular biology at North Carolina State, fluid power at Purdue, and astrophysics at University of California, Santa Cruz. However, to our knowledge, there are no published reports that document the effectiveness of these boot camps or describe how to develop one for the diverse but inexperienced audience of incoming REU students. We have incorporated a two-day boot camp that has successfully increased the confidence and experience level of our participants to accelerate their integration into host laboratories and their research in bioengineering. All of the REU students participated in the Boot Camp, which prevents comparison to a control group of non-participants. However, studies have shown that addressing gaps in training to improve self-confidence can have demonstrative effects on long-term performance and attrition [11, 12].

Although the training provided in the Boot Camp sessions and activities could be performed in each individual laboratory, organizing the training for the incoming students as a group nearly immediately upon their arrival generates several additional benefits. First, it helps ensure that this critical training barrier is removed as early as possible, which can be particularly important when, for a variety of reasons or scheduling constraints, personnel from the individual laboratories may be unavailable at the start of the REU. The Boot Camp also helps to even out and standardize aspects of the training for the cohort of students that is delivered by "near peer" mentors chosen by the director. Perhaps most importantly, the Boot Camp provides a unifying first experience for the cohort of students. Although the students meet weekly as a group with the director for a professional development seminar and participate in a number of social activities throughout the summer that help strengthen the cohort, the bulk of their time is spent in the laboratory. These students hail from all over the country, including several from small 4-year colleges. As indicated in the pre-Boot Camp surveys, the students enter the program with a significant lack of experience and confidence. As such, the research laboratory presents a substantially different environment that can be potentially very intimidating. The Boot Camp allows a student's first laboratory experiences to be together with others in the cohort who are at a similar experience level. Furthermore, the Boot Camp aids in developing a broader research network among the REU participants and the pre-doctoral and post-doctoral students serving as mentors in the program. Participants develop contacts with individuals outside their host laboratory who can serve as important sources of information, particularly when their own research mentor might be unavailable. The Boot Camp also introduces a common language to the cohort that is valuable in the professional development seminars when discussing research projects.

There are also reciprocal benefits to be reaped by the near-peer mentors assisting with the Boot Camp. For instance, we have leveraged the professional development activities of graduate trainees and fellows, such as those of partnering NSF IGERT programs. This can provide these graduate trainees with a complementary research mentoring experience. These opportunities can extend the intellectual as well as broader impacts of their research, which are two major criteria for all NSF projects. By interacting with the REU participants as a whole rather than only a single mentee, the mentors can establish a "baseline" and better calibrate the experience levels of the REU population. This can help them to be more empathetic and effective mentors in their specific research projects. Furthermore, participating as a laboratory instructor provides a real-world teaching experience that is positive for a mentor's professional development in general, and specifically fulfills requirements of many training programs such as IGERTs.

Selection of appropriate Boot Camp topical sessions and activities is especially critical to the overall success of the program outcomes. We attempted to choose areas that were common across research projects and were viewed as barriers to research progress. Some of the topics were obvious, such as sterile technique for cell culture. Others, however, were less obvious and only chosen after discussions with the prospective "near peer" mentors. For example, based on chemistry and other laboratory courses that are standard in the curricula from which the REU draws students, program faculty expect the incoming REU students to be proficient in preparing solutions. However, through discussions with the prospective "near peer" mentors, we learned that a substantial amount of time is spent with summer students, and undergraduate researchers in general, in reviewing and confirming calculations to prepare solutions of a specific concentration, molarity, normality, or dilution. Indeed, as shown in Figure 3, few among the incoming cohort were confident about their proficiency to perform sample preparations that are routine in a Cellular Bioengineering research laboratory, such as serial dilutions, or solutions where concentration is based on weight per volume or volume per volume percentage. According to these mentors, this represents a significant barrier. We believe that this example highlights the need to discuss the activities with all of the stakeholders, as none of the principal investigators cited the topic.

In preparing the Boot Camp activities, we recognized that they were not meant to be comprehensive training, but rather the beginning of the summer student's journey. Although the REU includes weekly seminars and workshops aimed at professional development as well as a good number of social activities, the overwhelming bulk of the summer is spent in the individual laboratories performing specialized research. As such, we attempted to maximize the impact of the training while minimizing the time away from the host laboratories. We found that the short, focused, hands-on activities could be successful in improving students' confidence. This was directly evident when activities for the digital microscopy session were modified to be more interactive (Figure 4).

Conclusion

Boot camps can be an effective means of training groups in new skills, techniques, and technology. For REU programs, whose mission is often to provide research opportunities to those that traditionally lack such opportunities and experience, boot camps to start the program can be especially valuable. In our REU in Cellular Bioengineering, we found that a two-day boot camp significantly improved participants' pre- to post-Boot Camp confidence in their abilities for routine laboratory skills in pipetting, preparation of solutions, cell culture, imaging, and image analysis. Importantly, this confidence was retained and often improved between the Boot Camp and the end of the program, which indicates that the boot camp activities were consistent with the laboratory research. We believe that a key to the success of the Boot Camp is the involvement of all stakeholders, including faculty and near-peer mentors, in selecting and designing boot camp sessions and activities, and in designing short but interactive, hands-on activities to engage the students.

Handouts and other materials that are used in the Cellular Bioengineering Boot Camp are available on our website: http://www.celleng.rutgers.edu.

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Brief Biographies

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PRABHAS V. MOGHE is a Distinguished Professor of Biomedical Engineering and Chemical and Biochemical Engineering at Rutgers University. He is also the Research Director for the School of Engineering at Rutgers and is responsible for developing new alliances and partnerships with biomedical and life sciences. He received a B.S. (Distinction) in Chemical Engineering from the University of Bombay, a Ph.D. in Chemical Engineering (Bioengineering) at the University of Minnesota and completed post-doctoral research training at Harvard Medical School. Dr. Moghe is Principal Investigator and Program Director of the Rutgers-NSF IGERT Program on Stem Cell Science and Engineering and has previously served as the Undergraduate Director and Graduate Director for Biomedical Engineering at Rutgers. His research is focused on advanced biomaterials, nano medicine, and regenerative medicine. He is a Fellow of the International Societies of Biomaterials Science and Engineering (ISBE) and the American Institute of Medical and Biological Engineering (AIMBE) and a recipient of several research and teaching awards such as the first Rutgers School of Engineering Faculty of the Year Award, NSF CAREER Award, and Leadership in Diversity Award. A member of the Editorial Board of the journal *Acta Biomaterialia*, he has published over 90 journal papers and over 200 conference presentations/abstracts. To date his research efforts have been supported by over $ 14 million in research funding from various major federal, state, and industrial institutions.

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