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Impacts of a Neural Engineering Summer Research Experience on High School Students (Evaluation)

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Dr. Laura Collins, from the Center for Research and Learning, has extensive experience of over 20 years in program evaluation and research. Her work includes proposal design, evaluation and research planning, needs assessment, data collection, both qualitative and quantitative analysis, and tailored reporting. She also has taught at two major universities and has expertise in educational methods, curriculum, and instruction.

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Jill Weber is a graduate of the University of Nebraska and holds a Bachelor of Science degree in Communication Studies and English. After graduation, Jill moved to the Seattle area to pursue a career with AT&T Wireless where she worked as a Project Manager in Information Technology as well as in the Marketing group, and was a corporate trainer for new hires. During her time at AT&T, Jill was in charge of managing large cross-company project teams and several large technology projects.

In 2005, Jill expanded her skills as a research analyst and completed the University of Washington Certificate in Program Evaluation. Currently, Jill uses her unique experience and knowledge to provide personal service to programs so that they can become more effective and better understand their outcomes.

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Impacts of a Neural Engineering Summer Research Experience on High School Students (Evaluation)

Neural engineering is a cutting edge field focused on improving people's lives by connecting brains with technology. Sensorimotor neural engineering adds a specific focus on designing closed-loop neural interactive systems to help restore sensory and/or motor functions that have been lost as a result of a neurological disorder or injury. The field brings together expertise across many engineering specialties along with computer science, robotics, mathematics, neuroscience, medicine, and bioethics. This interdisciplinary nature, as well as the goal of helping people with disabilities, can strongly appeal to students interested in science, technology, engineering, and mathematics (STEM) careers.

The Young Scholars Program (YSP) is a model developed and supported by the National Science Foundation that engages high school students in summer research experiences. In this paper, we describe the implementation of the YSP at the Center for Sensorimotor Neural Engineering at the University of Washington. We also share the design of the program evaluation, our findings, and lessons learned. Yearly evaluation findings and trends over the program's three year history were investigated.

Program Description

The YSP at the Center for Sensorimotor Neural Engineering (CSNE) is a mentored summer research experience that immerses high school students into the world of sensorimotor neural engineering research. The Center's mission is "to develop innovative ways to connect a deep computational understanding of how the brain adapts and processes information with the design of implantable devices that interact seamlessly with the nervous system."[1] Researchers at the Center aim to "create a closed-loop co-adaptive bi-directional brain-computer interface (BBCI)" which can both "record and stimulate the central nervous system to encourage neuroplasticity, promote recovery, and restore sensorimotor neural function."[1] This system is specifically being designed for people with specific types of spinal cord injury, stroke, Parkinson's disease, and other neurological disorders.

Each summer, the YSP is operated in tandem with a variety of other summer research experience programs at the Center. These include programs for undergraduates, veterans of the U.S. Armed Forces, international exchange students, and secondary science teachers. These pre-college, university, and professional level participants are placed in an apprenticeship role within the Center's research labs. These labs extend across the university, including the departments of electrical engineering, mechanical engineering, computer science, biology, physiology and biophysics, neurobiology and behavior, neurological surgery, rehabilitation medicine, speech and hearing sciences, otolaryngology, and philosophy.

All pre-college and university education programs at the Center—including the YSP—are designed to support participants' developing expertise in knowledge and skills related to the field of sensorimotor neural engineering. Program evaluation is centered on these skill sets, as defined below.

Sensorimotor Neural Engineering Skill Sets

1. **Fundamentals of neuroscience, engineering, and neuroethics research:** Knowledge of core concepts in neuroscience and neural engineering, designing and conducting experiments, analysis and interpretation of results, problem solving, understanding primary scientific literature, building scientific knowledge, and ethical and responsible conduct of research. (Knowledge & Practices)

2. **Neural engineering best practices:** Oral and written communication of neural engineering knowledge and research, confidence, working independently, working on a team, participating in a learning community, innovation, and persistence. (Personal Skills)

3. **Connections to neural engineering industry and careers:** Awareness of career options in neural engineering and pathways to a neural engineering degree, industry's role in neural engineering, and professional connections. (Professional Skills)

The Center for Sensorimotor Neural Engineering has hosted a total of sixteen students in the YSP during the summers of 2012-2014. The YSP is a commuter program intended for local students. High school students spend ten weeks in a neural engineering lab, under the guidance of an assigned mentor (usually a graduate student) and supervision of a faculty member. In the lab setting, students work on an authentic research project. Participants also attend a weekly scientific communications class, weekly seminars, and social events. At the culmination of the experience, students present a research talk to the research community and participate in a poster session at the university-wide Undergraduate Research Symposium. Students receive a $5,000 stipend for participation in the program. Each lab that hosts a summer student receives $500 for supplies and each student's primary mentor receives $500 to support their travel to a conference.

The YSP is funded by the National Science Foundation Engineering Research Center Award. In 2014, supplemental grant funding was received from the Army Educational Outreach Program's Research and Engineering Apprenticeship Program.

Conceptual Framework

As described in the Center's strategic plan, the goal of the entire education program, which includes the YSP, is:

> …to increase awareness of neural engineering and create K-to-career pathways by empowering people to pursue neural engineering at all stages of their educational careers. The Center offers training at multiple levels (pre-college to graduate) to provide the necessary skill sets to ensure that students reach their goals and enter the workforce prepared to be creative and innovative, effective in industrial practice, with the capacity to function effectively in a globally connected, innovation driven economy. Within the Center it is appreciated that the field of neural engineering will be most innovative and transformative when people from a wide range of backgrounds contribute. With this in mind the Center places a special emphasis on recruiting females, students from historically underrepresented groups, and people with disabilities into our education programs.[2]

As one of many Center education interventions developed to support the K-to-career pathways, the design of the YSP is aligned to concepts of apprenticeship and mentorship, as well as direct engagement with science and engineering practices.

Apprenticeship

A basic tenant of the YSP is that high school students apprentice into the work of practicing neural engineers in an authentic research context. Apprenticeship is defined by Dennen and Burner[3] as "a process through which a more experienced person assists a less experienced one by way of demonstration, support, and examples" (p. 426). Learning by apprenticeship is a model often undertaken for vocational purposes. Cognitive apprenticeship, originally described by Collins and quoted by Dennen and Burner[3] is "learning through guided experience on cognitive and metacognitive, rather than physical, skills and process" (p. 427). Cognitive apprenticeship is "situated learning", where "learning is an integral part of generative social practice in the lived-in world" (p. 35) [4]. In an apprenticeship process, scaffolding helps learners work within their zone of proximal development, as identified by Vygotsky[5]. These support strategies guide the learner in achieving tasks that they would not be able to attain without the support of a more experienced other[4]. Time is needed for the learner to engage in the process of Legitimate Peripheral Participation[4] in which "newcomers"—through observation, practice, and reflection[3]—become members in a community of practice. In the YSP, high school students enter the community of practice of their assigned research lab, engage in the processes of cognitive apprenticeship, and develop engineering skills and practices, all with the scaffolding provided by their primary mentor.

Vertical Mentorship

A mentor is an "adviser, teacher, role model, and friend;" he or she is "someone who takes a special interest in helping another person develop into a successful professional" (p.1)[6]. Vertical mentorship is a practice involving multiple layers of mentors and mentees within an institution. In support of K-to-career pathways, the Center provides a culture of mentorships at all levels, and specifically provides structured mentor programs for both high school and undergraduate students through summer research experience programs. YSP students are assigned a primary mentor in their host lab, with the hope that the relationship will continue beyond the summer session. Many students have also reported developing mentoring relationships with other members of their lab group in addition to their assigned mentor. Opportunities are available to YSP students who later matriculate at the University of Washington to continue working in Center research labs through an undergraduate research fellowship or work-study position.

Practices of Science and Engineering

As research apprentices immersed in engineering research labs, YSP students encounter and uptake content knowledge and skills while being exposed to the practices of professional engineers as they play out in context. It is these practices that are highlighted in the new vision for K-12 science and engineering education as developed in *A Framework for K-12 Science Education*[7] and codified in the Next Generation Science Standards[8]. The eight practices of science and engineering are intended to help K-12 students understand the authentic work of professionals, the ways in which understandings and skills develop, and the interplay between the fields of science and engineering[7]. In the YSP, students are immersed in engineering research labs where they not only observe engineers engaging in these practices, they directly participate in developing their own expertise in these same practices. Dennen and Burner[3] assert that "a major advantage of learning by cognitive apprenticeship as opposed to traditional classroom based methods is the opportunity to see the subtle, tacit elements of expert practice that may not otherwise be explicated in a lecture or knowledge-dissemination format" (p. 427). The YSP provides students with a window into the world of professional engineering where disciplinary content is applied in context to solve problems related to the human nervous system.

Program Implementation

Recruitment and Selection

Recruitment for the YSP generally occurred during November-January of each year. Program descriptions and flyers were distributed to local high school science faculty, youth-service organizations, and to students who visited the Center for class field trips. Recruitment tasks were accomplished by Center education staff and partner organizations, including the Disabilities, Opportunities, Internetworking and Technology (DO-IT) Program which supports students with disabilities.

During the program's first two years (2012, 2013), recruitment was mainly conducted by Center education staff making direct contact to local high schools. In service of the National Science Foundation's broadening participation in STEM initiative[9], recruitment strategies were refocused and realigned for the 2014 session. A partnership was formed with the University of Washington Math Science Upward Bound program, a federal TRIO program that serves low-income, potential first generation college students from three local high schools. Recruitment efforts were focused on these same three schools, which serve student populations that are racially and ethnically diverse, and low-income (free/reduced lunch eligibility ranged between 59.5%-73.4% for these schools)[10]. Therefore, the 2014 cohort consisted of students recruited from these partner schools, the DO-IT program and the Math Science Upward Bound program and represented a more racially and ethnically diverse cohort than the previous two years.

Applications were managed through an online system during a three month submission window. To be considered complete, submitted applications had to include school transcripts, a series of short essays, and two letters of reference. The questions on the application changed slightly from year to year. The number of applications and accepted students is reported in Figure 1, demonstrating the increasing level of interest in the program and the competitive nature of the selection process. Completed applications were reviewed and ranked by a committee of Center education staff.

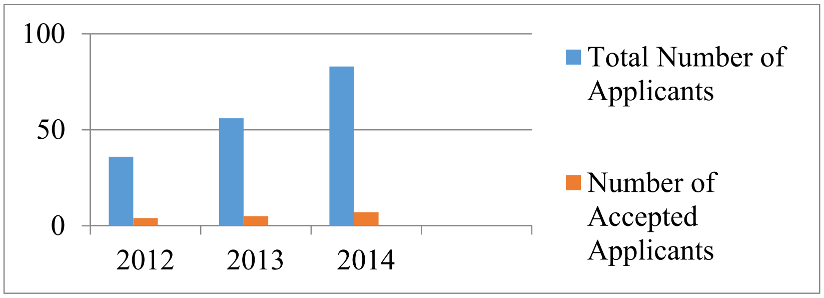

Figure 1. YSP Submitted Applications and Accepted Applicants by Year

Participant Demographics
Self-reported demographic information for the sixteen students who have participated in the YSP is reported in Table 1.

Table 1

Demographic Information of YSP Participants (2012, 2013 and 2014)

	2012 Cohort N=4	**2013 Cohort N=5**	**2014 Cohort N=7**	**Total N=16**
Gender				
Female	100.0%	40.0%	57.1%	62.5%
Male	0.0%	60.0%	42.9%	37.5%
Race				
American Indian/Alaska Native	0.0%	20.0%	0.0%	6.3%
Asian	25.0%	0.0%	42.9%	25.0%
Native Hawaiian/Other Pacific Islander	0.0%	0.0%	0.0%	0.0%
Black/African American	0.0%	0.0%	14.3%	6.3%
White/Caucasian	75.0%	40.0%	28.6%	43.8%
Two or More Races	--	20.0%	14.3%	12.5%
Other	0.0%	20.0%	0.0%	6.3%
Ethnicity				
Hispanic or Latino	0.0%	0.0%	14.3%	6.3%
Not Hispanic or Latino	100.0%	100.0%	85.7%	93.8%
Disability				
Have a Disability	25.0%	20.0%	14.3%	18.8%
Does Not Have a Disability	75.0%	80.0%	85.7%	81.2%

Research Apprenticeship
Program participants spent the majority of their time apprenticing in an engineering research lab. Each YSP student was matched with a Center-affiliated lab that conducted research aligned with the Center's research foci. The faculty member in each lab appointed a mentor to directly supervise the YSP participant. The mentors were most often graduate students, occasionally post-docs or lab staff, and rarely a faculty member. The mentors were responsible for providing training, eliciting students' research interests, collaboratively developing a research project, and providing support throughout the research process. Mentors also assisted the students in preparing their culminating research talks and posters. The research projects undertaken by YSP students over the past three years are presented in Table 2.

Table 2

YSP Student Research Projects and Associated Labs

2012	▪Discerning Selective Auditory Attention for BCIs with Amplitude Modulation (Lee lab) ▪Creating a Self-Sufficient Autonomous Quadrotor Helicopter (Morgansen lab) ▪Characterization of Emotiv Headset for Use in BCI Systems (Smith lab) ▪The Effects of Cannabinoid Receptor Blockers on Synchronous Spontaneous Activity in the Developing Mouse Cerebral Cortex (Moody lab)
2013	▪Detecting and Logging Tremor via a Wrist-Mounted IMU (Chizeck lab) ▪ Simulation of Quadrotor Processes in a Computer Setting (Morgansen lab) ▪ Making a BCI Timer to Keep Subjects on Task (Ojemann lab) ▪ Investigating Thermal Properties of Wireless Power Transfer Coils (Smith lab) ▪ Multi-channel Extracellular Recording from a Biological Gyroscope (Daniel lab)
2014*	▪Integrated Sensing of Depth Camera and Electromyography for Human-Computer Interaction (Daniel lab) ▪SSVEP Based Brain Computer Interface (Rao lab) ▪Graphical User Interface for BCI Privacy Experiments (Chizeck lab) ▪Coils for Wireless Power Transfer (Smith lab) ▪Agile Autonomous Quadrotor Flight (Morgansen lab) ▪Centering Ourselves: Examining the Scientific Self (Goering group)

**Note*. One student in the 2014 cohort did not present a research project.

Classes and Seminars

Students attended a weekly scientific communication course (1.5 hours per week). The non-graded class was taught by Dr. Lise Johnson, the Center's University Program Manager. The class was attended by YSP students along with undergraduate students participating in other Center-sponsored summer research experiences. The course goals included developing students' skills in scientific communication through various mediums, including research talks, research posters, and research articles. YSP participants were challenged to read journal articles, collaboratively write a scientific article based on a group experiment (making ice cream without an ice cream maker), as well as prepare an abstract, poster, and talk focused on their own research project.

In addition to the weekly communication course, participants from all of the Center's summer research programs—including YSP students—attended a weekly seminar series. Topics varied slightly from year to year. For example, the summer 2014 seminar series included the following topics: responsible conduct of research, ethics of animal research, neuroethics, industry, communicating to lay audiences, and applying to graduate school. In 2014, a new seminar was added specifically for YSP participants that focused on strategies for successfully transitioning from high school to college.

Special events were interspersed throughout the summer session, including social gatherings, community events, and field trips. These special events differed from year to year; examples included a tour of the university libraries with a focus on the engineering collection, a university-wide BBQ for summer research participants, and a field trip to a medical simulation lab.

Culminating Presentations

The YSP experience culminated with two presentations that allowed participants to share their research projects with the university research community. Students prepared for these experiences throughout the scientific communication course. Toward the end of the summer session, all Center summer research participants prepared and delivered a fifteen minute research talk to the Center's research community, which included peers, faculty, mentors, and lab members. YSP participants then presented their research posters during a university-wide undergraduate research symposium. This was truly a college level experience for the high school students participating in the YSP.

Evaluation Design

Evaluation is defined as the systematic collection and analysis of data needed to make data-driven decisions. For this project, the external evaluation team was dedicated to providing timely and accurate information for improvement, useful information for decision making, and documentation of progress toward project outcomes and goals. The primary goals of the comprehensive formative and summative evaluation for the YSP project are to inform the development of project actions and to review outcomes to assess goal attainment and effectiveness. Throughout planning, the NSF's strategic outcome of "developing a diverse internationally competitive and globally engaged workforce of scientists, engineers and well-prepared citizens,"[11] guided project actions and evaluation activities.

The evaluation methods focused on gathering data to measure the following YSP outcomes:

- Competency in and knowledge of sensorimotor neural engineering skill sets.
- Change in awareness of careers in neural engineering and readiness toward college coursework.
- Effective vertical mentoring relationships.
- YSP influence on innovative thinking.

In addition, the evaluation was designed and conducted in adherence to the Program Evaluation Standards of the Joint Committee on Standards for Educational Evaluation[12]. Created in 1975, the Joint Committee is a coalition of major professional associations concerned with the quality of evaluation. The Joint Committee provides guidelines for program evaluations that are intended both for users of evaluation and for evaluators.

The evaluation plan used mixed methods, both quantitative and qualitative measures, to generate a rich and comprehensive picture of project outcomes. Triangulation of data, a powerful technique that facilitates validation of data through cross verification, refers to the application and combination of several research methodologies. Using evidence from different types of data sources validates data and outcomes by cross-verifying information, which ultimately strengthens the investigation because of increased credibility and validity.

All quantitative data were entered into SPSS (Statistical Package for the Social Sciences) and analyzed for means, standard deviations, and statistically significant differences. Means for the retrospective questions were compared using a one-sample t-test. The figures that follow in the Findings section of this paper show results indicating that YSP students showed highly significant gains in all areas examined: 1) Fundamentals of neuroscience, engineering, and neuroethics research, 2) Neural engineering best practices, and 3) Connections to neural engineering industry and careers.

Post-program Reflective Surveys

An end-of-program survey was given to YSP students at the conclusion of each summer program to measure the impact on students' content knowledge and skill set competency in areas of neural engineering. A retrospective pre-test design was used on some survey questions to determine if there were statistically significant differences in knowledge of neural engineering skill sets.[13] Considerable empirical evidence suggests that program effects based on traditional pre- post- test self-reports are masked because people either *overestimate* or *underestimate* their pre-program knowledge, skill, or perceptions[14 15 16 17 18 19]. Moore & Tananis[20] report that response shift can occur in educational programs, especially when they are designed to increase students' awareness of a specific construct that is being measured. Additionally, a four point Likert scale was also used to measure increases in self-reported competency, college and career readiness, and mentor relationships. In 2014 a mentorship survey was added to the program evaluation; YSP mentors, both graduate students and faculty, were asked to complete the post-program survey.

Follow-up Interviews

In addition to end-of-program surveys, follow-up phone interviews were held with YSP participants five months after the summer program (see Table 3). Participating YSP students replied to emails from the program manager to schedule times for interviews with the external evaluators. Individual interviews were scheduled at convenient times for participants and lasted approximately 30 minutes each. Prior to beginning each interview, participants were informed of the interview process, and asked if they had any questions before proceeding. Interview questions addressed benefits of program participation, impact on neural engineering and scientific research skill sets, mentoring relationships, college and career aspirations, and how their experiences influenced them to think in more innovative ways. Interview data were analyzed qualitatively in order to evaluate themes and major categories of responses.

Table 3

Percentage of YSP Participants Interviewed by Year

YSP Cohort	Percentage of YSP Participants Interviewed
2012	75%
2013	80%
2014	71%

Longitudinal Tracking

Over the three-year history of the program, outcomes of participation were tracked for the YSP. Trend data provided program managers an opportunity to view results over time, to clarify and tighten program expectations, and to revise program activities to more closely align with program goals. This method also afforded an opportunity to investigate in further depth the distinctions of neural engineering programming for youth. Additionally, the Center's Education Director tracked students into post-secondary institutions.

Findings

Post-program Reflective Surveys and Longitudinal Tracking

End-of-program survey results provide evidence that the YSP afforded high school students the opportunity to gain substantial understanding of sensorimotor neural engineering and to interact with other high school, undergraduate, and graduate students and faculty in a university setting. This environment not only stimulated interest in neural engineering, but also introduced participants to cutting-edge innovation and career opportunities.

YSP planning and data gathering were based on designing activities focused on participants' skill set attainment. These skill sets were broken into three categories: 1) Fundamentals of Neuroscience, Neural Engineering, and Neuroethics Research (knowledge and practices); 2) Neural Engineering Best Practices (personal skills); and 3) Connections to Neural Engineering Industry and Careers (professional skills). Skill set trend data for the initial three years of the YSP program (2012, 2013, and 2014) were analyzed. It should be noted that during the first two years of the program the skill sets were broadly defined, and in the third year they were specifically noted as neural engineering skill sets.

<u>Fundamentals of Neuroscience, Engineering and Neuroethics Research Skill Sets</u> – Statistically significant differences in student gains in knowledge before and after the program were reported in the sensorimotor neural engineering skills sets of: 1) analysis of neural engineering data, 2) designing experiments in neural engineering, 3) interpretation of neural engineering results, 4) ethical and responsible conduct of research in neural engineering, and 5) knowledge of core concepts in neuroscience and neural engineering (Figure 2).

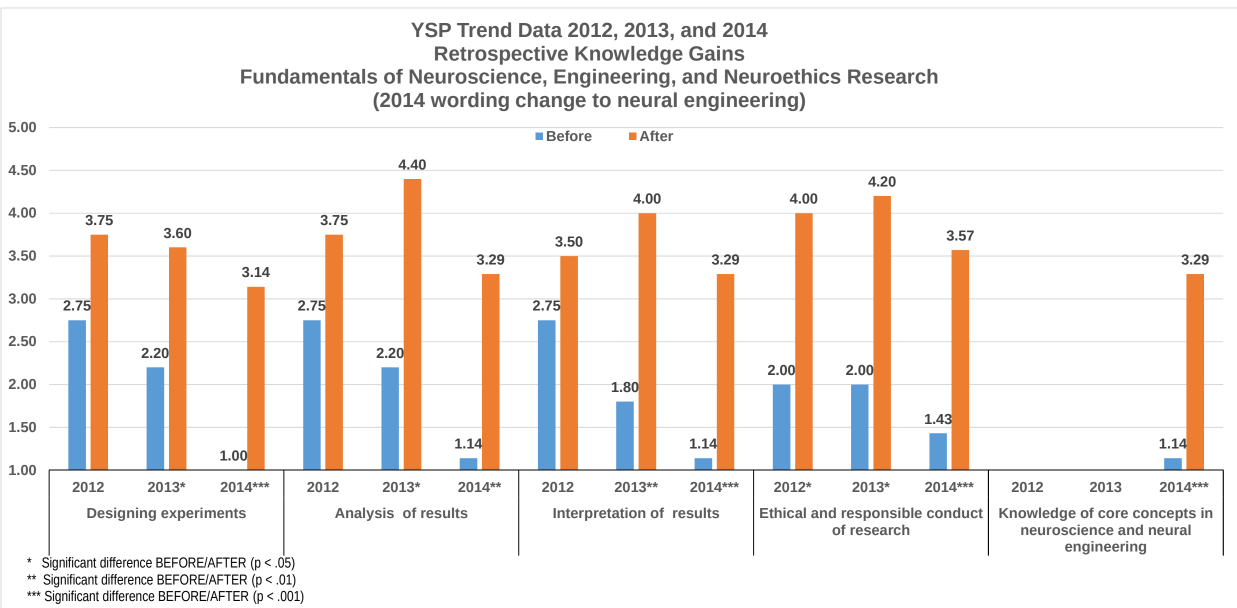

Figure 2. YSP Three-Year Trend Data – Knowledge Gains in Neural Engineering Fundamentals

Students also consistently reported increasing competence in: 1) their understanding regarding how to conduct a neural engineering experiment, 2) problem solving in neural engineering, 3) understanding primary scientific literature in neural engineering, and 4) building scientific knowledge in neural engineering (Figure 3).

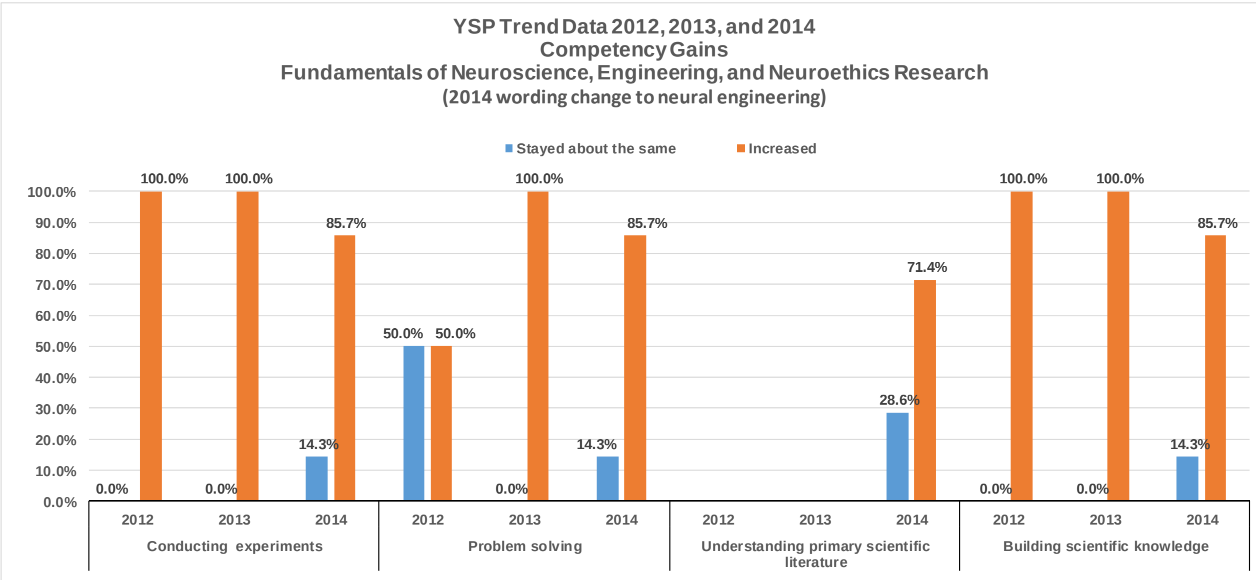

Figure 3. YSP Three-Year Trend Data – Competency Gains in Neural Engineering Fundamentals

In their open-ended survey responses, YSP students reported:

> *"Getting a solid background in a research environment a lot of people my age would not have."*

> *"Lab environment was the one part I had no grasp of. [I didn't know] how that would turn out, but now I have a more full understanding of what that entails. Being more self-directed – the independence was good for me."*

> *"[YSP] strengthened my research skills – I didn't have any before that in a lab like that."*

> *"It [YSP] reinforced my passion for neuroscience."*

<u>Neural Engineering Best Practices</u> – As a consequence of program changes made after reflection on evaluation data, 2014 results show statistically significant differences in student knowledge before and after the program in the skill sets of: 1) innovative practices in neural engineering, 2) oral communication of neural engineering knowledge and research, and 3) written communication of neural engineering knowledge and research (Figure 4).

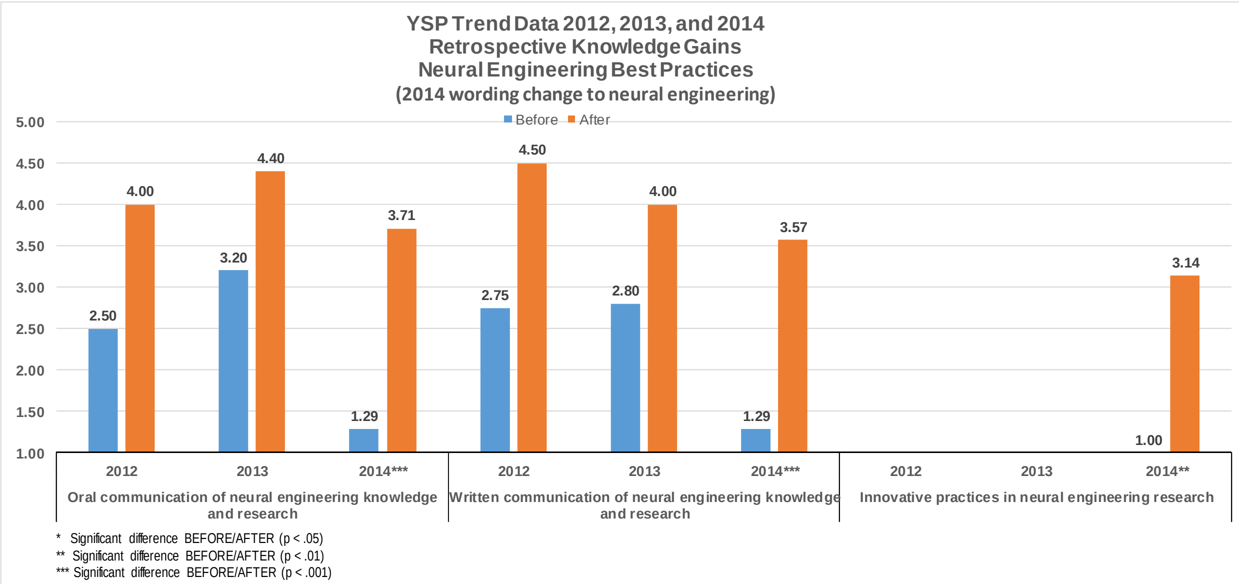

Figure 4. YSP Three-Year Trend Data – Knowledge Gains in Neural Engineering Best Practices

Among all three years, students consistently reported increases in: 1) their confidence of their neural engineering skills, 2) their ability to succeed at a college or a university, 3) working collaboratively with others on a neural engineering team, 4) working independently on neural engineering research and projects, and 5) their persistence in completion of neural engineering research. For a new item added in 2014, YSP participants also reported an increase in feeling competent to participate in a neural engineering learning community (Figure 5).

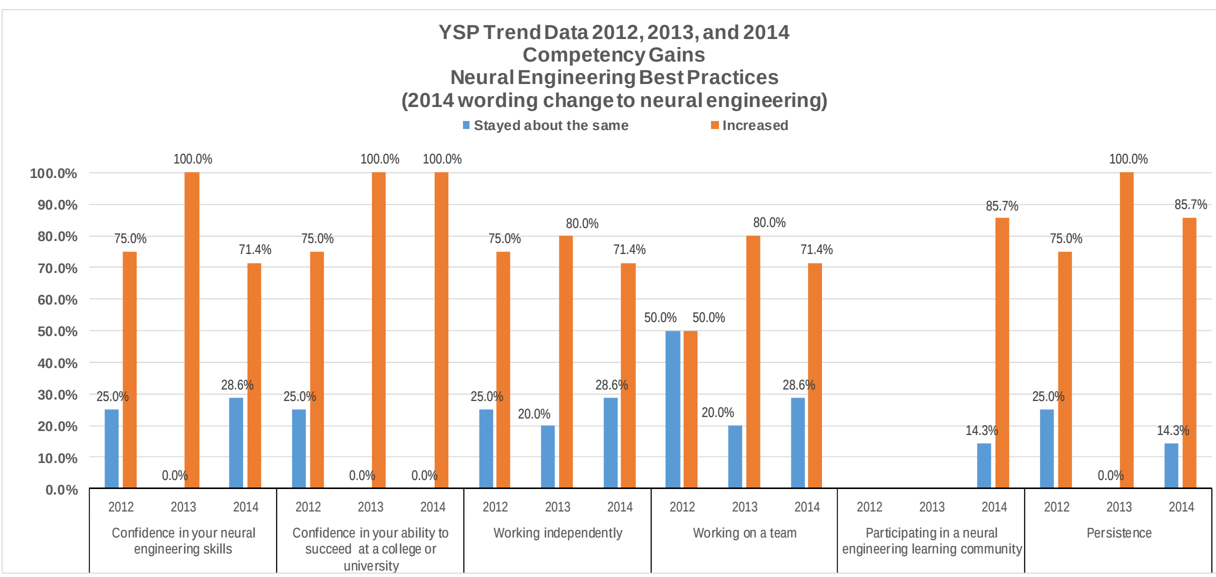

Figure 5. YSP Three-Year Trend Data – Competency Gains in Neural Engineering Best Practices

In their open-ended survey responses, YSP students reported learning:

"Scientific research is hard. Also to think critically about whether results make sense and methods are correct. You will be expected to prove that you know what you are doing. In other words, be able to effectively communicate your research and its implications."

"I learned more about scientific research, specifically what typical tasks are involved and life as a researcher such as oral and written presentations."

"I learned a lot about the collaboration between labs and universities on research, and how interdisciplinary so much of the research is."

"Neural engineering requires a lot of other engineering fields to come together."

"The networking involved in BCI [brain-computer interface] technology and related interventions. Specifically biology, mechanics, and coding."

"One general thing about neural engineering and research [I learned] was the skill set needed to complete the work. Even if you specialize in one area, you are still expected to know other fields as well, such as computer programming or math."

"I didn't know anything about research at all and someone is always the expert of something. You alone can't be the only expert at everything. You have to learn from others too."

<u>Connections to Neural Engineering Industry and Careers</u> – Regarding participants' knowledge of careers, results show statistically significant differences before and after for knowledge of: 1) industry's role in neural engineering, and 2) knowledge of careers in neural engineering (Figure 6).

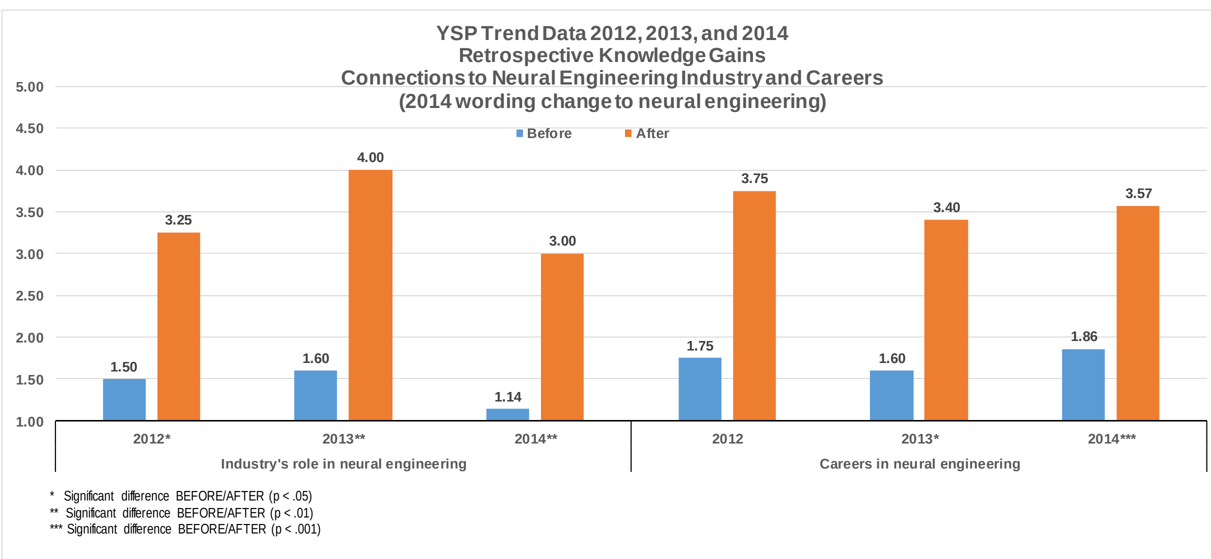

Figure 6. YSP Three-Year Trend Data – Knowledge Gains in Connections to Neural Engineering Industry and Careers

Among all three years, students consistently reported an increase in their awareness of: 1) career options in neural engineering, 2) professional connections in the field of neural engineering, 3) pathways to a neural engineering degree, 4) career paths of the people who work in neural engineering, and 5) the variety of STEM fields in which they could specialize (Figure 7).

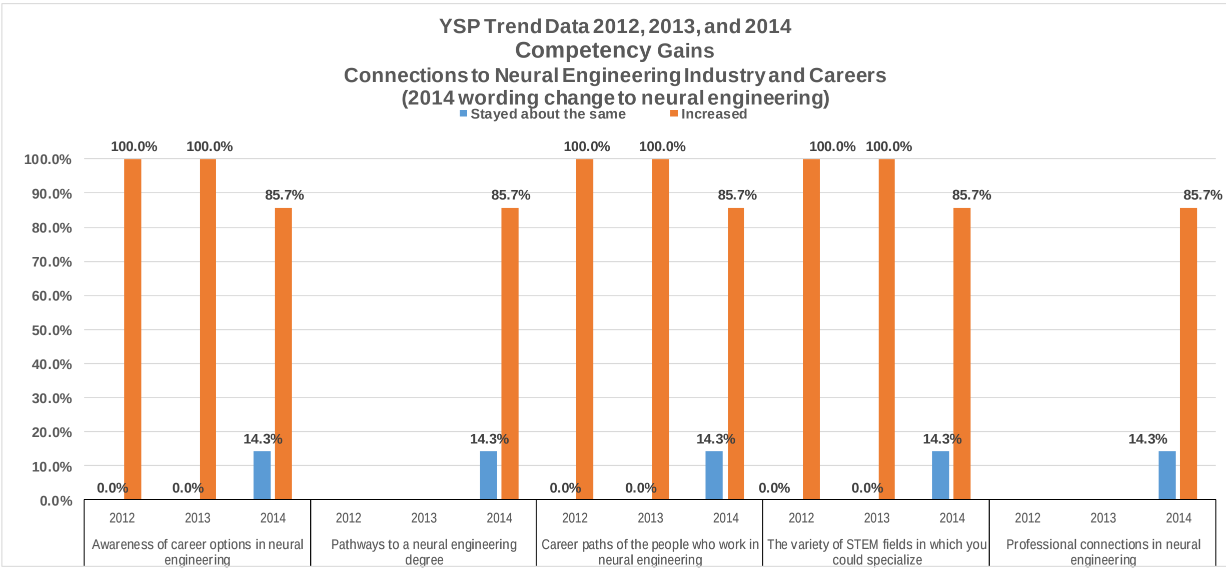

Figure 7. YSP Three-Year Trend Data – Awareness of Neural Engineering Industry and Careers

In their open-ended survey responses, YSP students reported:

"I really enjoyed the presentation about how to make the most of your education – it was very inspiring and helpful."

"The most important outcome is tied between reaffirming that I actually do want to work in a lab doing research and seeing that I might also be interested in majoring in computer science" [a field never considered prior to this experience].

"I realized I had a lot to learn. High school wasn't up to the level of what we did at YSP."

"I picked up on a research career more because of the program, most high school students are totally undecided; not a lot of career counseling from high school, so I wouldn't have considered this until I got to college."

"Discovering career paths in electrical engineering and choosing that as my major."

"I learned more about bioengineering careers and biomedical engineering careers."

"There are many different subsets of neural engineering. Before YSP I didn't even really know about neural engineering."

"There are many different options when choosing a career in neural engineering."

Vertical Mentoring Chain: Students—Student comments on end-of-program surveys indicated that a vertical mentoring chain was evident in the research labs. Evaluation data indicated mentors answered students' questions, and provided feedback and direction to the students. Further, the mentors also planned activities around students' interests and offered advice on courses to take in college.

Over three years, all (100%) students interviewed indicated they learned a great deal from their assigned primary mentor. In addition, their mentors helped them to understand scientific research processes. When asked for extended comments about their mentors, students responded:

> *"She was patient with me and didn't get frustrated when I didn't understand something the first time. She took time every day to check in with me and was always available for me to ask questions."*
>
> *"My mentor tried connecting the lab's focus to my goals."*
>
> *"My mentor was always available and there to help. He planned extra lessons around my schedule so I could complete my work assigned to me, but also do a variety of things that I had interest in. He planned meetings with my PI so I could learn about different fields, learn how to use tools, and new skills. I wouldn't do anything differently."*
>
> *"My mentor was always open to answer any of my questions and giving me guidance when I needed it. She also made a point that I try to figure things out for myself first before helping, which I liked."*
>
> *"My mentor was always there to talk to and initiated the conversation so many times I felt comfortable talking to him."*
>
> *"She took time to understand my interests and experience."*
>
> *"I got advice on classes to take, like Computer Science. Even if I don't want to major in it, I should take a coding class."*

Vertical Mentoring Chain: Faculty and Graduate Students—In separate end-of-program mentor survey added in 2014, mentors also responded that the experience was beneficial to their own professional development. When asked what was beneficial about being a mentor, they responded:

"I have been a mentor for about 30 years and every year I learn something new from each individual. Mentoring is very much about learning from others as much as it is about helping them along."

"The first thing that comes to mind is that teaching and relating what you know to others always help solidify your understanding in your own mind."

"The most beneficial aspect of being a mentor for me was understanding how do people learn, how do they approach their assignments, and what it takes to make them feel good about their project, their progress and about themselves in general. My experience thus far (and this was only reinforced this summer) is that, in general, people flourish when provided with positive feedback, and when their engagement, effort and hard work is being recognized and appreciated. Another useful things, in my experience, is letting the mentees know they are here to learn and grow, and that mistakes will sometimes happen, but that that is not the end of the world."

"Learn to adapt to the mentee's level of expertise. Explaining complicated design challenges in simple terms."

Learning – An emphasis on YSP participants' learning also emerged from mentors' survey responses to the question, "What do you hope your mentee learned from working with you?"

"Some wicked-cool math (specifically some calculus which she was going to take this year), how to program in Python and C++, how to solder, a little about electricity, and a little about electronics hardware. Overall, I think she learned that there are no "right" answers in research; to trust her intuition."

"I hope my mentee got a glimpse of how research is being conducted in an academic setting, and how do researchers go about organizing their projects. I hope she also got an exposure to programming and conducting scientific analysis."

"How to approach an engineering problem through design and testing."

"In depth understanding of the project assigned to him. Additionally, working independently when the problem space has been defined. He had a good sense of asking questions when he was stuck. How to read technical papers and MATLAB programming were two other focuses."

"I hope she learned: (1) how science and engineering help us understand the world we live in, (2) how she has the power to utilize the tools to tackle tough problems, and (3) how she has the potential to meet any challenge; and I am sure she does."

Challenges – Even though the mentoring relationship was beneficial to those involved, it was not without its challenges. When asked, "What was most challenging about being a mentor?" mentors responded:

"Designing research projects that are feasible to complete given the experience of the mentee, but represent sufficiently challenging tasks."

"Gauging the amount of work to assign to a high school student. As graduate students we tend to take some basics for granted. This experience brought me back to the important things that we build our research on."

Advice – Even with multiple challenges, one mentor stated the following advice to others:

"It is a rare and inspiring opportunity to help a young scholar see their own potential. Enjoy the process, realize that even small successes are important ones."

Follow-up Interviews
Five months after YSP participants finished the program, follow-up telephone interviews were conducted. Interviews gave the students an opportunity to further discuss the YSP and create an in-depth picture of the program's benefits, outcomes, and impact.

<u>Greatest Benefits</u>—Participants observed that the greatest benefit of the program was the hands-on lab and research skills they obtained. Students admitted that they had learned skills they would not have had the opportunity to learn if they had not participated in the YSP. Another benefit was having exposure to female researchers as role models.

> *"I wanted to learn how people do science."*
>
> *"I had never been in a real lab."*
>
> *"In high school, there is always a solution. But often in real science there isn't always a solution or the solution isn't what you want it to be."*
>
> *"The biggest benefit of the YSP for me was the exposure to female researchers; I wanted to see females being successful in scientific fields. The ratio is so overwhelmingly male. I wanted to see how she conducted herself and how she held her lab together. Very encouraging to see a female in power and not be questioned. I never had a female math or science teacher in high school and this was something that was important to me."*

<u>Innovative Thinking</u>—Concept mapping allows the researcher and others to "see" participants' meaning, as well as the connections across and between concepts or bodies of knowledge. In other words, a concept map is a visual organization and representation of knowledge. Participants were asked about how their experiences at the Center influenced them to think in more innovative ways, which was then organized by the program evaluators into a concept map. Two major concept categories emerged: 1) Exposure to New Perspectives and 2) Exposure to New Research Experiences (Figure 8).

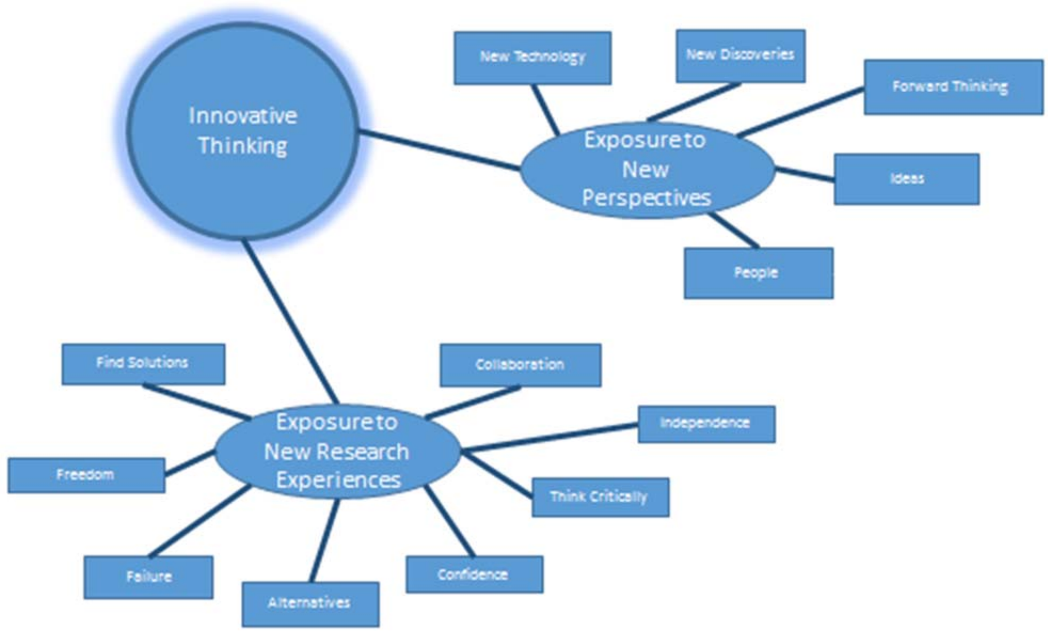

Figure 8. Concept Map of YSP Influence on Innovative Thinking

Supporting quotes:

> *"My way of thinking has changed a lot. Fixing problems and thinking outside of the box; finding my own solution."*
>
> *"Knowing the results could be indicative of something. Take it apart and finding you can do everything right and finding out it isn't in your control and find the right equipment."*
>
> *My lab was developing something new and it was weird to watch them develop it because it was new to the world. It didn't start out well, but each day it progressed a little every day until one day I walked in and it was working. Your own new thing and make your impact in the world."*

Longitudinal Tracking

In the fall of 2014, the Center's Education Director contacted students from the 2012, 2013, and 2014 cohorts by email requesting information on their anticipated college plans and majors. A response rate of 100% was attained. For the 2012 YSP cohort, one participant is still in high school. The other three have matriculated to the University of Washington (2) and Gonzaga University (1). None of these three students have yet declared their college major. For the 2013 YSP cohort, two of the six are still in high school, one is attending community college, and two have matriculated to the University of Washington. One student indicated electrical engineering as her major, the others are undecided. For the 2014 YSP cohort, two participants are still in high school. The other participants have matriculated to the University of Washington (3) and Colorado School of Mines (1). One other participant deferred enrollment to John Hopkins University for a study abroad program.

Conclusion

The program evaluation process provided insight into the successes and challenges of the first three years of the YSP—and helped illuminate ideas for future design changes. Trend data showed consistent increases for all neural engineering skill sets, which indicates that the program had a positive effect on participants' content knowledge, research skills, engineering habits of mind, and engineering practices. The YSP influenced students to think in more innovative ways and illuminated career options and pathways that they did not previously know. There was also evidence that a vertical mentoring chain existed, and that the mentoring relationship was beneficial for both the mentee and the mentor. YSP students interacted with graduate students and faculty, including building relationships with female researchers and role models. Moreover, the YSP affords students the opportunity to gain first-hand experience conducting research in a real research lab alongside engineers producing cutting-edge innovations—these are not things that can be taught in high school.

Future Design Implications

The results of program evaluation of the first three years of the YSP provide insight for future cycles of iterative program design. These planned design changes are directly in response to the same desired program outcomes that were the focus of evaluation activities:

- Competency in and knowledge of sensorimotor neural engineering skill sets.
- Change in awareness of careers in neural engineering and readiness toward college coursework.
- Effective vertical mentoring relationships.
- YSP influence on innovative thinking.

<u>Developing Expertise in Engineering Content and Practices</u>—Participants' competency in sensorimotor neural engineering skill sets, content knowledge, and engineering practices (as outlined in the Next Generation Science Standards) will be further supported in several ways. First, the weekly scientific communication course will be scaffolded by adding a weekly study session for YSP students. This regular session will allow for review of class content, guidance on class assignments, and collaborative work time among the YSP cohort. Second, the program manager will make visits to the labs to meet with YSP students in their research setting and help participants and their mentors bridge the research experience with the other elements of the program. Third, each YSP student will host a tour of their lab and research project for the other YSP students, and when feasible, tours will be arranged of other Center-affiliated labs to broaden students' exposure to research topics and career pathways within neural engineering. Fourth, YSP students will be asked to keep a reflective journal throughout the summer session; prompts will focus their reflection on issues including identity, developing expertise, career awareness, college readiness, innovative thinking, and mentoring.

<u>The Mentor/Mentee Relationship</u>—The existing mentor orientation session is focused on program logistics. A new workshop curriculum will be developed that introduces successful strategies for mentoring students in engineering research. Mentors will be introduced to the Center's neural engineering skill sets and the engineering practices of the Next Generation

Science Standards. A summary of program evaluation findings will also be shared with mentors to provide insight into the program's successes and challenges. Specific focus will be given to supporting the mentors in the process of identifying and structuring an independent research project for their mentees. Additional questions will be added to the mentor survey, which is administered to YSP mentors at the end of each summer session. Survey questions will prompt mentors to consider the values that the mentoring relationship might have for them personally and professionally.

Successful College Transitions—Some YSP participants transition directly from the program to their freshman year at college or university. Other YSP participants return to their high schools in the fall to complete their junior or senior years. Therefore, there is the opportunity to support students who are on the cusp of the college application process or starting their college careers. The design of the YSP will be further refined to support students at these two points. Examples include campus and dorm tours, meetings with admissions and financial aid counselors, university library tours, reviews of undergraduate degree requirements for STEM majors, and special seminars on strategies for successful college transitions.

Community of Learners—Upon entry into the YSP, participants become members of several communities including the YSP cohort, the larger cohort of summer research students, and the community of practice that makes up their lab group. Future design strategies will include offering more social events throughout the summer session for YSP students and for the entire group of summer research students, as well as special events for YSP students and their mentors. Another design strategy includes inviting parent participation in the program, including offering a parent orientation, and inviting parents to students' culminating research talks and the poster session at the university-wide research symposium.

We anticipate integrating these design changes over the next several years of the program in an iterative process that is responsive to the findings of yearly data and trend analysis from program evaluation activities.

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