

A New Model for a Multi-Disciplinary Engineering Summer Research Program for High School Seniors: Program Overview, Effectiveness, and Outcomes

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Abstract

The High School Summer Research Program (HSSRP) is a rigorous eight-week research experience that challenges high school students to a novel scientific question in an engineering laboratory at the Henry Samueli School of Engineering and Applied Science (HSSEAS) at the University of California, Los Angeles (UCLA). The program collates highly motivated students from all socioeconomic statuses, ethnicities, and genders to increase the diversity of applicants for STEM majors at four-year universities, and thereby potentially promotes a more diverse and innovative STEM workforce. To supplement students' unique research projects, HSSRP comprises several professional development opportunities, such as faculty presentations, lab tours, and industry tech talks. Students are trained to communicate their research through scientific posters and oral presentations in a "learn-by-teaching" system that further exposes all students to the multitude of creative strategies that are currently employed across the engineering disciplines to tackle world issues. This integrates with HSSRP's strong social element, which encourages students to act as a support system for each other in the midst of the challenging eight weeks, and serves as a network for students after the program. A survey of the 2014–2016 HSSRP classes indicates high satisfaction with the program, and a high likelihood of pursuing a STEM degree and advanced STEM degrees. Surveys of HSSRP alumni shows that a vast percentage of students are pursuing STEM degrees or are currently working in the STEM field.

1. Introduction

The demand for qualified and capable STEM professionals to push technological advances in today's society is estimated to grow by nine million jobs from 2012–2022 (US Bureau of Labor Statistics, 2016), faster than any other U.S. sector. However, a 2010 NSF study found that 87% of STEM professionals were either Caucasian or Asian (National Science Foundation, 2016). Diversity strengthens the talent pool and increases productivity by allowing multiple perspectives to engage in cooperative problem-solving (McGee, 2012; Science Mag, 2016). Additionally,

a diverse workforce can better understand the needs of all demographics (including cultural competency and accessibility) (Cohen, 2002; Chubin, 2005) and can drive innovation accordingly to serve the entire population.

There is a call to encourage high school students to pursue engineering degrees at ABET-accredited institutions, and high school outreach programs have demonstrated their efficiency in bolstering the diversity of the pipeline (Strayhorn, 2010). By engaging high school students of all backgrounds and exposing them to the field of engineering, they are better equipped to make informed decisions on their career paths and the types of societal challenges they wish to impact (Aschbacher, 2010).

Many summer engineering outreach programs are designed to introduce students to engineering concepts through additional instruction, as well as hands-on experience to coincide with coursework (Raines, 2010). However, very few programs offer students the experience of the true nature of engineering research. While several research based summer programs exist for high school students (Florida State University, 2016; Center for Excellence in Education, 2016; Northeastern University, 2016; Stony Brook University, 2016; Michigan State University, 2016), our model is unique for its emphasis on a combination of laboratory-based engineering research, seminars on applying to college engineering programs, development of scientific communication skills, and campus-based social opportunities.

In this paper, we outline a new model for a summer pre-engineering program that exposes students to real engineering research with a "learn-by-doing" approach. The High School Summer Research Program (HSSRP) at the University of California – Los Angeles (UCLA) Henry Samueli School of Engineering and Applied Sciences (HSSEAS) is an eight-week research-intensive program geared toward actively immersing exceptional rising high school seniors in engineering research laboratories. Students in HSSRP conduct projects designated by their assigned laboratory and are quickly instilled with the understanding that their projects are not guaranteed to succeed, enabling them to develop inquisitiveness in light of unexpected results, patience after failed experiments, and communication skills in working with their more

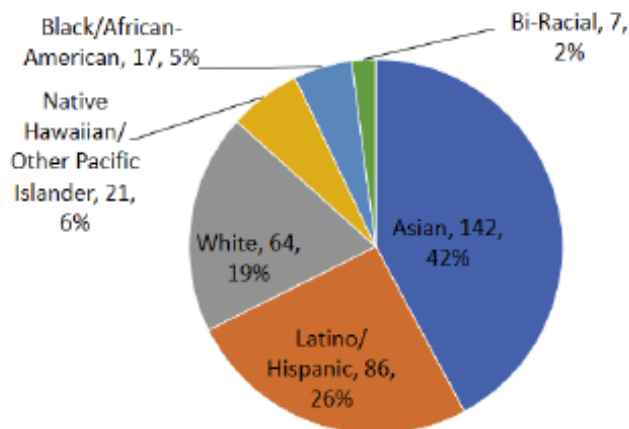
experienced research colleagues, such as undergraduate students, graduate students, developmental engineers, laboratory technicians, and post-doctoral scholars. The program emphasizes collaborative learning that uses the perspectives and input from all students to improve the quality of each student's final deliverables. This is facilitated by the strong social aspect that binds the students together to achieve a common goal. Motivation for success is governed by the notion of learning and contributing something new to the field. Students are encouraged to push the boundaries of current scientific knowledge as opposed to focusing on an assigned letter grade or score.

2. Program Demographics and Administration

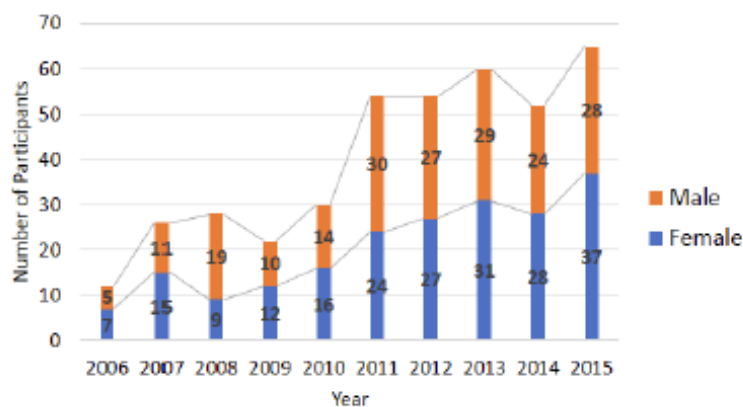
Outreach programs within the HSSEAS Engineering Science Corps (ESC) have implemented a pipeline strategy for increasing the merit and diversity in its applicant pool. High school freshmen and sophomores from UCLA-affiliated schools are encouraged to seek help from undergraduate students through HSSEAS ESC's Online Tutoring and Mentoring Program (OTMP) (UCLA Online Tutoring and Mentoring Program, 2016). The HSSEAS ESC's four-week summer program Tech Camp (UCLA Engineering Tech Camp, 2016) engages rising high school sophomores and juniors to collaborate in teams to design, build, and test a prototype with the assistance of engineering student mentors. This leads into the final step of the pipeline, HSSRP (UCLA HSSRP, 2016), where exceptional rising high school seniors are immersed in laboratories across one of the seven engineering departments of HSSEAS. Each individual student or student pair is given a unique research project that falls within the research scope of their host lab. They are simultaneously given the resources to prepare competitive applications to esteemed four-year engineering institutions, including UCLA. The program targets rising high school seniors in particular because of their maturity in handling themselves in laboratory environments and their receptiveness to the variety of pre-college materials and seminars that UCLA HSSEAS is well-suited to offer.

HSSRP selects students largely on merit, with most students being exceptionally motivated and high-per-

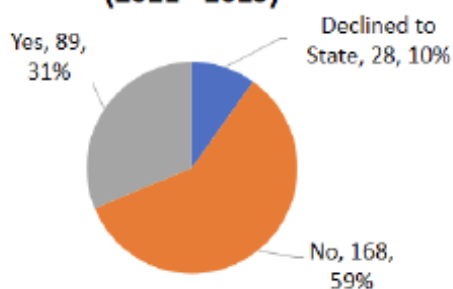
Overall Ethnicity/ Race Distribution (2006 - 2015)



Gender Count Distribution by Year (2006 - 2015)



First Generation College (2011 - 2015)



Low-Income Students (2011 - 2015)

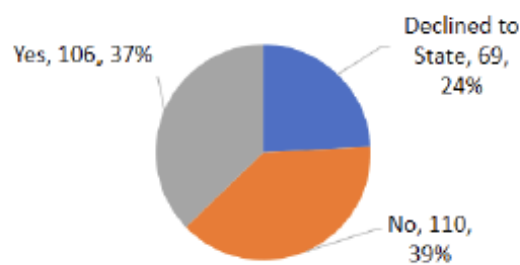


Figure 1: Demographics of the HSSRP program. From 2013-2015, 54.1% of HSSRP students were female, compared to 21.7% of the UCLA undergraduate engineering classes. During the same time period, 31.9% of HSSRP students belonged to underrepresented minority groups, compared to 5.8% of the UCLA undergraduate engineering classes (UCLA UCEE Report, 2015).

forming in their respective high schools. However, HSSRP is also targeted to low-income, first-generation, and underrepresented minority students, with a 50:50 ratio of male and female (Fig 1). Most students are California residents with approximately half commuting from the local Los Angeles area. Each student's HSSRP application includes a transcript, personal statement, letters of recommendation, and ranking of preferred engineering departments. From a pool of pre-selected students, participating faculty members choose the individual students they will host in their labs.

HSSRP has been supported by UCLA HSSEAS, the Ahmanson Foundation, Nicholas Endowment, Padway Foundation, and Samueli Foundation. Funding goes toward housing for low income students, catering, poster printing fees, and staff costs. The staff is comprised of one staff director who oversees all program activities, three graduate student facilitators who lead workshops and assist in program activities, and one undergraduate office clerk responsible for website organization and logistical tasks for each event. Additionally, five undergraduate residential team advisors were awarded free room and board in on-campus dormitories for their service in monitoring and mentoring in-residence students. Moreover, graduate student researchers and exceptional undergraduate stu-

dent researchers in each participating lab serve as unpaid daily lab supervisors (DLS) who volunteer to work directly with one or two students and oversee their projects. Other expenses typically go toward event logistics such as catering and room reservations. The program is free of charge to students except for room and board costs for students who opt to live in on-campus dormitories. Low-income students receive small stipends to cover their commute expenses, or for room and board if necessary.

Historically, the three graduate student program facilitators serve for multiple years, so most training is done on the job with guidance from the returning facilitator(s) and the director. Residential team advisors are hand-selected by the coordinator and facilitators in a unique group interview that qualitatively tests groups of five interviewees for how they work as a team to problem-solve realistic scenarios they would encounter as advisors. Faculty advisors and their laboratories are largely solicited by the coordinator based on their service in previous years, and the faculty advisor can select a graduate student from his or her lab to serve as the DLS. The program's facilitators partner with the Engineering Graduate Student Association (EGSA) to host information sessions that target graduate students interested in serving as a DLS. In this bottom-up ap-

proach, graduate students are solicited by their interest in mentorship and outreach, as well as goals of future careers in academia or education. All DLSs are required to attend a pre-program information session that discusses their duties in assisting the students to fulfill program requirements in their independent projects, as well as strategies on mentorship and types of projects suitable for students to complete in the eight weeks. They are provided a document known as a Preparedness Timeline to keep them on track with their students, as well as an optional luncheon to share their experiences and learn mentorship strategies from other DLSs.

Program staff members and DLSs are responsible for the safety of their students. Each HSSRP student is required to attend relevant UCLA laboratory safety training courses before beginning their projects. It is also the responsibility of faculty and DLSs to outline laboratory-specific site orientations and safety protocol. Additionally, an emergency contact list of all students, their guardians, and their daily lab supervisors is prepared at the beginning of the program to ensure every student is accounted for at all times of the day. Since residential advisors are primarily responsible for the well-being of thirty minors who are living away from home for the first time, they

attend mandatory, three-day intensive training sessions covering safety and emergency protocols, reporting and documentation procedures, mentoring techniques, and basic mental health training to be able to respond to any issues that arise. Housing students are required to notify their designated residential advisor of their location at all times and are required to follow strict curfew regulations.

3. Program Overview and Goals

HSSRP strives to be mutually beneficial to all constituents of the program. HSSEAS aims to continually increase the strength of its undergraduate applicant pool by attracting highly exceptional high school students. The program staff, including advisors and graduate DLSs, garner professional development in the form of mentorship skills. All HSSRP affiliates share the goal of giving high school students the rare opportunity to perform cutting-edge scientific research, which leaves them more well-informed in deciding future academic and career paths.

3.1. Research Experience

The primary focus of HSSRP is for students to conduct real, cutting-edge research in an engineering lab at UCLA, motivated by a full scientific question, hypothesis, and research plan. Students are paired with a DLS from their lab, who works closely with the students on a day-to-day basis in managing their project progress, teaching hands-on lab tools and techniques as well as theoretical background knowledge, and offering support in designing their program deliverables, such as the scientific poster and seven-minute oral presentations. HSSRP projects are commonly closely related to the DLS's research and always fall within the broad research objectives of the lab. Students are expected to produce enough results to draw appropriate conclusions and discuss contributions to their field. Through active engagement in the scientific process with a project of unknown outcome, students develop understanding of the true nature and excitement of scientific discovery.

Research projects are selected by each host laboratory. Approximately half of HSSRP's students work on individual projects and the other half work in pairs, which is also determined by the host laboratory. Seven sample research projects are listed below, while the full list from past programs can be found online (UCLA HSSRP, 2016):

1. Diaz, A.C, Wong, V., & Kamei, D., "Determining bio marker concentration with lateral flow immunoassay," Dept. of Bioengineering, UCLA HSSRP (2016).
2. Fernandez, A., Azzam, S., Simonetti, D., "Synthesis and application of electrospun nanofibers for the desulfurization of hydrocarbon streams," Dept. of Chemical and Biomolecular Engineering, UCLA HSSRP (2015).
3. Barajas, K., Hernandez, G., Ballard, Z., Ozcan, A., "Tear analysis on a contact lens using a cellphone-

Monday	Tuesday	Wednesday	Thursday	Friday
9a-10a: Journal club 5p-6p: Industry Tech Talk	11a-1p: Faculty presentation and luncheon	9a-10a: Journal club 4p-6p: Lab tours or graduate student panel	3p-5p: Poster workshop 6p-8p: Full group dinner	9a-10a: Weekly check-in meeting 12p-1p: Open office hours with program facilitators

Table 1: Typical weekly schedule for out-of-lab activities. Students are expected to attend all HSSRP group programs and work in their laboratories throughout the remainder of the work week.

4. Pino, A., Ye, P., Xie, Y.-H., "Fabrication of two-dimensional molybdenum disulfide crystals by chemical vapor deposition for use in transistors," Dept. of Materials Science and Engineering, UCLA HSSRP (2015).
5. David, B., Zeller, C., Eslami, M., Brandenburg, S., "Investigating the engineering properties of fine-grained soils with varying pore fluid," Dept. of Civil and Environmental Engineering, UCLA HSSRP (2016).
6. Castillo, C., King, C., Sarrafzadeh, M., "Development of a smartwatch user interface to improve usability for asthma management," Dept. of Computer Science, UCLA HSSRP (2016).
7. Kamnani, S., Pikula, D., Song, Y., Hopkins, J., "Design, analysis, and fabrication of non-periodic microstructural compliant airplane wings using freedom, actuation, and constraint topologies," Dept. of Mechanical and Aerospace Engineering, UCLA HSSRP (2015).

In addition to deep immersion in a single engineering lab, students take a series of lab tours of their choice of over thirty-five different labs from the seven departments in HSSEAS - Mechanical and Aerospace Engineering, Materials & Science Engineering, Electrical Engineering, Computer Science, Bioengineering, Chemical and Biomolecular Engineering, and Civil and Environmental Engineering.

Outside of their lab work, the students attend seven weekly presentations from distinguished faculty from each of the different engineering departments. They attend five industry tech talks from UCLA HSSEAS alumni representatives of major engineering companies such as Two-Bit Circus, Disney Imagineering, Raytheon, Tempo, and Northrop Grumman. Presenters enthrall students with their line of work and offer guidance based on their career path and experience. Taken together, the research component of HSSRP enables students to make a conscious choice of which fields of engineering, if any, are most appealing to them.

3.2. Science Communication

Equal emphasis is placed on learning and developing effective laboratory research communication in a concise and captivating manner to both scientific and non-scientific audiences.

The graduate student facilitators lead two main types of workshops that enable students to hone their skills in appealing to their audience: journal clubs and poster workshops. Table 1 provides an example of a typical week in HSSRP.

The three facilitators lead concurrent biweekly journal club sessions, where students take turns delivering a seven-minute talk on a journal article related to their project (weeks 2-4), as well as a seven-minute talk on their progress in lab (weeks 5-7). The facilitator and the students in each section's audience provide real-time written and oral feedback to their peers regarding presentation strengths and areas of improvement. As audience members, the students are further exposed to specific research projects in the seven engineering departments, but also pick up creative and effective presenter skills they can use for their own presentations. In the final week of the program, all students give polished seven-minute oral project summary presentations and answer questions from their audience of fellow students, teachers, mentors, lab mates, and professors.

Facilitators also lead five poster workshops where they teach students how to craft compelling and professional scientific posters. In addition to personalized facilitator input on communication clarity and appealing poster layout, students learn from their peers, as they are free to walk around during the sessions and organically offer constructive criticism of each other's work. On the final day of the program, students present their posters to professors and family in a poster symposium. This event (Fig. 2) serves as the culmination of the program: students wear conference attire, the event is catered, awards for best oral presentation and best poster are given to top students, and certificates of completion signed by the Dean of HSSEAS are awarded to all students at a formal ceremony.

Finally, students complete lab reports of their work to develop skills in writing and formatting for a publication while simultaneously producing a writing sample to submit in college applications.

3.3. Social Development

The program places great emphasis on the social aspect with the realization that the strong bonds students develop with their peers, lab mates, and program staff will serve as a component of their life-long personal and professional network. Typically, students are far from their

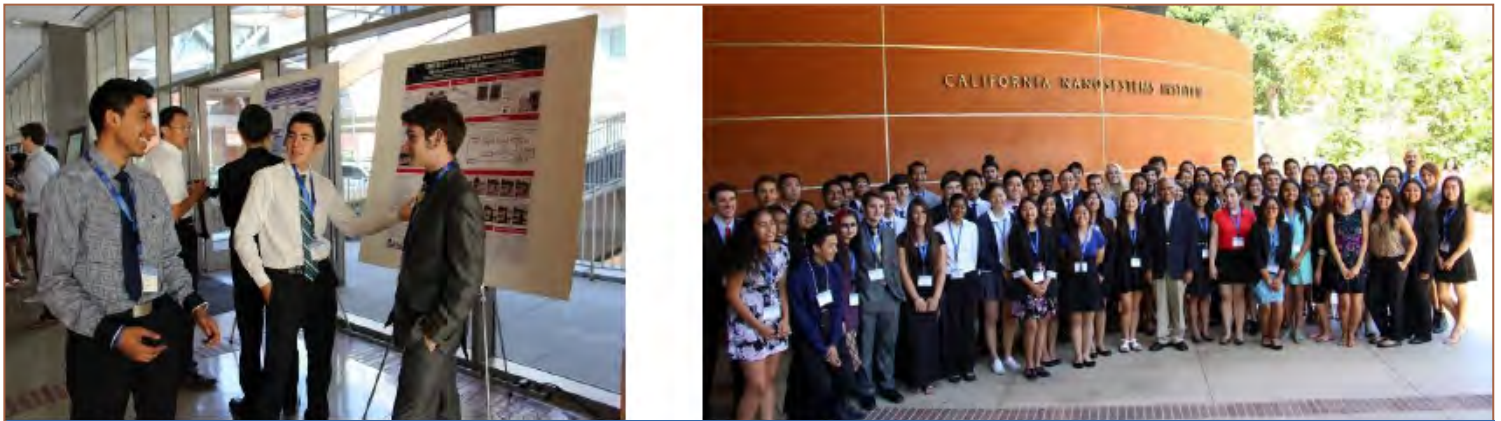


Figure 2: The final poster symposium is the program's culminating event. (Left) Students deliver their one-minute program pitch in front of their poster and (right) all sixty-five students from the 2015 program have their photo taken with Dean Vijay K. Dhir.

comfort zones when they arrive, due to being away from home for the first time and being in an environment where they know comparatively very little. The initial focus is to establish the tone of the program as a rigorous, yet enjoyable eight-week experience. Research shows that building a strong sense of community among students increases persistence, particularly in traditionally underrepresented communities (Toven-Lindsey, 2015). Several ice-breaker activities such as a campus scavenger hunt and a full afternoon at the campus ropes course facilitate the group's tight-knit culture.

Roughly half of the students are local Los Angeles residents and commute to campus, while the other half stay together in the UCLA dormitories. The housing component adds significantly to the social aspect for those students since they live together and experience a taste of college life. Furthermore, five undergraduate residential advisors monitor the residential students and serve as additional mentors throughout the eight weeks. The residential advisors, as well as the facilitators, plan numerous social activities available to all students of the program, ranging from team sports and dinners to visits of Los Angeles attractions.

Because the program is characterized by diverse research labs with research projects that do not guarantee success, facilitators lead weekly check-in meetings, which serve as a safe space for students to freely discuss their research pitfalls. These include experimental failures and social struggles with their HSSRP team mates or lab mates. Students work in sub-groups of five or six people to problem-solve their challenges together, with the facilitator available to offer their expert advice. Sub-groups were assembled with diversity in mind; the student population itself is highly diverse ethnically, culturally, and socio-economically, and many students quickly appreciate the exposure to a vast spread of perspectives. Ultimately the weekly check-ins serve as another avenue for students to be exposed to the full breadth of possible challenges that may arise in a research setting and to diverse lab cultures (i.e. large vs. small labs, structured vs. open-ended research goals, or experimental vs. theoretical methods).

3.4. Preparation for the Future

Several out-of-lab activities are geared toward preparing rising seniors for college applications and scholarship deadlines after HSSRP. A personal statement workshop, followed by personal statement draft deadlines encourage students to compose their University of California personal insight essays, and upon request they receive feedback on flow and structure of their personal narratives.

Graduate student panels provide strategies for overcoming common research pitfalls, and also discuss education and career paths of a few diverse engineering graduate students. HSSRP alumni panels bring in former HSSRP students to discuss their experience in the program and offer advice on how to take full advantage of the opportunities that are offered in the eight weeks. They also discuss strategies for college preparation, including their balance of classwork with applications in their senior year, and what to consider when choosing a college and a major. Finally, HSSRP online alumni mentors provide personalized advice to two current HSSRP students on fulfilling program requirements and considering college applications.

4. Survey Results

Surveys were conducted to assess the HSSRP student satisfaction. Survey results and historical data were analyzed to determine program growth, benefits to the HSEAS applicant pool, and the long-term impact of HSSRP on its students.

4.1. Program Exit Survey: Qualitative Results

A qualitative assessment of the HSSRP program was given by all students in the 2014, 2015, and 2016 programs. The goals of the survey were to (1) investigate the overall degree of participant satisfaction and (2) gather information about specific aspects of the program (including journal clubs, poster workshops, and weekly check-in meetings) so that these components can be further refined in subsequent years. All questions in Tables 2 and 3 were framed on a 1-5 scale with 5 representing the

highest level of satisfaction or agreement, 1 representing the lowest level of satisfaction or agreement, and 3 representing a neutral stance.

Results regarding program satisfaction and components are summarized in Table 2. Questions 1-4 illustrate that most students reported positive experiences with their individual research projects, daily lab supervisor, and lab teams. Based upon DLS feedback, the high ratings are primarily a result of both (1) the DLS training sessions and (2) repeated encouragement for students to seek help through a multitude of channels when they encountered difficulties in their research, which highlights the critical role of mentoring in the program. While professors hosted HSSRP students in their labs, they typically enlisted their graduate researchers to advise HSSRP students on a day-to-day basis. However, as a requirement, each student met their professors at least once at the beginning and once at the end of the program for interviews, where they were coached on how to ask for feedback from the professor and ask for a letter of recommendation. Additionally, all students were strongly encouraged to attend their research laboratory's group meetings where they can interact with the professor and all of the graduate students to get a holistic view of how their lab operates. However, each lab environment represented an uncontrollable variable for the program staff so it was especially important to effectively communicate expectations and responsibilities to both students and supervisors. In some rare instances it has been necessary for HSSRP staff to contact professors directly about obstacles in working relationships between students and their supervisors.

Questions 5-9 assessed the four main weekly or bi-weekly HSSRP program components. Students reported positive experiences with the industry tech talks and faculty presentations, likely because they offered a chance to learn about different cutting-edge topics across all engineering fields, further facilitating decisions on their future career paths. The journal club and weekly check-in ratings had lower mean scores with higher standard deviations, but these components are recognized as important student development opportunities and continued to see

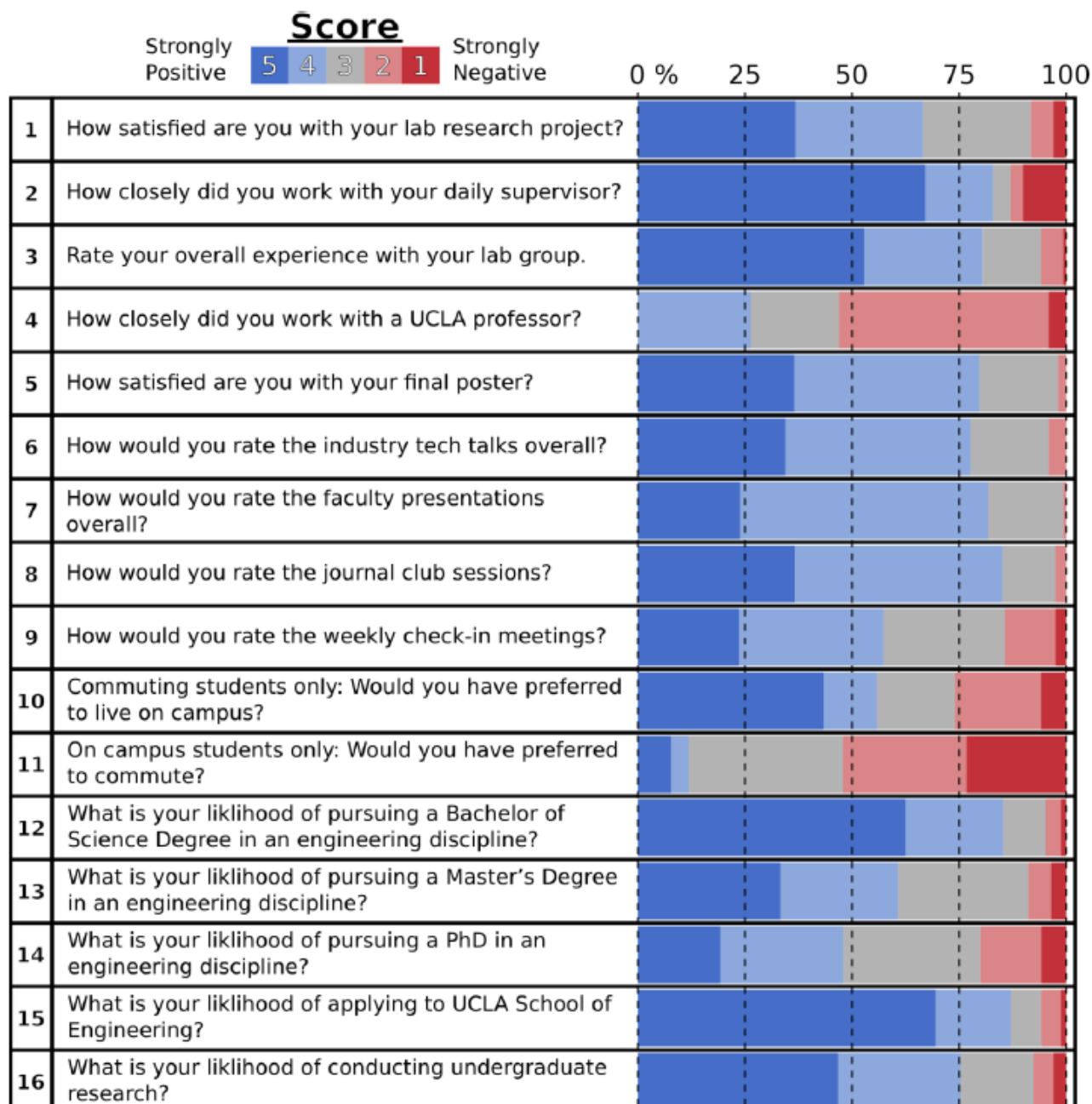


Table 2: Questions and results from the 2014, 2015, and 2016 program exit surveys, in which 169 students were surveyed.

improvements over the years. For example, this section now begins with the facilitators posing social scenarios for students to solve in teams; these scenarios closely resemble research and common social pitfalls that students face in the program. These commitments mandated regular participation from all students in terms of both delivering research progress as well as giving and receiving feedback. It was important for the facilitators to maintain a positive and encouraging environment while simultaneously providing honest critique of student work.

Questions 10-11 in Table 2 demonstrate the value of on-campus housing. Students who opted to live in UCLA-owned dormitories reported higher levels of satisfaction than those who commuted daily from the surround-

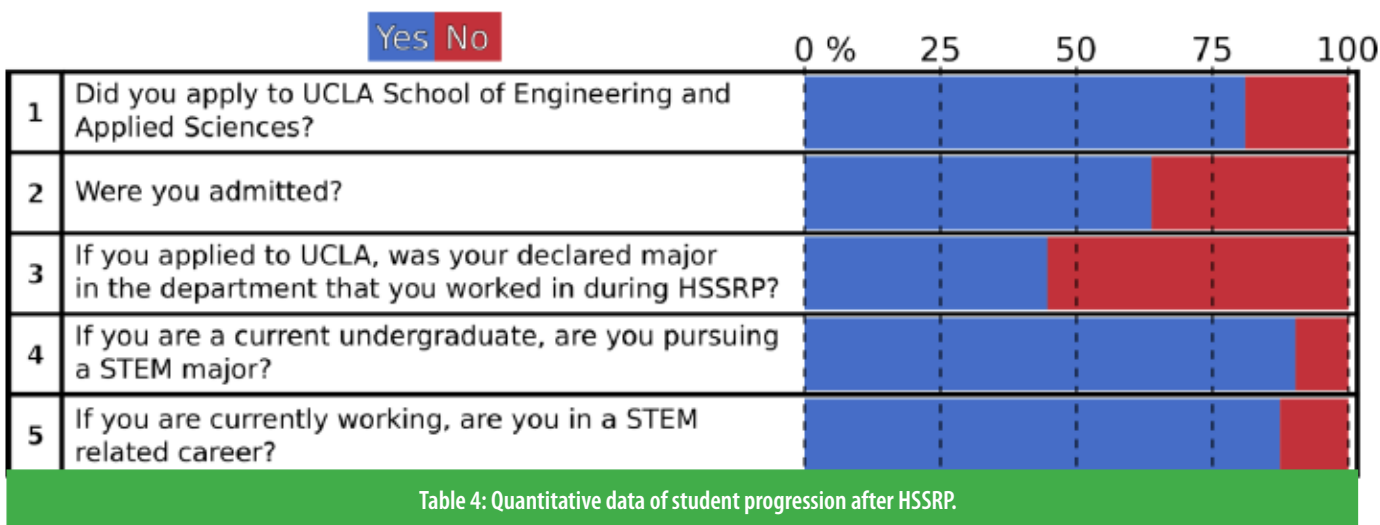
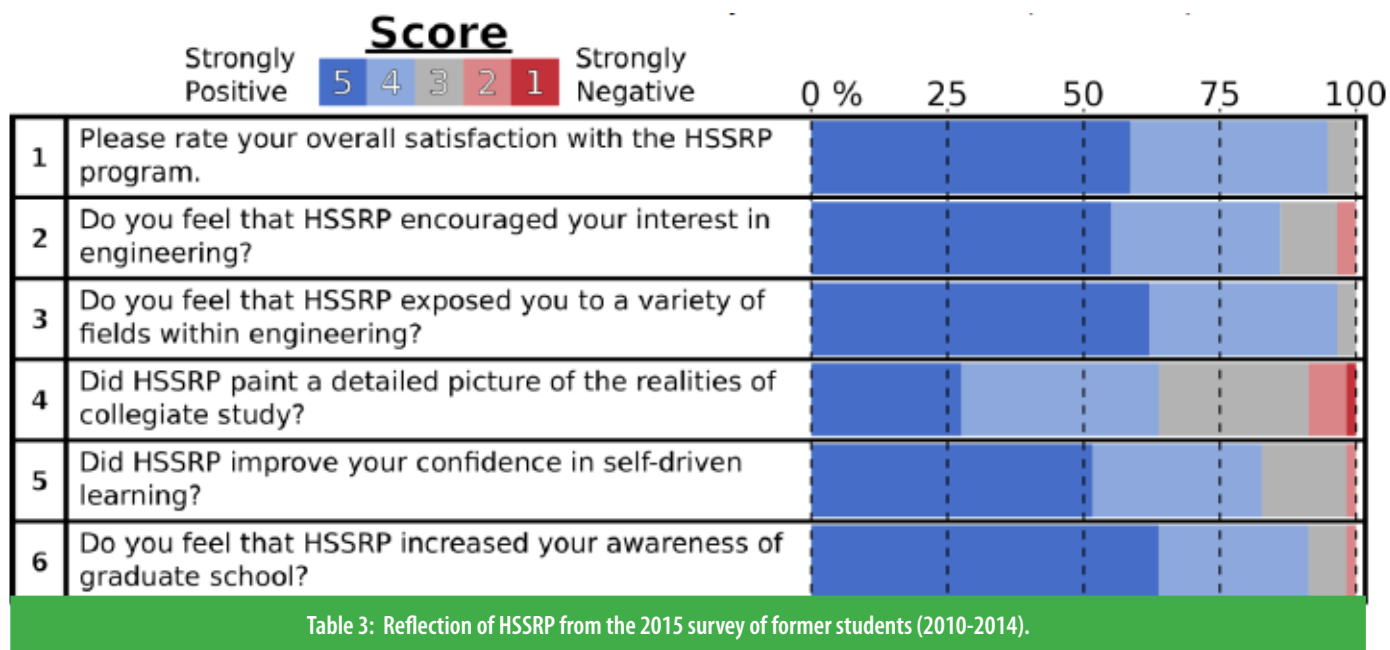
ing area. On-campus students had the benefit of dining commons and gym access, as well as the option to travel home on weekends or participate in weekend programming organized by the residential staff. Additionally, each year the program staff witnessed the on-campus students rapidly develop strong friendships which also served as a support network for lab-related issues. Commuting students had the benefit of returning home to their families each evening, but that came at the expense of less shared time with peers and having to travel through Los Angeles traffic.

The results regarding engineering as a future path are summarized in questions 12-16 of Table 2. The students reported a high level of interest in an undergraduate

engineering program. The mean scores decreased and standard deviation increased as the questions extended to Masters and Ph.D. programs but still show a favorable rating. The most positive response was present in question 15 where students showed a strong inclination towards applying to UCLA HSSEAS. It was a direct result of encouragement to apply by program staff throughout the summer. This outcome was highly desirable for UCLA as HSSRP was built as a pipeline program to increase the number of qualified undergraduate applicants.

4.2. Alumni Survey: Mixed Methods

During the summer of 2015, a mixed methods alumni survey was sent via email to student alumni from



the 2010-2014 programs and we received fifty-eight responses. The objectives of this survey were to (1) reassess satisfaction ratings one to five years later and (2) gather quantitative information about the students' choices in undergraduate programs. All questions in Table 3 were posed on a 1-5 scale as previously mentioned.

The qualitative feedback in Table 3 show a high level of satisfaction among past program participants. We believe that the high mean values observed for questions 1-3 suggest that HSSRP was successful in both illuminating and promoting engineering as a field. With regards to question 4, one drawback of the HSSRP program is that it does not explicitly aim to discuss the realities of undergraduate study - by pairing HSSRP participants with graduate student mentors, the HSSRP experience falls more in line with that of a graduate student researcher. However, we believe that the research skills, sense of scientific curiosity, and intellectual confidence promoted by HSSRP are directly applicable to any undergraduate field of study.

Quantitative data from the alumni survey is summarized in Table 4. The vast majority of former students went

on to apply to UCLA Engineering and were admitted at a rate approximately four times higher than the average UCLA Engineering acceptance rate. Interestingly, only half of the students who applied to UCLA chose their major from within the same department as during their HSSRP program. This suggests that while their interests prior to HSSRP placed them in a specific field of engineering research, their exposure to all engineering disciplines during the program allowed some students to make more informed decisions on which STEM fields are more suited for their personal academic and professional endeavors.

Past participants also reported acceptances to a wide variety of strong undergraduate engineering programs, including MIT, Stanford, California Institute of Technology, UC Berkeley, UCLA, UCSD, UC Davis, University of Pennsylvania, Carnegie Mellon, Princeton, Cornell, University of Michigan, University of Texas at Austin, Rice, Cal Poly San Luis Obispo, and Georgia Institute of Technology. Among the forty-one current undergraduates, thirty-three selected engineering as a major, four selected other science fields, and four chose non-STEM fields (including

economics and architecture). For the sixteen students currently employed post-college, fourteen are in STEM-related fields.

5. Conclusion

From an education standpoint, the strength of HSSRP is a consequence of its effective teaching strategies and overall structure. HSSRP employs an outcome-based education model (Hoogveld, 2005) where students are taught the theory of their research and science communication, and are then expected to deliver scientific posters and oral presentations to demonstrate these skills. With sufficient practice and feedback through journal clubs, poster workshops, and weekly check-ins, the staff set the tone for a collaborative learning environment that builds interpersonal skills and interdependence within groups of diverse students (Gokhale, 2012). This is in stark contrast to a grade-based competitive system characteristic of most traditional classrooms. HSSRP students independently learn sufficient background science to

conduct their research project; through the workshops, students are taught how to teach their knowledge to the rest of the class, thereby solidifying their own grasp of their work (Nestojko, 2014). All of this is fostered with a strong social aspect that unites all students and staff from various backgrounds and interests to achieve the common greater goal: increased exposure and excitement toward STEM education. As evidenced by the overwhelmingly positive student evaluations and clear student proclivity toward STEM, HSSRP serves as a strong model for other research institutions to develop similar summer outreach programs.

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