The Biophysicist

Building Interdisciplinary Skills and Mentorship Opportunities in a 2-Week Research Experience

Yee-Hung Mark Chan[1,2], **Michelle Phillips**[1,3], **Katherine Nielsen**[1,4], **Diana S. Chu**[1,2,*]

[1]Center for Cellular Construction, San Francisco, CA, USA
[2]San Francisco State University, San Francisco, CA, USA
[3]Phillips & Associates, San Francisco, CA, USA
[4]Science and Health Education Partnership, University of California San Francisco, San Francisco, CA, USA

ABSTRACT A framework for a 2-wk summer research course is presented, with a mindset of discovery and self-advocacy that is interdisciplinary and inclusive. The foundations of the course are built upon 2 pillars: (a) a well-defined educational plan focused on cellular engineering, with a goal to instill an engineering mindset into the cell biology field; and (b) a tailored Dimensions of Mentoring policy, which uses a structured feedback system to define and strengthen mentor attributes and provide multiple opportunities for mentorship and mentorship training. Undergraduate and master's student participants work with PhD students or postdoctoral/professor team leaders in small teams in discovery-based research projects. Multiple teams work in parallel during the 2-wk period and convene in course-wide meetings to share findings and give feedback. Working in small teams with multiple levels of peer and team lead mentoring, students experience advancement in research and technical skills. Participants also experience gains in their understanding of the overarching educational goals in cellular engineering and science communication skills through course-wide activities. The principles from the Dimensions of Mentoring were also effective, with mentors at different levels building strong inclusive teams, coaching practical skills, and promoting individual advocacy. Meeting basic needs, providing relatable role models, and prioritizing enjoyable team-building activities were found to be critical factors in providing inclusive and productive environments. Overall, participants report high satisfaction with a discovery-based interdisciplinary research experience because of a supported environment. This creation of a strong community benefits individual career development and contributes to sustainable research productivity.

KEY WORDS research experience; undergraduates; mentoring; inclusion; cellular engineering

I. INTRODUCTION

Summer research experiences are ideal introductions to the fundamentals of research in particular subfields for undergraduate students. Students gain technical skills, increase their self-identification as scientists, and extend their career networking opportunities, leading to increased retention in science, technology, engineering, and math (STEM) fields (1–3). Thus, summer research experiences are invaluable for college-level participants, particularly those from groups underrepresented in STEM fields (4–7).

Previous studies have found that summer research experiences that provide sustained opportunities for mentorship are a critical factor in

"*" corresponding author

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college students' overall satisfaction with the experiences and in determining how these students will select future research projects, especially for those that are minority groups in STEM fields (8–10). However, their impact can be limited because laboratories often host only 1 to 2 students per summer. In addition, this format, in which students work closely with 1 mentor, may limit exposure to a range of scientist mentors. Thus, a model was developed that would provide a genuine research experience for several trainees at varying skill levels while also providing multiple opportunities to interact with different mentors. This format also served to build a sense of community, benefitting all participants during and beyond the summer.

Strategies are presented for hosting a 2-wk interdisciplinary summer experience with 2 main goals: maximize discovery-based research in the field of cellular engineering and build mentorship and team-building skills that strengthen community among members. The course is hosted by the Center for Cellular Construction (CCC), a National Science Foundation–funded Science and Technology Center with members from the University of California San Francisco (UCSF); University of California Berkeley; Stanford University; San Francisco State University (SFSU); IBM Research-Almaden; and the Exploratorium. The goal of the CCC is to transform the field of cell biology with an engineering mindset and toolkit.

The CCC cellular engineering summer course has been held each July from 2019 to 2023. The participants are from different career stages: undergraduates, master's students, PhD students, postdoctoral fellows, and professors. Each team of approximately 4 to 6 members experiences a full discovery-based research arc that includes posing questions centered around cellular engineering, designing and conducting experiments (including developing techniques and instruments, if necessary), and analyzing data to discover the answers to the posed questions. The small, team-based approach provides ample opportunities for research and mentorship training that benefit all members of every team.

The CCC summer course is built on 2 overarching frameworks. First, the CCC has established a Framework for Cellular Engineering Education (Supplemental Material 1) that includes 3 core tenets that are introduced and practiced during the 2-wk period: (a) cells are machines that can be engineered, (b) application of an engineering approach to biological problems generates transformative new directions and insights, and (c) the engineering of complex biological systems requires working across disciplines. The second framework is the CCC Dimensions of Mentoring, which is adapted from the National Center for Biotechnology Information/National Institutes of Health framework and National Academies' report (11; Supplemental Material 2). Specifically, the adapted recommendations provide a structured feedback system to build and strengthen mentor attributes and multiple mentorship structures for participants.

The 2-wk session allows for an immersive, yet contained, experience that provides strong interdisciplinary educational experiences for participants at multiple levels in cellular engineering while simultaneously forming strong connections between participants and long-lasting feelings of community.

II. RECRUITING AND BUILDING INCLUSIVE TEAMS

It is a challenge to build teams comprising members from different levels that support a diverse range of backgrounds and experiences. A key goal of the course is for each team member to feel supported to improve their knowledge base, to increase their research and mentorship skills, and to make contributions to the team regardless of experience level. To address this, the Dimensions of Mentoring principles were actively applied to signal psychosocial support during recruitment and early team activities, including respecting the values and priorities of individuals, promoting belongingness/using privilege and power to support, and fostering communication (Supplemental Material 2).

To recruit students, upper-division students in biology, chemistry, math, physics, engineering, and computer science were targeted. All promotional materials explicitly stated that "no prior research experience is necessary" to reduce barriers to entry, allowing the program to be accessible to a broad range of students. Because of the interdisciplinary nature of the course, prerequisite course requirements were not necessary. Pictures of past summer course groups were included so that interested students can see that participants and mentors of diverse backgrounds and similar ages are welcome. Candidates from minority-serving institutions were actively sought and encouraged to attend to maximize opportunities to create a broad and inclusive pool of talent (Supplemental Material 3). Regarding advertising the course, a course information slide was provided to instructors at SFSU to advertise the course to upper-division undergraduates. Instructors and research advisors from all CCC institutions were asked to recommend students from their upper-division courses or research laboratories, and personalized invitations were sent as a follow-up; the instructor recommendation is a valuable positive affirmation for students. Materials were disseminated to student groups at SFSU and UCSF that include Black Excellence in STEM (BE-STEM) and the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) chapters. Additionally, prior participants (who are currently in college) of the Cellular Construction Workshop, a high school summer course hosted by the CCC and the Science and Health Education Partnership at UCSF, were invited. Peer mentors are selected from past CCC Summer Course participants who possess valuable team experience and some data analysis skills, with an additional requirement of being available for preparation 1 wk before the workshop. Overall, a multipronged, targeted, and personalized approach to student recruitment was implemented.

To best anticipate support needed, participants are asked to complete precourse surveys about their prior experience with coding and research, preferred pronouns, dietary restrictions, any foreseeable issues with technology or attendance, and any other information that participants think is essential for course leaders to know about them (Supplemental Material 4). Participants are expected to be present every weekday from 9 AM to 5 PM; although missing 1 or 2 workshop sessions may be allowable, repeated absences greatly hinder an individual's ability to contribute to the team equitably. The initial survey ensures that participant needs can be accommodated effectively, with the provision of necessary loaner computers or hard drives as appropriate. The surveys are shared with Team Leads to help guide the formation of small teams with similar interests and complementary schedules.

Doctoral students and postdoctoral fellows serve as Team Leads. Diversity and gender balance are key considerations in our recruitment process because participants benefit from mentors with whom they can identify (12). In recruiting our Team Leads, the number of female and minority mentors has been increased by recruiting generally from minority-serving institutions and by specifically recruiting PhD students (who are more likely to identify as female and/or under-represented minority than postdoctoral fellows). Recruitment occurs at CCC retreats and meetings, highlighting that a short summer experience is a highly beneficial and efficient way to gain skills in inclusive mentoring practices in a supported environment that can be beneficial in future job searches. In addition, past participants have graduated into Team Lead roles. Team Leads are encouraged to be available $\geq$1 wk in advance of preparation before the summer course begins, although communication with Team Leads about their project ideas and needs often occurs during the spring semester before the course to refine the scope of the projects and anticipate equipment, supply, and space needs. Team Leads can bring their own data for analysis or develop a data-collection plan during the course. Having multiple Team Leads each year greatly helps to foster an environment of inclusivity and collaboration.

In preparation for the summer research experience, strategies have been devised to help our diverse group of participants, including undergraduate students and Peer Mentors, acquire necessary skills and knowledge to excel in the program. The specifics of this preparatory process are found in Supplemental Material 5. Two components are emphasized to best prepare all team members for the 2-wk intensive experiences.

Appropriate resources for knowledge and skill building are provided. Many student participants appreciate and benefit from having materials that give them the opportunity to prepare beforehand (13–15). To do this, we encourage Team Leads to provide introductory materials 1 mo before the 2-wk workshop to establish a foundational understanding of the research project. These materials include 1 review article and 2 to 3 primary research articles focused on the research topic, plus information and instructions on how to download and install coding languages, analysis tools, or other software. Students are provided with information about online courses for learning programming in python, R, or image analysis by using ImageJ. Alternatively, students have the option to engage in collaborative learning through the SCIP (Science Coding Immersion Program), where teams work together on these online courses, fostering a sense of camaraderie and shared learning (16, 17).

Communication and formative assessment are essentials for the course. Multiple communication channels are used immediately before and during the course (e.g., Slack, Discord, and regular check-ins by direct messages or in person), to ensure open and effective interaction and to surface challenges. Daily exit tickets, which are short online surveys (Supplementary Material 3), help Course Directors and Team Leads identify and address any issues daily (18, 19). For example, students have been able to voice their desire to change projects or their need for greater 1-on-1 time with their Team Lead. Team Leads, Peer Mentors, and Course Directors also meet at the end of each day of the course to share experiences and provide or receive advice and support (Fig 1). Reassurances or interventions that help students address personal or logistical issues or problems with team dynamics enable individuals to continue with the course productively.

III. FORMAT AND SCHEDULE

The 2-wk course is structured with daily activities that include All Hands meetings, where all participants gather together for presentations; Flexible Research Time, where teams work independently on research projects; Socials, where participants decompress and bond; and Check-in Times, where individuals can report on issues and receive support (Fig 1).

The first week begins with an orientation to research projects and then an introduction to their teams. Because most of the time in the course is spent working in small teams, establishing team norms during the first meeting is crucial (20). This democratic approach, where each member has a say in how the team operates, helps establish trust and shared expectations. The goal for the first week is to learn about project specifics and to determine questions and hypotheses to test. Team Leads lead discussions on articles provided before the course and teach techniques and data analysis methods. Team members pose questions, design experiments, and begin to collect data.

The All Hands meetings provide opportunities for participants to work across teams and have interactions with other participants and Team Leads. The teams present their progress and findings on the first Friday to help them establish research goals for the second week. These presentations allow them to reflect on successes and failures and to receive and give feedback to other teams. Presenting also provides the participants valuable practice in science communication skills. The second week is focused on data collection and analysis to address questions and hypotheses. The last Friday culminates in a celebration after participants present their overall findings to the larger group.

Four additional features of the course have been especially valuable in creating inclusive and enjoyable environments emphasized in the Dimensions of Mentoring guidelines. These include providing a course directory for sharing of personal preferences, ensuring that basic needs of participants are met, inviting guest speakers to relate personal experiences, and providing elements of fun throughout the course.

Time	Mon	Tue	Wed	Thu	Fri
9–10	**All hands Meeting: Welcome!** Orientation to Projects	Project Planning/ (Optional: Field Trips)	Research and tutorials	Research	Presentation planning
11	Introduction to Groups				
12	Lunch	Lunch and Games	12:00 All hands Lunch Meeting: Speaker: R01 Partner on Focus Topic	12:00 All hands Lunch Meeting: Speaker on Specialized Topic	**12:00pm Project Update Presentations and Lunch**
1–4	Research and tutorials	Research and tutorials	Research	Research and tutorials	Project Planning for next week
5	Regroup/ Assess	Regroup/ Assess	Regroup/ Assess	Regroup/ Assess	
5:30	Project Lead/Peer mentor check-in	Project Lead/Peer mentor check-in	Project Lead/Peer mentor check-in	Social Event	

Weekend

Time	Mon	Tue	Wed	Thu	Fri
9–11	Research - meet with teams to strategize for the week	Research	Research	Research	Finalize Presentations and ouputs
12	12:00 All hands Lunch Meeting: Speaker: R01 Partner on Focus Topic	Lunch	Lunch and Games and Group Photo	12:00 All hands Lunch Meeting: Big Idea Pitches and Career Panel	**12:00pm Final Presentations Concepts, Findings, Celebration**
1–4	Research	Research - leave for Arcadia by 4:30pm	Research; 4:00 Meeting: Speaker on Specialized Topic	Research/ Presentation Planning	
5	Regroup/ Assess		Regroup/ Assess	Regroup/ Assess	
5:30		Social Event	Project Lead/Peer mentor check-in		Project Lead/Peer mentor check-in

Color legend: Activities include	
green: All hands!	All hands Meetings: The meetings in green have speakers on research topics or focus topics like ethics, science communication, or techniques. On Fridays all teams meet together to learn from on another and give feedback to all teams.
clear: flex time	Research/tutorials time: Teams work together on research projects.
pink: Check in!	Regroup/Assess: Participants are reminded to fill out exit tickets to update your group on theirstatus (what you accomplished today and what you plan to do tomorrow.) Coordinators, Team Leads, and Peer mentors check in to debrief about team dynamics and needs and troubleshoot issues with participants.
Socials	These social and professional networking opportunities take place either during the course or after hours informally.

Fig 1. Sample 2-wk research course schedule. Different types of course activities are color coded. The majority of time is spent conducting research in small teams, with course-wide All Hands meetings that focus on either learning about cellular engineering or career development. Check-in times are integral for Peer Mentors, Team Leaders, and Course Directors to share experiences, provide support, and troubleshoot issues that arise in teams.

Students are encouraged to share personal preferences (e.g., favorite foods or restaurants, bands or artists, hobbies) on an online participant course directory. This allows students to connect through similar interests or learn about new ones. Some participants contribute to a yearly online-platform music playlist that reflects the music of all participants, which is played in the background during lunches or before talks.

Meeting basic needs, including technology and meals (breakfast and lunch), is a priority. Doing so allows participants to focus on their scientific goals without logistical concerns. Further, food options featuring different cuisines (from participant recommendations) signals an appreciation and valuation of different cultures. It also provides an opportunity for participants of different cultures to try something new or share their culture with others.

Guest speakers—accomplished professors or professionals with expertise in aspects of cellular engineering and representing diverse backgrounds—are featured in some All Hands meetings. Guest speakers are specifically requested to share their scientific journeys so participants can relate to and hear experiences about a range of career options from these successful individuals.

Elements of fun and camaraderie that are provided on a regular basis are critical for success. Team-building activities, games, and, when possible, field trips are incorporated into the program to achieve a well-balanced experience. These activities are attended by students and Team Leads and provide stress relief and bonding in teams and across the course. Furthermore, Team Leads and Peer Mentors are encouraged to include times in the Research blocks for their teams to take breaks and commune together. These features, which may seem like add-ons, are often the most memorable parts of the course for participants. They allow for input from individuals and interactions across teams that enable additional mentorship opportunities. The boost of morale and energy they provide participants is vital fuel that further drives their research work.

IV. RESEARCH PROJECTS

The Team Leads from the CCC are at the heart of the course; they develop projects that span the multidisciplinary facets of cellular engineering inspired by their own research. The projects have contributed to developing new avenues of research or advancing the research programs of the participating Team Leads and Peer Mentors.

To date, summer course students have been included as co-authors in 2 publications, 4 manuscripts in preparation, 1 patent disclosure, and 9 presentations at national conferences (3 oral, 6 posters; 20, 21). Students have also developed activities to engage the public, including the Exploratorium's After Dark events (San Francisco, CA) and the Estuary and Ocean Science Center's annual Marine Lab Open House (Tiburon, CA). These outcomes illustrate the potential for this course to advance the field and provide a broad range of opportunities to all participants.

A subset of these activities is described to illustrate the scope of project designs that address the CCC Educational Framework and to show how they have been successful.

A. Nonmodel organisms

A number of projects have focused on nonmodel organisms, which are easy to culture and offer a rich set of novel cellular structures and functions that can drive student inquiry. In 1 set of projects, students constructed mazes on agar plates with different physical barriers, then imaged and computationally tracked the growth of the slime mold *Physarum* to adapt to its environment (featured at the Exploratorium as Slime Mold: Unconventional Intelligence).

In other projects including nonmodel organisms, students probed and quantified the habituation behavior of the giant ciliate *Stentor*. A team of multiple students led by a PhD student Team Leader allowed for testing different variables and directions that contributed to a publication (21).

B. Technology development

A key goal of the course is to introduce students to the interdisciplinary nature of cellular engineering. Several projects allowed students to implement the engineering framework to design, build, and test devices that enable new experiments in cellular engineering. These have included a field trip to the Team Lead's laboratory at Stanford University to build microfluidic channels that perform cellular microsurgery (featured at the Exploratorium as Cellular Surgeons and also published [22]), as well as an automated optical system that can generate large-scale data sets.

C. Cutting-edge biology

One fruitful approach for project design is for expert Team Leads to use the 2-wk course to generate data for their newest projects. This setup allows students to engage in experiments at the forefront of cell biology that instill a sense of ownership and contribution to project development. Examples of this approach include optogenetic manipulation of cell signaling to track, quantify, and model mechanisms of polarization and motility of neutrophils and application of optical tweezers to determine chromosome features that influence segregation efficiency during mitosis.

D. Field-based research

To connect laboratory research to real-world effects, several projects address environmental questions from a cellular engineering lens. One project asks how the methane-reducing effects of certain seaweeds is connected to organelle structure and function; students were tasked to collect seaweed samples during a field trip and then perform microscopy to quantify peroxisome content. Another project involved performing and developing machine-learning techniques for the molecular identification of ciliate samples collected on a field trip from nearby ponds, leading to the potential discovery of new species.

E. Using existing data sets

Many projects focus on leveraging existing data sets to develop machine-learning and other computational tools for cell and organelle structure analysis. This type of model was particularly valuable and imperative during the

COVID-19 pandemic, when projects had to be developed for remote modalities. During that time, 1 project modeled the effect of policies aimed at mitigating the spread of COVID-19 in the Navajo Nation population (23).

V. METHODS

The course evaluator joined the course coordinators in planning meetings as they discussed the design of the course, enabling the team to develop a range of formative assessment strategies that would support their goals of creating an inclusive community while being responsive to individual participants' needs and desired outcomes. The assessments included a survey that participants completed before the course began, daily exit tickets, team debrief meetings, and leader debrief meetings (Supplemental Materials 4 and 6). Questions and prompts were developed that would illuminate participants' understanding in process and content goals for the course. The subsequent data are drawn from the final course assessment.

The final course assessment was conducted by using a retrospective pretest–posttest (RPP) design, which asks respondents to record their pretest status (then) at the time of posttest (now). This design, using 2 specific frames of reference, addresses many of the validity issues of the traditional pretest–posttest design, particularly when measuring noncognitive constructs such as confidence, self-efficacy, identity, belonging, and perceived changes in participants' understanding (24). This approach allows the following:

> The RPP design allows participants to gauge the degree of change that they experience with greater awareness and precision than a traditional approach (25).

The RPP designs are also particularly useful for capturing changes in career aspirations (26). In addition, scholars in evaluation have found that an RPP provided greater evidence of change than traditional pretest and posttest of a relatively brief program that participants self-select into, which is true for this course (24). We further chose this method to reduce survey fatigue, given that participants already responded to 2 precourse surveys that helped determine team placement and understand individual participant priorities and interests, which directly addresses one of our core Dimensions of Mentoring aims (Supplemental Material 2). The final survey asked respondents to respond to questions by using a 4-point scale, from 1 to 4. In addition to scaled items, the RPP survey contains open-ended questions that allow participants to provide additional detail and context for their ratings. (Responses to 6 of the open-ended questions are provided in Supplemental Material 7.) The responses to the open-ended questions highlight particularly relevant instances of the psychosocial and emotional support provided throughout the course. Examples of student quotes are interspersed in the description of the results from the quantitative data to further reflect how the foundational principles of the course and approaches of the mentors influenced students' personal and professional development.

For each dimension assessed each year, first, the mean of all participants' prescores on a particular dimension, the mean of all participants' postscores on that dimension, and the change (delta) in those means are calculated. When examining changes across all years of the course (2019–2023), the cumulative means of presurvey scores, the cumulative means of postsurvey scores, and the change (delta) in the cumulative means are calculated (i.e., depicted as "mean delta for combined years" in the tables).

VI. RESULTS AND OUTCOMES

Recruitment strategies were successful in producing a diverse community. In agreement with others, including a minority-serving institution (e.g., SFSU) was critical for broadening participation of groups under-represented in STEM fields (27–29). Of 136 student participants (including peer mentors and Team Leads) over 5 y, 95 were from SFSU (Supplemental Table S3). From self-reported demographics, the student representation of the course mirrors that of the student population of SFSU (Supplemental Table S3). For example, 37% of CCC students taking summer classes reported identifying as Latino/

a/x/Hispanic/Latin American/Mexican compared with 34% from the general population at SFSU. Regarding gender balance from survey respondents, 41% identified as female, 53% identified as male, and 6% identified as nonbinary/gender nonconforming/genderqueer/genderfluid (Supplemental Table 3).

For Peer Mentors and Team Leads, the goal was to provide relatable role models; 38% and 62% of Peer Mentors and Team Leads identified as female and male, respectively. Regarding diversity, Team Leads primarily identified as White or Asian; however, Peer Mentors, who were all SFSU students, reflected the same diversity as the participants. As such, Peer Mentors were found to be approachable and helpful liaisons between participants and Team Leads, which contributed to effective role modeling and mentor training (27). Student participants were often eager to serve as Peer Mentors the following year, and 2 former participants from SFSU served as Team Leads in subsequent years after starting in PhD programs at other institutions.

The progression of 95 SFSU participants was tracked to PhD programs. Of 47 master's students, 20 have entered or have been accepted into PhD programs; of 83 undergraduates, 10 have entered or have been accepted into PhD programs. Of these 30 students, 20 are from groups underrepresented in STEM fields, providing an invaluable opportunity and contribution to the field. Thus, the training provided by the course not only has potential for a significant effect on the future careers of these diverse students but helps build diverse PhD programs across the country.

The final assessment of the student participant experience of the course focused on three overarching goals: addressing the components in the CCC Educational Framework (Supplemental Material 1), determining the extent to which the Dimensions of Mentoring were experienced (Supplemental Material 2), and collecting reflections of participant experience on each year's specific content (Methods; Supplemental Materials 6 and 7).

In addressing the CCC Educational Framework, the survey questions focused on knowledge and skill building in different categories: course-wide, research team–specific, career-related, and transferable (Table 1; Supplemental Material 6). The overarching question was asked: What is your level of confidence in understanding each of the following areas both BEFORE you took this summer course and now, AFTER you have completed the summer course? Some of these categories were consistent across 4–5 y of the course. Another subset of questions was research team specific. For example, several teams in 3 different years had a focus on microscopy, whereas COVID-19 was the focus of 1 team for only 1 y. Because all students in the course are required to participate in and listen to each team's presentations each year, students, regardless of team, learned something about other teams' research topics for that year. For example, 1 student commented that although their team's focus on 1 strategy immersed them in that practice, they also gained knowledge of other topics and tools that other teams used with which they may not have had as much direct experience (all student comments are provided in Supplemental Material 7):

> I didn't know anything about microfluidics or optogenetics before the course started. While I only was immersed in one, I feel that I have, to some extent, added both to my "toolbox" as ideas that I can use in experimental design.

Regarding course-wide knowledge and skills surveyed most consistently (for 4–5 y), significant changes were found in confidence levels (Table 1A) across categories that correspond to core components of the CCC Educational Framework that address "applying an engineering approach to biological problems" for all participants for all years. These include engineering cells and manipulating cells. One student commented:

> Previously, I had only considered evolutionary and genetic perspectives in thinking about biological systems. I will now be incorporating systems thinking and the "engineering mindset" towards my current research and in my future career.

Table 1. Knowledge and skill-building assessment. Participants were asked to answer the following question: "What was/is your level of confidence in understanding each of the following areas both BEFORE you took this summer course and now, AFTER you have completed the summer course?" The mean delta is the change in cumulative means of presurvey scores and postsurvey scores: number of years is the number of years the topic was covered in the course and assessed over a 5-y period, and number of respondents is the number of respondents over a 5-y period. Open-ended responses are provided in Supplemental Table 7. Questions fall into the following overarching categories: course-wide knowledge and skill building, team-specific knowledge and skills, and career development knowledge and skills.

Understanding and learning category	Learning area	Mean delta for combined years	No. of years	No. of respondents
A: Course-wide knowledge and skill building	Image analysis	1.14	5	100
	Manipulating cells	0.97	5	100
	Engineering cells	0.88	5	98
	Coding	0.63	5	97
	Cellular structures	0.85	4	81
	Machine learning	0.70	4	83
B: Team-specific knowledge and skills	Microscopy	0.82	3	57
	Metabolic engineering	0.75	3	53
	Applied math and modeling	0.74	3	56
	Microfluidics	0.96	2	36
	Optogenetics	0.87	2	37
	Electron microscopy	0.81	2	38
	Climate change	0.74	2	43
	Cellular decision-making	1.29	1	19
	COVID-19	0.91	1	22
	Cell mobility	0.76	1	23
	DNA	0.12	1	21
C: Career development knowledge and skills	Implicit bias	0.68	4	80
	Ethics and responsible research	0.61	4	80
	Data presentation	1.08	3	61
	Science communication	0.90	3	61
	Biotechnology and industry opportunities	0.98	1	28
	Entrepreneurship and knowledge transfer	0.92	1	28

Participants also experienced increased confidence in interdisciplinary knowledge and skills building with image analysis, coding, and machine learning.

Students came to appreciate that cellular engineers should have a strong understanding of computer science and programming. For example, 1 student stated the following:

> While working on this project, I had many ideas on how this program could be enhanced to better analyze our images; however, I lacked the coding skills necessary to develop a program myself. I see it is important for a cellular engineer to have computer science skills because they know what they are looking for in an efficient program. A different type of program developer may not have the appropriate background knowledge in biology to create an algorithm that meets your criteria of analysis.

Increases in confidence on items associated with team-specific knowledge and skills were seen in participants each year (Table 1B). This was most evident with climate change or COVID-19, which were covered only by 1 team each for 2 or 1 y, respectively. Gains in confidence across the course are attributed to the weekly presentations and interactions across teams where knowledge was shared. For comparison, assessing gains was included for categories that, although covered in the course, were already well known to students (e.g., DNA); little gain was found, largely because participants are quite familiar with DNA and its structure and function when they enter the course.

Each year, focus was placed on knowledge and skills that would aid in a participant's career development (Table 1C). Students feel more confident in themselves after a 2-wk period; achieving this goal helps participants in both their short- and long-term educational aspirations. For example, significant changes in confidence were seen in data presentation and science communication. Students' comments on the RPP survey illustrate increased confidence in and enjoyment of research, resulting from the inclusive nature of the course and the communication between leaders and participants. One student stated the following:

> I would definitely say that after having taken this course, I have more confidence in myself. I think that by boosting the confidence in my own scientific abilities, I have fostered a sense of belonging in the research community. This has led me to truly believe that I can do a PhD.

Moderate gains were found in other content-based categories, such as implicit bias (0.68) and ethics (0.61), and high gains were found in entrepreneurship and knowledge transfer (0.92), which were covered mostly in guest lectures (Table 1). A student commented the following:

> The discussions about implicit bias and machine learning made me way more aware of how engineers'/programmers' implicit biases can affect people once the technologies they develop are put to use in the world. I was very unaware of how prevalent machine learning–based technologies already are in our society, how they are shaped by their developers' biases, and how that is leading to unequal treatment of minorities and people of color.

Another student stated the following:

> The CE [cellular engineering] course helped me to remember that in cellular engineering, the onus lies on us to not only advance science, but to do so in a responsible way, with responsible conduct of research.

Students were encouraged to share their views on how the summer course experience would affect them in their future, and they were surveyed about how they felt about knowledge and skills from the course that they would view as transferable to their career development (Table 2). A set of these transferable skills directly relate to the CCC Educational Framework, where increases in confidence were seen in using quantitative techniques and computers to analyze and visualize biological data and in "employing an engineering mindset to solve biological problems," a key goal of the CCC (Table 2A). Thus, despite working on different specific research projects, uniform benefits in the overall goal to promote a cellular engineering mindset and principles were found.

One student noted the following:

> When I began my research career, I believed that basic computational skills would suffice and that most of the analysis was done through microscopy and qualitative observations. After this course, I have learned that having more advanced skills in computer science can serve as a great tool to both qualitatively and quantitatively analyze your data and get more clear results.

Another student stated the following:

> The course demonstrated to me that I am able to gain significant competency within a short period of time (given the right tools and support). It also showed me how useful even a small toolbox of computer science skills can be in answering biological questions. I am also more likely to apply to jobs that take an engineering approach to biology (I am planning to go into biotech after my degree).

Substantial gains were found in confidence in communication and management skills (Table 2B), some of which are directly drawn from the CCC Dimensions of Mentoring, including working with others and making decisions about research

Table 2. Transferable skills assessment. Participants were asked to answer the following question: "What was/is your level of confidence in each of the following areas both BEFORE you took this summer course and now, AFTER you have completed the summer course?" The number of years is the number of years the topic was covered in the course and assessed over a 5-y period, the mean delta is the change in cumulative means of presurvey scores and postsurvey scores, and number of respondents is the number of respondents over a 5-y period. Open-ended responses are provided in Supplemental Table 7. Questions fall into the following overarching categories: skills from CCC Educational Framework and communication and management.

Transferable skill categories	Experience areas	Mean delta for all years combined	*N*	No. of y
A: Skills from CCC Educational Framework	Employing an engineering mindset to solve biological problems	0.96	93	5
	Applying quantitative techniques to solve biological problems	0.92	96	5
	Using computers to analyze data	0.92	97	5
	Using computers to visualize data	0.88	96	5
B: Communication and management	Working with others with different experience levels	0.96	99	5
	Working with others from different disciplines	0.96	98	5
	Making decisions about research design	0.90	98	5
	Managing research time	0.80	96	5
	Communicating what you do to an audience outside of science	0.73	96	5
	Developing good presentations	0.66	96	5
	Providing feedback on others' research	0.63	96	5

design. These results show that the framework created with principles from the Dimensions of Mentoring was effective. Mentors at different levels were able to build strong inclusive teams, coach practical skills, and promote individual advocacy.

The following student quotes are highlighted to illustrate the students' experience with mentorship in the course and how that experience has influenced them.

> I liked the level of independence we had with the project. It allowed me to develop better problem-solving skills as well as enhanced my decision-making skills. I also liked how my mentor stepped in when necessary and provided guidance while allowing us to figure things out on our own. I feel this kind of mentorship allowed me to flourish as a scientist.

> Having the ability to connect with different PIs [principal investigators] who all took different routes toward their current career opened my eyes on the different options I have when it comes to preparing myself for graduate school.

> I think this course helped me better engage with the research community. It helped set a precedent for me that it matters what lab and lab members you are with. It made me consider looking into research as a career again.

> I was paired with team members of various levels of experience and skill. We all came together to make a cohesive product that was presented to dozens of experienced scientists. We came together because of good leadership, and an encouraging, well-spirited team, with some pressure of succeeding. All of these aspects are things I will take away from the course.

VII. DISCUSSION

A structure is introduced for an interdisciplinary and inclusive summer course that maximizes opportunities for mentorship and provides long-lasting feelings of community across members from different educational and career levels. The following critical factors were found to contribute to the success of a 2-wk summer experience.

First, a productive mindset that aligns expectations from different participants must be emphasized. In 2 wk, gains in technical skills, addressing individual research questions, combined contributions to short-term research projects, and embracing failure are invaluable. Working in small teams that celebrate effort and encourage originality creates a positive community where all members, regardless of level, feel supported, valued, and energized (30). Further, providing fun activities often has the most long-lasting effect—simple games or field trips can level the playing field across the community, increase feelings of inclusion and belonging, and produce long-lasting relationships that benefit both students and mentors.

Second, a commitment to respecting the values and priorities of every individual is an essential message during the course; this messaging begins with precourse surveys. Setting team norms among team members on the first day sets the tone that individual contributions will be respected. Daily exit tickets provide a way for participants to alert course directors and Team Leads to issues that can be addressed quickly (18, 19). Having multiple levels of mentors via Peer Mentors and Team Leads allows students to confide in and build relationships with those with whom they feel most comfortable. Peer Mentors, in particular, provide a critical link between students and Team Leads (27). During the course, Peer Mentors gain confidence in research and mentoring skills and develop mentoring relationships that result in positive recommendation letters that contribute a significant outcome on their STEM careers.

Third, a multitiered environment of multiple small teams, in which members can help one another learn skills and work on research discovery, allows for strong bonding and support. Engaged and supportive Peer Mentors and Team Leads serve as critical role models and technical advisors (7). All-hands meetings, socials, and career panel activities allow for increased interactions across teams that provide additional mentorship opportunities. Thus, although teams work in parallel on different research projects, a shared sense of experience and bonding is found from the multiple daily activities.

In preparing and assessing the course, it is critical to have advisors and partners who have expertise in education and assessment. For this project, partnership occurred with the Science and Health Education Partnership at UCSF, which has extensive experience hosting and assessing summer courses. The regular interaction between course directors and these partners allows for tying course goals with the CCC Educational Framework and Dimensions of Mentoring. The Dimensions of Mentoring policy evolved year to year with the development of the course. The continued conversation about how the practical aspects of the course aligned with the principles allowed these overarching guiding documents to evolve as well. It also allowed for optimizing course content and assessment year to year.

Three notable setbacks and challenges occurred during the courses. First, the second year of the course occurred during the COVID-19 pandemic in 2020. To adapt, the course shifted to a fully online format. This required changing research projects from in-person data collection to remote data analysis conducted on personal computers. Data sets were shared on flash drives via mail, and students worked remotely through online platforms (e.g., Zoom and Slack). Students gained valuable computational data analysis and presentation skills and also formed strong personal connections. Connection through team-building activities—online group meetings, work sessions, and interactive online games—was critical to success.

Recruiting Team Leads demonstrated a second challenging experience. Payment for participation and having involvement explicitly encouraged and valued by the leadership of the CCC proved to be integral factors that helped incentivize participation of PhD students, postdocs, and professors. Past participants testified that the time and effort are well spent and enjoyable.

The third challenging task comes from the intense 2-wk period experienced during the course. Successfully teaching and implementing research projects and then having 2 research presentations in a 2-wk period requires a significant amount of learning and effort. Course Coordinators are invaluable for organizing activities and supporting and overseeing the experience of all participants. Overall, the intensity allows for immersive engagement and bonding of team members. Having some flexibility and strong communication, as well as fun activities and food availability, allows for successful outcomes and experiences.

Finally, it is relevant to emphasize that the work of all participants was valued not just in principle but also monetarily (31). Student participants were paid a small sum to help them pay for transportation costs and to offset loss of employment during the 2-wk period. Even so, some students who work full time were not able to commit to a 9 AM to 5 PM schedule for 2 wk. Providing loaner computers and flexibility with some aspects that would normally be barriers for some participants, including Wi-Fi access or excusing a missed partial day because of unforeseen issues, also greatly helped with student participation. Peer Mentors, Team Leads, and Course Coordinators were also paid for their work during preparation time and the 2-wk period. It is acknowledged that some funding agencies have specific rules that prohibit costs for food; for this project, private foundation funds were able to be leveraged, but it is advocated to use funds with appropriate justifications to create environments that are welcoming and have sufficient resources to enable participants to focus on work as much as possible.

Overall, although it is an intense 2-wk period, participants report high satisfaction with a discovery-based interdisciplinary research experience because of the supported environment. The strong community created with the mindset of discovery and self-advocacy has had a lasting positive effect on individuals and the overall research productivity of the Center.

AUTHOR CONTRIBUTIONS

Y-HMC, MP, KN, and DSC designed teaching materials, curriculum, and educational research; Y-HMC and DSC performed teaching and educational research; Y-HMC, MP, and DSC analyzed data; MP and KN contributed analytic tools; and Y-HMC, MP, and DSC wrote the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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