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BOARD # 293: Reflection on Outcomes Data from Eight Years of a Summer REU Site in Systems Bioengineering and Biomedical Data Sciences

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Reflection on Outcomes Data from Eight Years of a Summer REU Site in Systems Bioengineering and Biomedical Data Sciences

Background and Motivation

Innovations in medicine and in the biological sciences are increasingly dependent upon a quantitative understanding of how the myriad individual biological components—including DNA, proteins, cells, tissues, and organs—interact with one another as an integrated whole to yield functional outcomes relevant to healthy physiological function and to disease. Describing these complex systems quantitatively and predicting their emergent behavior will be essential for not only identifying novel drug targets and understanding the etiology of complex diseases such as cancer and heart disease, but also for achieving truly personalized medical diagnostics, therapies, and surgical approaches toward treating these diseases [1-4]. Systems bioengineering has thus become an essential toolkit in the biotechnology and pharmaceutical industries [5]. Inherent biological complexity and high-throughput measurement approaches lead to massive "big data" sets, often with thousands of heterogeneous values [6]. This complexity requires data science tools such as data-driven modeling [7-8] and machine learning [9-10] to appropriately integrate heterogeneous data [11]. It is imperative to train a diverse new generation of scientists in the concepts and practice of multi-scale systems bioengineering and biomedical data sciences (BDS) research. Within the biotechnology sector and academia, demand for graduates who possess expertise in the analysis of high-throughput data, as well as the modeling skills needed to analyze pathological states and identify viable therapies, has increased dramatically [5].

NSF Project and Methodology

To address the need for training students in this rapidly growing field, we have established an REU site in Multi-Scale Systems Bioengineering and BDS (NSF #1560282 & #1950374) at the University of Virginia that has supported 81 students engaging in research projects for the past eight years (2017-2024). These students were recruited out of a total of 1,375 applicants (Table 1). Recruitment occurred through a combination of targeted engagement with HBCUs in the Southeast and with small undergrad-focused institutions, through mentor networks, and through a broad national distribution, as well as posting on the NSF ETAP common application portal. Nearly 80% of admitted students accepted their offers. The enrolled REU students were then matched to a mentor based on a combination of student interest in specific sub-areas of systems bioengineering and mentor availability each summer. Most research projects relied primarily on previously developed methods and tools and typically involved application to biological data and generation of testable hypotheses. The specific research projects included a wide variety of topics in the field, ranging anywhere from molecular scale biophysics models to cell-scale signaling models, biomedical data science analysis of genetic data, tissue-level biomechanics models, and image analysis algorithms for quantifying cell distribution in tissue-engineered constructs. The participants took part in an introductory bootcamp on the fundamentals of systems modeling and had multiple opportunities to present their research progress throughout the summer to experts in the field. They also received professional development training on research ethics, technical communication, and launching careers in systems bioengineering. Figure 1 shows a summary of the

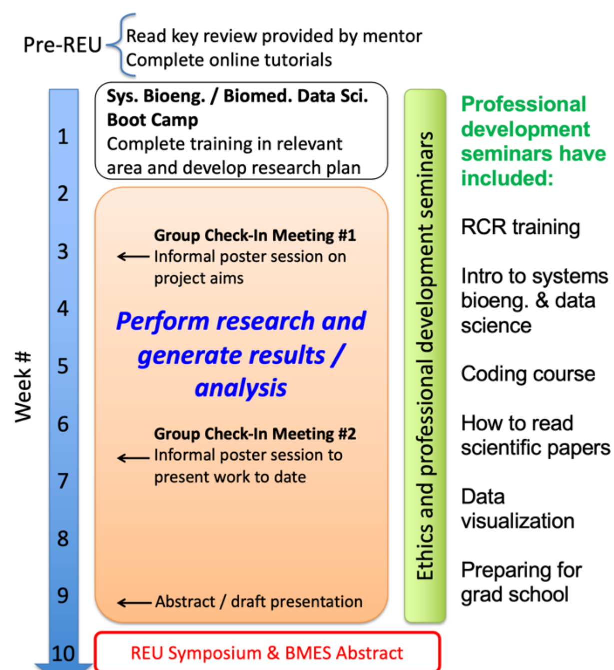

Figure 1. Schedule of activities in the 10-wk summer REU program

activities in a typical summer. For two summers (2020 & 2021), the program was run as a completely virtual REU due to institutional constraints on visiting researchers due to the pandemic, as the nature of systems bioengineering and BDS research enables it to be conducted outside a laboratory setting. To assess the program each year, we analyzed participant demographics, outcomes in presenting and publishing their work, career outcomes, exit interviews, and anonymous survey metrics and comments from each summer's cohort.

Outcomes and Results of the REU Site from 2017-2024

The 81 REU participants from 2017-2024 (Table 1) came from 54 colleges and universities and represented 24 different majors, with 47% of them biomedical engineering (BME) majors, with the remainder from biochemistry, biophysics, chemical engr., biology, microbiology, math, CS, physics, neuroscience, & mechanical engr., among others. Summary demographics include 68% from groups traditionally underrepresented in STEM, 32% first-generation students, 58% women, and 41% attending non-R1 institutions. Two-thirds of participants presented their work at national meetings, and nine have become co-authors on ten papers. Of the 60 students who have since graduated, 85% are either in graduate school or in STEM industry positions.

Table 1. REU enrollment statistics 2017-2024

	Applicants			# of total	Enrolled				
Year	**Total**	**% URM**	**% Female**	**offers**	**Total**	**# AA**	**# Latino**	**# 1st-gen**	**# female**
2017	179	36%	54%	16	10	3	3	2	5
2018	186	31%	54%	12	11	2	3	2	6
2019	315	24%	55%	16	10	3	3	1	5
2020	154	35%	66%	14	14	8	5	5	9
2021	154	27%	63%	14	9	4	3	1	6
2022	96	24%	58%	12	12	4	1	6	10
2023	128	21%	54%	14	11	1	3	7	5
2024†	163	29%	56%	6	5	1	2	2	2

† Due to a lack of NSF funding in 2024, we enrolled only 5 students, of which 4 were funded internally

While we have not yet completed analyzing data from 2024, post-REU surveys of participants from 2017-2023 revealed that 98% of respondents rated their overall experience with the REU as either "very satisfied" or "satisfied" (average 4.72 on a 5-point Likert scale). Evaluations of specific program objectives and mentoring quality were similarly high (Figure 2 on the next page shows evaluation data from 2020-2023 across a range of metrics). Regarding impact on long-term professional goals (and thus the goal of increasing the workforce pipeline in this field), 75% of respondents from 2020-2023 said that the REU increased their interest in STEM and in a research or academic career, and 70% indicated that the experience encouraged them to pursue further education. Additionally, 45% said the program helped solidify their interest specifically in systems bioengineering, and 17% stated that the REU led them to change their career plans.

The overall ratings from year to year were consistently very high except for the 2020 and 2022 cohorts (mean ratings for 2017-2019, 2021, & 2023 were 4.53±0.16 SD, whereas 2020 & 2022 averaged 4.26). The 2020 cohort was completely online due to the pandemic, and while mentor ratings were similarly high (4.92), multiple ratings were lower than the other years' cohorts, particularly ratings of group social activities (3.14), support and guidance from other REU students in the cohort (3.17), orientation activities (3.29). All three of those were likely the result of not only being in an online program soon after the pandemic started but also reflected a lack of experience by our REU team (PI and mentors) in adapting to a fully online research training environment. We added more intentional online interaction among the cohort in 2021 (also online), and those ratings were much higher (mean 4.78, among our highest in seven years of assessing the program). The cause of the slightly lower ratings for the 2022 cohort are less clear but are likely the result of pivoting back to a fully in-person experience after two years online. The mentor and lab matching ratings were lower in 2022 (4.54 relative to 4.77±0.08 for the other 6 years), but we are not aware of any issues that would explain this anomaly.

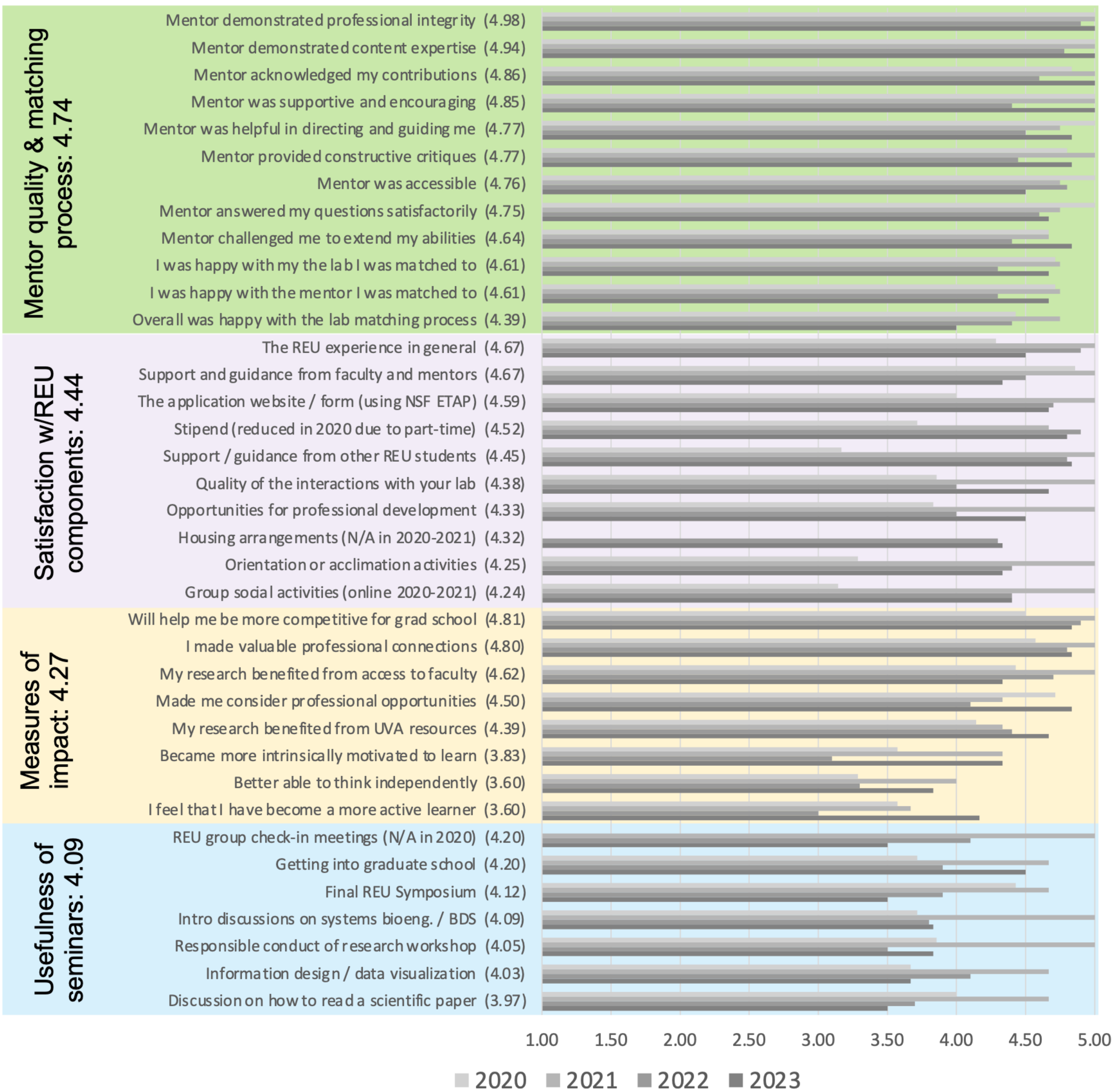

Figure 2: Post-REU survey results (2020-2023). Agreement with survey statements / satisfaction on 5-point Likert scale (e.g. 5=highly satisfied, 3=neutral, 1=highly dissatisfied), rank-ordered from highest to lowest average (across four years) within each section. The 4-year mean for each response is provided in parentheses to the right of the label, and the mean for each section is indicated next to each section heading.

In free response questions from post-program surveys asking respondents to describe in more detail anything they especially liked or that they thought should be changed about the program, the responses were overwhelmingly positive, with most critiques relatively minor suggestions—e.g. a desire for more industry engagement, introductory coding workshops, etc. In the first online cohort (2020), one student specifically mentioned the challenges of feeling included in online social "gatherings" with the cohort. In summary, the REU program outcomes in terms of applications, targeted recruitment, and program evaluation were all highly positive over the eight years of the program thus far, with exceptionally high levels of satisfaction from the REU students. However, some challenges with the social component of the REU program were evident with the first online cohort as everyone was adapting to the isolation associated with the pandemic.

Discussion and Conclusions

From a programmatic standpoint, we have several recommendations drawing from our experience of the past eight years. The relatively large number of applications each year and the high student acceptance rate of offers suggests that the specific research area is an important factor in student recruitment. If an exciting research field is well-presented to possible applicants from the outset, the specific field itself can be a highly motivating selling point.

Our experience during the pandemic was that a virtual REU can yield positive research outcomes, although cohort bonding and the experience of working in a lab are diminished relative to an in-person experience, as indicated by multiple REU component responses to the post-assessment survey (Figure 2, purple-shaded section). While we do not currently envision returning to a virtual or hybrid program except by necessity, based on participant feedback, we believe that the benefits of a virtual program strongly outweigh the potential drawbacks if in-person research is not feasible for whatever reason, as was evidenced by the improved survey results the second year we ran an online REU program (2021).

One challenge of a one-size-fits-all introductory bootcamp is appropriately accommodating the student training needs for the widely varied research topics. Some projects in this field require coding, but others do not since they use established software tools; some require model development, but others require data science techniques. We are continually iterating to find the optimal balance of instruction in topics that support every student in the program, and we have recently begun to offer "opt-in" training and coding bootcamps to allow participants to customize their experience to best align with their prior experience and the needs of their chosen project.

Our final observation is that while the programmatic seminars and professional development activities are highly important components of an REU site, the research experience itself—and especially the deep relationships with mentors and interaction within each lab's community of researchers—is essential to a successful REU program. REU students need to truly feel that they are a part of the lab during their time in the program, as a sense of belonging and of tangible contribution to the research mission have been shown to improve professional identity and retention in STEM research [12].

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