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ARTICLE

Classroom-Based Research Experiences to Support Underserved STEM Student Success: From Introductory Inquiry to Optogenetics in the Embryonic Chicken

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In order to help overcome barriers to success for undergraduate STEM students from disadvantaged backgrounds, we developed two classroom-based research experiences (REs), *Connecting Life* (CL) and the *Summer Research Institute* (SRI). These REs were implemented over a two-year period (2014-2015) for regional community college students as part of the Southern Illinois Bridges to the Baccalaureate (SI Bridges) program. CL and SRI, broadly centered in biomedical sciences research, are designed to be offered in tandem. CL utilizes a guided inquiry approach with microscopy work-stations in experimental cell biology to experientially introduce research while building skills and confidence. CL serves as the gateway experience for the SRI, an intensive summer RE in which scholars engage in authentic research using modern technologies including optogenetics. We piloted the REs in year 1 (9 scholars) and made refinements in year 2 (10 scholars). Participants ("Bridges scholars") were enrolled full-time at one of two regional, rural community colleges, and came on-site to Southern Illinois University at Carbondale (SIUC) for the paid REs. Here we report the development, design and implementation of CL and the SRI, and report improved STEM research-related attitudes and aptitudes as a result of these experiences. Our findings suggest that guided inquiry with increasingly technical authentic research projects in a classroom-based and supportive learning community-style setting is a positive model for the transformation of underserved community college students into confident, motivated scientists with research-ready skills, and is likely translatable to other research novices.

Key Words: active learning; disadvantaged; biomedical science; CURE; community college; cell biology; neuroscience education

A growing number of studies support the inclusion of research experiences (REs) as positive education factors in the undergraduate curriculum of science, technology, engineering and mathematics (STEM) majors (Valantine and Collins, 2015; Association of American Colleges & Universities, 2018; Pierszalowski et al., 2018). REs can improve attitudes and aptitudes in STEM courses and may contribute to increased retention and success of students in STEM careers (Bhatt and Challa, 2018; Corwin et al., 2018; Hernandez et al., 2018). Furthermore, REs are increasingly recognized as potentially effective components of intervention strategies for retention and career success of underserved students, including underrepresented minority, low-income, women and first-generation students in STEM fields (Valantine and Collins, 2015; Hernandez et al., 2018; Pierszalowski et al., 2018).

While increased diversity in STEM fields, including in the biomedical sciences is recognized as a critical need, a significant gap between goals and reality still lingers (Valantine and Collins, 2015; Estrada et al., 2016; Rottinghaus et al., 2018; Pierszalowski et al., 2018; Werner-Washburne, 2018). Underserved students face social, academic and institutional barriers to persistence and success in STEM. Such barriers at the undergraduate level often include inadequate pre-college preparation, a paucity of inquiry-based and other active learning experiences (in K-12 and/or as entering freshmen), unawareness by students and support members of their community (such as parents and other family members) of STEM opportunities and careers, financial stresses that require students work during college or result in attrition, a lack of representative mentors, and many other social, academic and institutional barriers (Valantine and Collins, 2015; Pierszalowski et al., 2018).

Many community college STEM students, a high proportion of whom hail from disadvantaged backgrounds, do not matriculate to a four-year university (Jenkins and Fink, 2016; Jenkins et al., 2018). Underrepresented minority students disproportionately fail to complete a biology degree at the undergraduate level compared to white or Asian American students despite similar initial expressed interest in the biological sciences (Meyers et al., 2018). Furthermore, many underserved students qualify as underserved by more than one criterion which further compounds their difficulties (Pierszalowski et al., 2018). Importantly, a lack of exposure to research and engagement in REs at the undergraduate level is recognized as a significant barrier to persistence and success in biomedical science careers (Valantine and Collins, 2015). Studies support strategies that engage students in research as early as possible in their undergraduate career (Rodenbusch et al., 2016; Corwin et al., 2018). Other active learning strategies such as learning communities may be effective as well, alone or in combination (Freeman et al., 2014; Valantine and Collins, 2015).

RE structural models include apprentice-like REs where an undergraduate or handful of undergraduates work alongside a faculty mentor in the mentor's laboratory, and course-based REs, where all students enrolled in a course engage in research (Valantine and Collins, 2015; Hernandez et al., 2018). Regardless of structural detail, undergraduate REs typically involve pursuit of an unanswered ("authentic") research question in a field of study closely aligned with the faculty mentor's interests and expertise. REs invariably combine elements of traditional laboratory instruction including theory and bench methods with experiential learning. REs developed as intervention tools to increase engagement and retention of underserved students in STEM may be apprentice-style, course-based, or other styles, including summer research experiences (Hernandez et al., 2018). Course-based REs have the potential to reach more students and may provide more structure and equitable access to students from diverse backgrounds (Hernandez et al., 2018). On the other hand, students may potentially receive pay to participate in apprentice-like REs and/or summer research internships. Paid REs have the potential to relieve financial impediments to engagement in research by underserved students. A recent study indicates that sustained REs (at least two semesters, ≥ 10 hr/wk) may be necessary for effective intervention (Hernandez et al., 2018).

How do we, as educators, engage underserved students in meaningful REs that support their transformation from research novice to confident scientist-in-training? To address this question and help overcome some of the common barriers to STEM careers faced by students from underserved populations, we developed and implemented two unique research experiences (REs) as part of an NIH-sponsored Bridges to the Baccalaureate program in southern Illinois. In *Connecting Life* (CL) and the *Summer Research Institute* (SRI), qualifying regional community college students participated in a paid, classroom-based, learning community-style laboratory series broadly centered around biomedical sciences research. Scholars explored research in a wide range of topics including cell biology, biotechnology, developmental biology and neuroscience. The experiences combine guided open inquiry with modern research problems and technology in a safe and somewhat familiar (classroom) learning environment to build to meaningful and productive research experiences for underserved STEM students.

We identified five major STEM research career-critical areas (Table I) and designed REs to support improvements in these areas. Anticipated learning outcomes for each area are outlined in Table I. Here we report the design of the REs, including piloting the REs in year 1 and refinements in year 2 with approximately 10 scholars in each cohort, and report assessment results in the five key areas we targeted. Our data support the conclusion that early and sustained engagement of underserved students in REs can be an effective intervention tool to improve underserved student attitudes and aptitudes in STEM and may improve persistence by underserved students in STEM careers.

MATERIALS AND METHODS

Scholars and Program Overview

The REs described here were developed and implemented as paid experiences in the Southern Illinois Bridges to the Baccalaureate Program ("SI Bridges" Program; NIH-NIGMS R25GM107760); the REs were carried out in the spring and summer of 2014 (year 1) and the spring and summer of 2015 (year 2). All human subject research was approved by the Institutional Review Board of Southern Illinois University at Carbondale (SIUC). Scholars for the program were recruited from two regional community colleges, John A. Logan College, Carterville, IL and Shawnee Community College, Ullin, IL. Scholars were selected through an application process that included required program criteria (STEM interest, underserved status), a written application with personal statement, interviews and reference letters. In year 1 (cohort 1), 10 scholars completed CL and 9 of these completed the SRI (the scholar who left the program cited personal reasons); in year 2 (cohort 2), 10 out of 10 scholars completed both RE experiences. In addition to RE events, professional development and community outreach activities were a part of the broader SI Bridges program. During the SRI, scholars selected SIUC faculty who agreed to serve as research mentors in the year following the SRI, with an overall program goal of research education and matriculation post-community college to a 4-year institution.

RE Instructors

The primary instructors and pedagogical designers of the REs have backgrounds in cell and molecular biology (Fromherz) and neuroscience (Sharp); they had previously established a collaboration using optogenetics in embryonic chickens (Sharp and Fromherz, 2011) and both had previous experience in STEM education for underserved students. A graduate student assisted with each RE including Whitaker-Fornek in the year 1 SRI and all of year 2. She was a Master's student in the Molecular, Cellular and Systemic Physiology Program at SIUC at that time. Several cohort 1 Bridges scholars assisted in year 2. As part of the broader SI Bridges program, two community college instructors, one from each participating institution, joined in many of the RE activities. The instructor and peer mentor pool consisted of individuals with diverse backgrounds that included ethnic, economic and gender diversity.

Facilities and Setting

All activities were carried out in a teaching laboratory in the Department of Plant Biology at SIUC. During the semester (CL activities), the space was used during the evening and scholars assembled and disassembled their workstations each session. For the SRI, the space was converted into a dedicated research space by moving in the necessary equipment and supplies. Some equipment used, such as autoclaves and centrifuges, were housed in common areas in either the Department of Plant Biology or the Department of Physiology at SIUC.

Before starting wet-lab research, scholars were given training in laboratory safety and the ethical conduct of research. They provided informed consent for participation in the SIUC Institutional Review Board-approved education research aspects of the program. Safety and ethics topics were regularly reinforced throughout the program. Scholars were outfitted with personalized lab coats with their names

STEM Research-Critical Areas	Anticipated Learning Outcomes
	Scholars will show improved:
1) Process & Profession	Ability in the design and conduct of research; understanding of the scientific process; awareness of STEM careers, potential pathways and pitfalls
2) Confidence & Commitment	Self-confidence to pursue STEM research and related careers; enthusiasm for and commitment to a career involving STEM research
3) Communication	Written, oral and collaborative communication skills in STEM
4) Critical Self-Reflection	Ability to self-evaluate, to analyze and to discern meaning from varied experiences, and to develop new meaning through the integration and synthesis of experiences
5) Mastery	Knowledge of core STEM concepts and experimental methods; ability to describe and apply evolutionary concepts; ability to problem-solve and apply prior knowledge to new situations

Table 1. Identified STEM research-critical areas and anticipated learning outcomes for scholars participating in the REs.

and program affiliation embroidered. This small gesture was a significant source of pride and distinction.

General Features of the REs

A key element of the RE design was creation of a trusting, safe environment conducive to learning for research novices. To achieve this, we converted a teaching lab – a type of space familiar to the scholars - to a research space and emphasized positive support and scholar strengths while providing opportunities for critical self-reflection and growth. In addition, snacks and occasional meals were shared during breaks, instructors shared stories of their career experiences, and scholars were encouraged to share whatever they wanted. These activities were initiated in CL and continued through the SRI.

The first RE (CL) was held during the spring semester while scholars were enrolled as full-time students at their respective colleges. It was therefore limited to in-session activities and was designed primarily to engage novice researchers in the scientific process while laying a foundation for deeper learning. When scholars regrouped for the summer, they were poised to ramp up and handle the high-intensity, technically and conceptually complex and highly focused research training and projects of the second RE (the SRI). Samples of activities for both REs, piloted in year 1 (cohort 1) and refined in year 2 (cohort 2) are described in this report. The authors are happy to share additional materials upon request.

Connecting Life

Overview. Connecting Life was named to reflect the infusion of evolutionary concepts in this RE. Scholars experientially learned the scientific process as they designed and carried out simple but meaningful research projects involving the unicellular ciliate, *Tetrahymena thermophila* and other simple eukaryotes, and learned about the many evolutionary connections from microbes to humans (Smith et al., 2012). Scholars were introduced experientially to several foundational research concepts, including scientific inquiry, use of technology, collaboration, critical thinking and self-directed learning. Scholars met for one week night evening or Saturday per week for 4 hours each session over 15 weeks.

For the first ~2/3 of CL (~11 weeks), scholars worked in pairs to carry out guided inquiry investigations to build foundational skills. Two of these activities, "Green Bias" and "Organisms X," are described further below. The last ~4 weeks were spent with scholars designing and carrying out relatively simple open inquiry experiments in *Tetrahymena*. Scholars then gave oral presentations of their research efforts to the entire group.

Activities were designed to be fun, inquiry-driven, structured yet flexible, and accessible while encouraging scholar reflection and learning growth. As scholars progressed through CL, process steps were repeatedly practiced, with incremental introduction of more complex content. Scholars were coached in how to keep a proper laboratory notebook and practiced that skill. Time was set aside on a regular basis for oral and written formative instructor-, peer- and self-assessments, as well as self-reflection. Scholars worked in pairs, but they changed partners every 5 sessions, in order to build new connections and a more cohesive cohort.

Pedagogy. The pedagogical approach we chose to take is rooted in the “5e Learning Cycle” (engage, explore, explain, extend, evaluate) because it nicely models the process of science (Bybee et al., 2006; see also BSCS Science Learning, 2016). Clickers were used in many instances to capture instantaneous responses to queries that could be shared anonymously in bulk with the entire group. The events in CL were designed to support improvements in all five STEM research-critical areas we identified (Table I), with emphasis in this RE on the first four: Process and profession, confidence and commitment, communication and critical self-reflection. In addition, we designed CL to address deficiencies in select areas that were evident from pre-assessments. That is, scholars pre-CL lacked confidence and/or had little to no experience with:

- Experimental design;
- Compound light microscopy;
- Careful observation and data recording;
- Use of complex technical equipment.

To mitigate these deficiencies, we designed a work-station complete with compound light microscope, Motic X Wi-Fi video camera (www.motic.com), Windows 8 tablet, and large screen monitor (Figure 1). Scholars were challenged to assemble and disassemble the workstation each time, learn the image capture software (Motic Images Plus 2.0), manage data files and become skilled with the overall technology. Importantly, the work-station allowed scholars to obtain microscopic images without having to look through an ocular lens. Other significant work-station benefits included the fact that the microscopic images were huge on the big screen (a significant wow factor for this group), and images were readily shared (for example, with onlookers as well as friends and family outside the classroom) and captured for later cropping or analysis. The Motic cameras were used for video capture and for still photographs. Scholars were encouraged to carefully describe and draw what they observed in their notebooks. They were given frequent constructive suggestions on their efforts from the instructors and in some cases from their peers, and were given time each session to self-identify improvement areas.

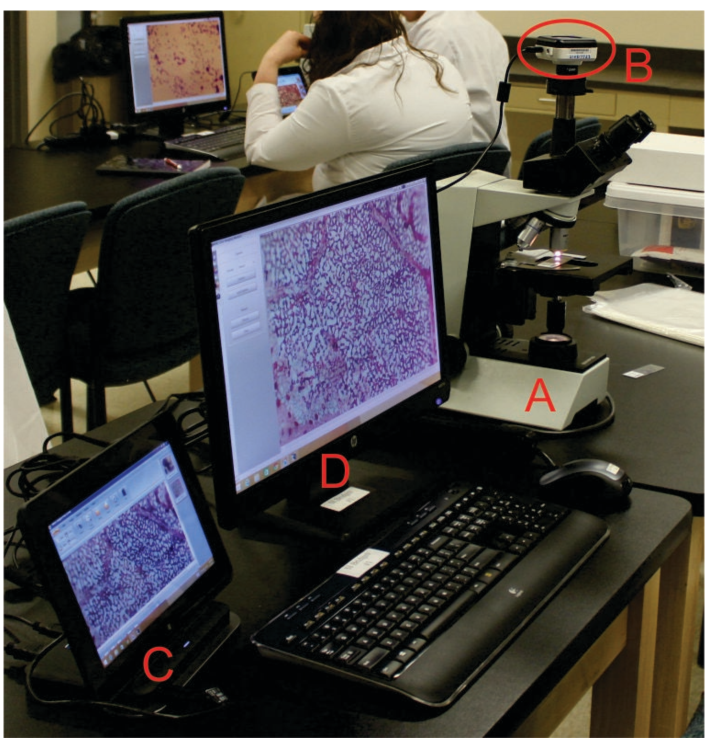

Figure 1. Student-assembled microscopy work-station consisting of compound light microscope *(A)* outfitted with a Motic (Wi-Fi) video camera *(B)*, which in turn is connected to a Windows 8 tablet computer with docking station *(C)* and large screen monitor *(D)*. Attached to the camera is an USB cable for power.

Formal instructor-to-student teaching ("lecture") in CL was kept to a minimum. For virtually all activities, scholars engaged in extensive peer instruction and collaboration, and shared informal discussions with the instructors. Starting with an inquiry prompt, scholar pairs brainstormed questions and hypotheses, designed and carried out simple experiments, and collected, evaluated and shared their data with the rest of the group. The group was provided interactive instruction on sharing positive feedback in a supportive manner. Regular exercises worked foundational skills such as reading, writing, problem-solving, oral communication and self-directed learning. Scholars practiced activities critical to the process of science including experimental design and keeping a laboratory notebook. The importance of careful observation was emphasized. Breaks between activities were accompanied by a brief wrap discussion, often over snacks. After clean up, every session ended with a short self-reflection activity where scholars shared their thoughts, including (questions on the reflection form): What did I learn today? What did I like the most about what we did today? What did I like the least? Reflection sheets were collected by the instructors and reviewed. Various student-generated materials and responses to assessment questions including pre-post questions to assess learning gains in STEM research-critical areas (Table I) as a result of specific events and activities were regularly collected and evaluated by the instructors.

Activities. CL activities were designed to help scholars practice fundamental skills and boost their confidence. Most activities were presented with inquiry steps closely and explicitly aligned with the "5e Learning Cycle" (Bybee et al., 2006) so that scholars could more readily follow the learning model. Learning objectives for each activity were provided.

At the start of CL, scholars were *engaged* with short and accessible videos such as, “The Inner Life of the Cell” (Harvard Biovisions, 2014). Scholars were polled to gauge interest and were given an opportunity to share their curiosity questions. Scholars were then challenged to form pairs and assemble a microscopy workstation. Scholars *explored*, practicing microscopy skills along the way. They were encouraged to make careful observations, and document their thoughts and findings. Scholars designed simple experiments to address their curiosity questions. Scholars *explained* their findings through discussion with others in the group. Scholars were then challenged to *extend* their learning by having to apply skills and concepts in the next session to a novel set of inquiry challenges. Finally, scholars *evaluated* each experience by reflecting on the process, with emphasis on their personal experiences, partner interactions and perceived learning outcomes; they were encouraged to record their thoughts as journal entries and define personal learning goals. Instructors and peers exchanged ideas and suggestions to wrap up each experience. Instructors reviewed scholar-generated materials prior to the next session and offered individual and group feedback.

Other activities were designed to combine guided inquiry with careful omission of detail at defined moments. In an activity dubbed "Green Bias," for example, scholars carried out a series of exercises to uncover assumptions based on prior knowledge ("bias"). For this activity, four species of organisms that were green for different reasons were used. One (*Elodea* spp.) was named and the other three were not. The unnamed organisms were an algal-fed "water flea" (*Daphnia magna*), a "green hydra" (*Hydra viridissima*) and "water bears" (tardigrades) in green pond detritus. The exercises challenged scholars to answer questions that helped distinguish bona fide observations from both correct and incorrect application of prior knowledge. For example, scholars were asked if they thought the organism was single-celled or multicellular, and what they thought was the basis for the green color. Scholars were potentially able to use clues such as size, motility and the appearance of appendages and other features; they were also encouraged to design and carry out simple experiments to learn more. The same set of questions was repeated for each organism.

In another activity, "Organism X," the cell biology and environmental toxicology model organism, *Tetrahymena thermophila*, as well as a simple assay to monitor phagocytosis in *Tetrahymena,* were introduced through the back door (omission of detail at defined moments). Scholars were first *engaged* by being invited to prepare wet-mounts of and view the unnamed "Organism X" (*Tetrahymena*) and record their observations. Scholars were then provided inquiry prompts and instructions to *explore*, testing various dyes and other treatments, some of which scholars would note appeared to immobilize/kill the organism and others that behaved as vital stains. One treatment included incubation of *Tetrahymena* cells in the presence of nontoxic levels of India ink, and scholars discovered that over time dark structures appeared in the cells (uptake and concentration of India ink in vacuoles darkens them considerably). Once again scholars were challenged to share and *explain* their experiences through informal 'screen sharing' as the entire group gathered around each workstation. Once the identity of "Organism X" was revealed, the instructors provided information about *Tetrahymena* and its importance as a model organism. Scholars were challenged to *extend* their learning to include finding examples in the literature where *Tetrahymena* was used as a model, and by reading about India ink uptake as a simple visual assay for phagocytosis (e.g., Bozzone, 2000; Gray et al., 2012; Smith et al., 2012). Finally, scholars were asked to *evaluate* aspects of the process they had just completed: They were asked to reflect on the connectedness of life, on the events they had experienced, and on their personal growth.

During the last ~4 sessions of CL, scholars designed, carried out, and analyzed the results of simple experiments in *Tetrahymena.* We adapted previously described India ink-based assays of phagocytosis for these experiments (Bozzone, 2000; Gray et al., 2012).

The CL experience culminated in oral presentations by scholar pairs to their peers and program affiliates followed by a "pair and share" activity for peer evaluation of presentations. For the "pair and share," scholars were individually asked to respond to two questions for each presentation: 'What are two aspects of each group's experimental design that impress you or that you admire? What are two suggestions you have to offer for their future experimental design?' Each scholar pair was then combined with another group, and the four scholars were asked to describe their collective understanding of the scientific process and what makes for experimental design. Responses were shared and discussed with the entire group, and instructors provided constructive feedback.

Summer Research Institute

Overview. The technically more advanced SRI followed CL and was held during the summer when scholars were not in school. The group met for 8 weeks, approximately 40 hr per week. Each day was organized into blocks of events, with short breaks and one longer lunch break in-between. In both years, the first 3-4 weeks of the SRI were heavily focused on training activities. The remaining four weeks were primarily devoted to authentic research. Professional development activities and visits from SIUC faculty who had agreed to be post-Bridges research mentors were interspersed throughout the 8-week program.

An intense learning environment combined hands-on training in technical methods with content-rich lectures, discussions and professional development activities. Throughout the SRI, we engaged scholars in metacognitive activities including daily reflections. They also engaged in regular writing and synthesis exercises including keeping a laboratory notebook and developing flow charts, and were given iterative instructor feedback.

In both years 1 and 2, much of the training exercises in weeks 1-4 were designed to give scholars 'essential' background in areas such as developmental biology and neuroscience. Optogenetics applications to control movement in mid-stage embryonic chickens were introduced (Sharp and Fromherz, 2011), and served as a major focal end-point to drive the choice of background information.

Within that framework, scholars in year 1 were challenged to come up with and develop ideas for their own research projects. In year 2, the instructors had, in advance, identified and conceptually outlined several projects for scholar pairs to choose from and pursue; scholars learned about the projects on the second day of the SRI, and ranked and chose their favorites. Scholars were paired based on their chosen projects. The training activities during weeks 1-4 were tailored to prepare scholar pairs for their specific projects in addition to providing common skills training for the entire cohort.

Weeks 5-8 were primarily devoted to carrying out authentic research projects, analyzing data, and preparing and presenting their research. In year 1, scholars took the lead on their project design. In year 2, the instructors initiated project design and then assisted the scholars in refining their projects.

In both years, scholars were challenged on a variety of fronts. Topics that were heavily addressed through inquiry labs, mini-lectures, films and discussion included DNA and DNA-related technologies, developmental biology, and neurobiology. Technical skills learned included molecular skills such as the use of standard equipment (micropipettor, autoclave, gels, centrifuges, incubators, thermocycler) and common biotechnology laboratory methods (e.g., plasmid DNA isolation, PCR amplification, transformation, restriction enzyme digests, gel electrophoresis, Western blotting and computer-based approaches including database searching, sequence alignments and sequence analysis). Scholars were challenged to write a formal lab report on plasmid DNA isolation and received critical feedback from both peers and from the instructors. Chicken embryology skills taught included embryo/egg incubation and general experimental manipulation in the embryonic chicken, DNA injection into the neural tube and electroporation, fluorescence microscopy, and behavior recordings and analysis.

Year 1. In the first year of the SRI, scholars were challenged to identify research questions that particularly intrigued them from the collectiveexploratory events they experienced. This allowed students to follow their own interests with a great deal of freedom.

The first four weeks of the RE were dedicated to research education that extended what scholars had experienced in CL and provided background for scholar research projects. For example, scholars learned about developmental biology, neuroscience and molecular biology as they learned how to carry out effective literature searches, write a laboratory report, and carry out effective experimental design and analysis. Safety and the responsible conduct of research were also revisited. We modeled and gave scholars many opportunities to practice skills important for self-directed learning. Several activities were critical for the student projects. Students engaged in skills exercises as well as exploratory laboratories in areas such as chicken embryonic development and biotechnology. These were used, along with introductory mini-lectures, to provide select background on topics such as behavior, optogenetics, sensorimotor development, neuroscience (i.e., electrical excitability, morphology, synaptic transmission, sensorimotor circuitry), developmental biology, genetics and molecular biology.

We discussed research questions and challenges in these areas, and then scholar pairs were challenged to identify a research question they could pose and test. With each initial idea, instructors worked with the pair to identify practical investigations and refine their proposed projects. All scholars chose to develop projects based on optogenetics methodology, and each scholar pair set out to alter diverse target neural or muscular tissue activity with this system. A total of four projects were developed, with each project aimed to determine the effects of light-driven electrical activity on the (1) developing eye, (2) heart, (3) skeletal muscle and (4) spinal cord, respectively. In preparation for their ultimate projects, all scholars learned to electroporate our original channelrhodopsin expression construct (Sharp and Fromherz, 2011) into the neural tube of embryos. On subsequent days, they checked for successful expression by detecting the associated fluorescent reporter protein using inexpensive LEDs and filters (Thorlabs, www.thorlabs.com). This community learning approach was chosen to help support acquisition of the complex technical skills and concepts necessary for optogenetics research. Further, it allowed for informed group discussion and improved troubleshooting that was invariably necessary for each project.

During week 5 the students carried out pilot experiments in their chosen research areas. After further discussions and refinement, the student pairs carried out their research projects in weeks 6 and 7 as well as writing an abstract of their work for publication in the upcoming symposium brochure. In the last three weeks, scholars worked on data analysis, poster preparation (based on a template) and oral presentation skills. The summer program ended with a mini-symposium where scholars presented their research to the invited public in both poster and oral PowerPoint presentation formats.

Year 2. In the second year of the SRI, the first four weeks were split between developmental training exercises similar to those of year 1 and development of scholar research projects. In year 2, scholars did not develop their own projects from scratch; instead, we followed a model often used in research labs and suggested research questions for scholars to choose from. Prior to the start of the SRI, the instructors identified and conceptually planned five research projects. Scientific merit, feasibility and likelihood of scholar success were significant factors when deciding which projects to pursue. Therefore, projects chosen for development aligned with the research interests and expertise of the instructors. On day 2 of week 1 in the SRI, scholars were given a brief description of each project and were asked to indicate their top three choices in order of preference. Projects differed in the tool-set needed as well as the intellectual question asked. Scholars formed pairs based on their interests. As luck would have it, every scholar was able to engage in a project that was their first choice.

Scholars worked closely with the instructors to develop projects in the following areas, all of which were carried out in embryonic chicken models:

- Potential acute or chronic effects of ethanol (consistent with maternally-derived exposure levels) on early embryos' motor activity;
- Adaptation of a genetically-encoded fluorescent voltage sensor, Accelerated Sensor of Action Potentials (ASAP; St-Pierre et al., 2014), to allow non-invasive monitoring of neuronal activity during embryogenesis;
- Development of a proprioceptive neuron-selective promoter expression system for optogenetic manipulation of proprioceptive neurons;
- Western blot approach to determine vitamin B_6 effects on select protein profiles in embryonic chickens;
- Optogenetics approach to hyper-activate early embryonic motility to determine if such activity can alter later spontaneous motor activity.

The same general scheme as Year 1 was used to organize the rest of the Year 2 SRI.

Assessments

Several assessment methods were used to monitor changes in scholar attitudes and aptitudes. These included peer evaluation, scholar self-reflections and descriptive responses to surveys. In addition, instructors observed scholars in real time, and evaluated laboratory notebook entries, laboratory reports, experimental design worksheets and other scholarly materials written by the participants. Clickers (iClicker, www.iclicker.com) were used at varied times throughout the REs to poll opinions and gauge mastery, for both instantaneous anonymous feedback to the instructors and scholars and for later evaluation of individual or bulk responses. Instructors also evaluated scholar oral presentations, posters and video productions. We also collected feedback and observations by select SIUC faculty who had agreed to mentor individual scholars in research post-REs. Finally, we administered a 24-question semi-quantitative survey to cohort 2. Each question mapped to one or more of the five STEM research-critical areas (Table I); scholars responded with a numerical score (1, 2 or 3) depending on how strongly they agreed with the statement.

Professional development

Our RE program was infused with a variety of activities and discussions related to scholar professional development. These were especially prevalent in the SRI. For example, during the first four weeks of the SRI we read and discussed chapters from E.O. Wilson's *Letters to a Young Scientist* (Wilson, 2013) and discussed topics such as career options, pathways in science and getting there, choosing a lab, and choosing a project. Additional on-campus development of writing skills and other professional development activities were provided as part of the broader SI Bridges program. Finally, several SIUC STEM faculty visited with the scholars as part of our scholar-research mentor pairing program for research post REs. Each faculty member had an opportunity to share their perspectives on 'career essentials' while sharing background about their own research interests. We felt it was important to provide regular, revisited discussions of career essentials and the provision of multiple perspectives, so that the concepts could percolate and hopefully be absorbed by the students more readily than if we had set aside a "career day."

Equipment and Supplies

Laboratory equipment was either borrowed from on-campus resources or was purchased as part of the program. Reagents and supplies were purchased from scientific supply companies, including ISC Bioexpress (general molecular biology), New England Biolabs (DNA-modifying enzymes), Qiagen (plasmid DNA isolation), Lonza (SYBR green), MP Biomedicals (Geneclean), Biorad (protein work), and Carolina Biologicals (live microscopic organisms and India ink). Fertilized White Leghorn chicken eggs were acquired locally by the instructors. Clickers and software were from iClicker.

RESULTS AND DISCUSSION

Participants in the REs were underserved students enrolled full-time in STEM fields at two rural, regional community colleges. Detailed features of the REs were pointedly designed to support improved engagement and learning by participating scholars. Scholars came onto the campus of SIUC for the REs. The campus was at first unfamiliar to the scholars. Holding the classroom REs at SIUC allowed us to gradually introduce the students to both the physical and social aspects of the university. With time, the campus became increasingly familiar and one significant barrier to matriculation to a four-year university was potentially mitigated.

In pre-RE surveys, we established baseline prior knowledge and experience and determined, not surprisingly, that scholars showed significant deficiencies in STEM research career-critical areas. For example, scholars reported little to no awareness of STEM research and STEM careers beyond traditional health professions careers. Their responses to questions that assessed prior knowledge of the scientific process, career considerations, wet-lab methods and core concepts (such as 'What is DNA and how could you study DNA?') were generally incomplete and/or superficial. In surveys and conversations, scholars reported a similar lack of awareness of STEM research and careers by their family members and other members of their community. Since the scholars were new to research and had no experience with the environment of a research lab, we sought to create a transitional working space by offering the REs in a converted teaching lab setting.

Prior to the REs, virtually all scholars reported having no prior experience with scientific research based on their understanding of what that meant. Furthermore, most scholars had very limited STEM coursework or lab experience, although several had taken or were taking an introductory biology class with lab at their respective community college. Scholar self-reporting strongly suggested that their STEM learning experiences had so far been largely memorization-focused. After some experience in the REs, upon reflection (see below), scholars admitted that in their course-work they were used to rushing through teaching labs to get finished as quickly as possible.

Connecting Life

CL was designed to engage scholars in relatively simple guided inquiry activities that were fun and accessible and that fostered research thinking and skills. Careful development of a trusting, supportive and collaborative learning community-style environment was achieved through careful positive mentoring and leadership, through facilitated discussions and through community sharing activities such as story-telling and snack-sharing during breaks. We focused on scholar strengths and self-identified learning goals and sought to work with each scholar on an individualized basis. By encouraging scholars to reflect on their personal interests, learning and overall experiences - and identify positive outcomes while setting personal learning goals - scholars were able to develop skills in critical self-reflection and self-directed learning.

CL was first offered in 2014. One significant adjustment we made mid-stream in this pilot program, after implementing our initial plan, related to time. We found that each step warranted considerably more time than originally envisioned in order to allow all scholars to be comfortable and ready to move onto the next challenge and allow ample opportunity for discussions and peer-sharing. The original time estimates were based on the instructors' prior experience teaching undergraduate course-based inquiry laboratories. However, in contrast to the latter, our scholars were not taking the REs for course credit, were simultaneously enrolled as full-time students at their respective community colleges, and were rarely asked to complete any work or preparations outside of the in-ground RE session.

We first set out to engage scholars in the excitement of science using short, accessible and compelling videos such as the music-only version of "The Inner Life of the Cell" (Harvard Biovisions, 2014). After watching, scholars excitedly shared their curiosity questions and were anxious to learn more.

Having captured their interest, one of our next goals was to improve scholar microscopy skills while starting to remove any fear of technology and research equipment. Prior experience in teaching labs suggested to the instructors that for undergraduates, using a microscope well was not trivial and was often intimidating. To make microscopy more immediately accessible and inviting, we developed microscopy work-stations (Figure 1). Scholars were challenged to assemble and disassemble their work-station, thereby engaging them in a core part of research (equipment assembly and usage) early in their training. Most scholar groups were hesitant or at least challenged by the prospect of assembling the work-station. Based on their comments, in most cases this was the first time they had had to build anything technical.

As part of the facilitated learning process, we briefly demonstrated assembly/disassembly of a work-station and talked about care and safety of each element prior to the scholar pairs trying it themselves. Then, with help as needed, we had scholars assemble and disassemble their work-stations in one session. We purposefully held off having them image a specimen in this session. The next session, one week later and many distractions in between, they were challenged to re-assemble their work-stations, this time on their own. As expected, they were extremely challenged and experienced a lesson in, 'write things down!' Scholars also struggled to get the equipment working, or working well, and in general the reasons were varied. Thus, we had an opportunity for peer instruction, both within a partner set and across partner groups.

Learning how to use the work-stations meant mastering software and fundamental microscopy skills. However, the work-station approach allowed relatively rapid success and excited satisfaction with respect to their microscopy efforts. For example, upon seeing the large screen image of a live, moving microscopic specimen for the first time, scholars expressed audible delight with exclamations such as,

> *"This is the coolest thing I have ever seen!"*

Scholars reported that already the early CL experiences had entirely transformed their outlook on lab-work. For example, after experiencing CL for a couple of sessions, scholars realized they were engrossed in the activity and having fun. Several commented that in previous lab experiences they routinely rushed through the lab and could not wait to finish. In contrast in CL, they reported feeling challenged, curious, personally invested and willing to spend quality time. They wrote reflections such as:

> *"Today's class was fun. We were introduced to some unfamiliar specimens, which was nice. I really liked the snail-like qualities of the green thing ["green Hydra"] because it was simple yet so perplexing."*

One barrier we had to help scholars overcome was their tendency to want to show off any knowledge they had instead of relying on their observational skills. Exercises such as "Green Bias" and "Organism X" helped scholars uncover some of their biases and/or data mis-interpretation. Scholars with the greatest prior knowledge tended to show more bias and on average showed lower effective use of observational skills. For example, students who knew that *Elodea* had chloroplasts expressed certainty that they could "see" chlorophyll. Some scholars, observing "Organism X" (unicellular *Tetrahymena*) after incubation with India ink, incorrectly deduced that the organism must be multicellular and "what is inside" must be cells (in reality ink-filled vacuoles). In some instances, the same student (correctly) identified cilia, which were visible on the periphery of each *Tetrahymena* cell after staining. Moments such as these provided great opportunities for discussion, critical self-reflection and growth. In reflecting on the "Green Bias" activity, one scholar wrote:

> *"[My partner] and I [had] hypothesized that organism 3 ("green Hydra") was unicellular. We thought [this was true] because it was green and that meant it had chloroplasts. [We have now learned that these] hydras are multicellular and have a symbiotic relationship with green algae that live right below [the] surface; hence, [they are] green."*

Similarly, later in the RE, when scholars were asked to reflect on events of the past several sessions, one wrote:

> *"Today we finished up our observations of 'organism X', and we took a look back at what we had written about organisms 1-4 and 'X'. Looking back with [one of the instructors], I noticed two things. Being objective is extremely difficult. In an attempt to "show off" my knowledge, I had missed the point of the exercise. The point was to observe, meaning to record what we had seen. However, all of the things I had written down were my own pre-conceived ideas. Another thing I learned was to take better notes. I need to slow down and articulate ideas on paper better for future reference."*

The individual nature of each scholar, including their varied experiences and learning styles, meant that learning paths and rates were varied. For example, even after multiple (e.g., 10) sessions, comments such as the following from two different scholars were not uncommon:

> *"Today's class was really fun. The organisms ["Organism X"] were hard to find at first and there [were] very few of them but then we finally hit the*

mother-lode and saw 50+! It was awesome."

"*Today I felt a little more confident in my use of the software and my general knowledge of the organism being used*."

Instructor observations and pre/post-CL surveys suggested positive learning gains in scholar understanding of the scientific process, although there was still room for improvement. For example, for cohort 2, we found pre-CL that most (7/10 cohort 2) scholars had a partial understanding of what scientific research is and what is entailed in that process; two more described the process accurately and thoroughly; only one scholar provided an incorrect response to the prompt. These data suggested scholars had learned *about* the process of science in prior experiences. This is in contrast to the vast majority (9/10) that reported having no prior experience *doing* scientific research. The post-CL survey revealed that, not surprisingly, all 10 scholars reported having had experience doing research. They also provided more correct descriptions of the process with half now describing the scientific process accurately and thoroughly, and half providing correct, partially complete responses.

Instructor observations and pre/post-CL surveys also suggested improved conceptual understanding of evolution, again with room for growth. For example, with cohort 2, we found that pre-CL only 1/10 scholars correctly and thoroughly responded to the prompt, 'Describe how different living things (e.g., humans and microorganisms) are related to each other according to your current understanding.' Of the remaining scholars, 5 provided a completely incorrect response and 4 provided a correct but only partially complete response. Post-CL, 7/10 of scholars provided correct but partially complete responses; two scholars provided correct and complete responses, and one scholar continued to reply with a completely incorrect response. These results suggest that CL was modestly successful in increasing scholar understanding of evolutionary concepts including the evolutionary relatedness of life.

Overall, from the CL introductory research experience, we found that scholars showed improved attitudes toward and aptitude in STEM research and made learning gains in all intended learning outcome areas. Especially evident were improvements in confidence and commitment. Representative comments from three scholars as they reflected on CL illustrate these points:

“It is a unique learning experience. The staff is very motivating and you are allowed to explore your own boundaries.”

“We are like a big family, helping and motivating each other.”

“Keeping a journal really helped me because now I am in a better habit of writing things down and it helps a lot. At the time I didn’t like it but I believe it improved my writing skills and made me grow.”

The Summer Research Institute

We designed the SRI with the goal of providing the necessary background and resources for scholars to successfully carry out more technically advanced, authentic research projects. In thinking about the design, we knew the groundwork that had been laid in CL provided a learning-ready platform. The scholars were acclimated to their environment, were still and perhaps even more enthusiastic, were more confident, and had a greater appreciation for what it means to do research. To bring them to the next level, scholars were heavily coached as they participated in training and research activities that were technically more advanced and required significant acquisition of scientific content.

We chose the chicken embryo as the model system in part because of its importance as a model for developmental biology and biomedical sciences research and in part due to the instructors' expertise and research interests. Like recently described laboratory exercises using optogenetics (Vilinsky et al., 2018; Rose, 2018), we included this approach in part because of its appeal as a cutting-edge neuroscience technique. However, by also including optogentic construct development and embryo transformation, we introduced the scholars to the sometimes necessary process of methodology adaptation to answer an important scientific question.

As reported below, scholars experienced learning gains and improvements in all five STEM research-critical areas (Table I). The adjusted approach we took in year 2 proved to be most effective for supporting the transition from research rookie to empowered research-ready scholar.

Year 1. The first four weeks of the SRI were devoted to content-heavy background delivery in the form of interactive lectures, assigned readings, and laboratory exercises. Scholars essentially experienced a crash course in select areas of embryonic development and neuroscience. With each of these topics it was necessary for scholars to acquire sufficient knowledge in foundational sub-topics. For example, scholars needed to learn about DNA, genomes, plasmids and molecular tools to appreciate the "genetics" part of optogenetics, and had to learn about action potentials, ion channels, properties of light and the green alga, *Chlamydomonas* for the "opto" part of optogenetics.

After these background exercises, scholar pairs were challenged to lead development of a research project plan. Scholars had to carry out literature searches, unpack unfamiliar technical literature, discuss with instructors and peers, and refine their plans accordingly. Scholars crammed a tremendous amount of study, planning, trial & error efforts, data analysis, poster preparation, and talk preparation into the last four weeks, culminating in formal poster and talk presentations.

We observed significant improvements in time management skills as scholars realized the time they allotted for each step was severely underestimated. The stress of having and barely meeting a deadline was itself a learning experience. We also observed, and scholars perceived significant learning gains in all five targeted STEM research-critical areas. Representative comments that illustrate student perceptions of their learning are as follows:

Process and Profession

"This [experience] *really changed my outlook on self-directed learning. I didn't look things up because I had to. I looked them up because I truly wanted to know."*

Confidence and Commitment

"Before the program I always liked science, but now I love it. I enjoy being in the lab and having the opportunity to continue my research"

"I am 100% sure that a career in science is where I'm headed."

"I used to be terrified of labs, and now I feel comfortable and confident in a lab and in learning new technologies."

"After participating in [the REs]*, I not only believe I can make a successful career out of biomedical research, I am certain I will continuously enjoy it."*

Communication

"Getting to experience different lab partners helped me learn how to work with different types of people. I learned how to deal with conflict without fighting, and I gained some great friends."

"I believe that keeping a journal and the instructors enforcing us to write everything we did and what we felt at that moment really helped me because now I am in a better habit of writing things down and it helps a lot. At the time I didn't like it but I believe it improved my writing skills and made me grow."

Critical Self-Reflection

"Because of the self-directed learning style I adopted from the SRI, I can now better isolate problems, and determine what needs to be done to fix them, which is helpful in almost every aspect of my daily life."

Mastery

"Before the SRI, I was completely LOST! I could read one paragraph and not obtain a word. I got to learn how to break scientific literature down, and how to better understand it."

"Through the whole program, nothing was about memorization. I am so thankful that we actually got to learn instead of memorize. I have now taken that attitude and have applied it to college, and it makes learning much easier."

Shortly after the end of the SRI scholars were asked, 'What events or activities in the SRI do you feel were especially positive toward your growth and development as a scientist and scholar?' Representative responses:

"Injecting the embryos and getting expression; seeing that your work has been successful. It was amazing."

"Having to present our project made me feel like I was a scientist! That is something that I have been wanting for a long time. It feels like I have more of an open door to achieve my goals."

"[The SRI] was an immersion program in the culture of science. This was great and exactly what I needed to fully realize that the science culture is something I want to be a part of. Everything that added to this perceptive realization I feel were positives of the program; this includes but is not limited to: Learning how to ask the right questions; learning how to efficiently do research; all the lab hands-on (from PCR to cutting eggs open), and the theory behind the hands-on work. Really, it all helped me realize what would be needed of me to be a scientist, and moreover that I could accomplish it."

"When I started connecting how chicken embryos relate to humans, and how they are a good model organism for humans [was an especially positive event]*."*

"When I started doing research for my project and I realized that trying to figure out how something worked was enjoyable [were especially positive events…] *…especially not having any background knowledge."*

"Designing my own project and making a poster were beneficial experiences."

"All of the molecular work (E. coli, running gels, making LB, PCR) were extremely helpful pre-knowledge for my current lab experiences. I'm really grateful I know how to do those things. I'm also grateful I learned how to follow a protocol."

We also asked scholars for any suggested changes in the SRI. We heard suggestions about time management from several scholars. For example:

"[I would have liked] more time for our projects. I feel like I would have liked way more time to study the project and actually get great results from it because now if I think about my project I can think of many things I could have done differently to make it work."

"One change would probably be to manage time a little bit better because I thought that at the beginning of the SRI, everything was very relaxed and then at the end we were trying to push everything really fast…"

Organization and time management were challenges that we also observed in year 1 of the SRI, perhaps not surprisingly given its pilot status. One other observation seemed particularly important. As we worked with the students to develop their projects, it became increasingly clear that the students were driven primarily by the 'cool tool' aspects of optogenetics and not by well-founded research questions. The groups attempting to transform cells in the heart, eye and skeletal muscle were only able to achieve brief ectopic expression in non-target cells. However, one group was able to achieve expression of halorhodopsin in the spinal cord. They were able to maintain one embryo until embryonic day 9 (E9) and to record changes in behavior during photo-stimulation.

Overall, the scholars lacked sufficient knowledge-base to lead development of strong research proposals and therefore meaningful results were limited. We realized this was likely due in part to the fact that their chosen projects were beyond our direct expertise. Given time constraints, our ability to determine and provide expert-level advice on their experimental details was more limited than it would have been if research questions aligned with our specific expertise in sensorimotor system development. These observations contributed to the changes we made in year 2.

Year 2. After piloting the SRI in Year 1, we took scholar suggestions and our own observations under consideration and implemented small but significant changes in the program design. The most significant adjustment was that the instructors identified and pre-developed, in general concept, potential research projects. Scholars joined the development process more like apprentices, or as they might join a research lab as beginning graduate students. As evidenced by the results described below, providing research focus areas allowed the scholars to develop a better knowledge of their research question, a stronger research hypothesis, greater research progress and stronger research presentations. We feel this was an important improvement in the program as evidenced by learning gains in all five intended learning outcome areas, reported below. More generally, events in the second year were more organized and proceeded more smoothly than in the pilot year. This likely improved the learning environment and may have contributed to the gains we see.

Research outcomes themselves were not our primary goal. However, project results help illustrate scholar learning gains. The group studying ethanol exposure was able to determine a treatment protocol that resulted in reproducible behavioral changes at E9. The group working with ASAP was able to subclone the open reading frame from the commercially-available ASAP gene into our expression plasmid. They were then able to demonstrate expression of ASAP through E7 by monitoring fluorescence. The group trying to generate a parvalbumin promoter construct with channelrhodopsin were able to design and generate their construct, but lacked sufficient time to test it in embryos. The group studying vitamin B_6 effects were able to treat embryos with B_6, isolate thigh tissue and quantify protein levels, and succeeded in carrying out a control Western blot to detect myosin light chain. The group seeking to hyperactivate embryos to assess effects on development were able to successfully achieve expression of channelrhodopsin in the spinal cord and to obtain acute light activation of movement on several days between E5 and E9.

While development of the project ideas into detailed research plans was necessary and a major part of the scholar-instructor efforts in the early weeks, having projects that were pre-identified for their importance and likely success provided a more focused platform from which scholar learning could occur. Instructors were able to provide a stronger intellectual foundation and guide the projects more pointedly to success. To determine if the changes we made from Year 1 had an impact, cohort 2 scholars were asked on the last day of the program to reflect. Like the first cohort, they were asked: 'What events or activities in the SRI do you feel were especially positive toward your growth and development as a scientist and scholar?' Representative responses:

> *"I liked many aspects of the SRI, but I mostly liked how much I was able to learn about all the techniques real life scientists are using. Being able to carry out my own experiment really helped me understand what it is like to do research."*

> *"I felt like I gained a lot of knowledge and confidence working with various protocols, having input from the instructors, but ultimately working most closely with my lab mates, working things out. The public speaking and diving right into science was especially helpful."*

> *"I liked the wonderful support I received. I was never handed answers; I was handed resources to challenge myself to go above and beyond what I would normally learn in a classroom setting. I received the opportunity to gain real hands-on lab experience and meet great new people. Public speaking helped me articulate my scientific findings. Overall, I have grown as a student and a person from the SRI."*

> *"I liked the intensity of the program very much and how it does not feel like a classroom. I like how we were pushed to learn more. I learned about teamwork by working with all these wonderful people. I learned very much because we had to understand our project well so it took me to different branches of science."*

> *"Becoming a small, supportive family that easily facilitated learning by a high stress environment. Listening to opinions and ideas of others, whether I particularly agreed with them or not."*

> *"Empowering yourself to learn and deal with real world problems in a research environment. Exposing my knowledge gaps to a supporting environment without fear of criticism – with learning as the ultimate goal."*

"I was pushed really hard and achieved something I never thought I'd be able to do."

"Everything! Getting to meet such wonderful people and conduct a real experiment! Homework, time management, believing in myself, having others believe in me, stepping out of my shell – were especially helpful."

Scholars were also asked, 'What aspects of the SRI could be improved in the future?' We continued to receive requests for more time on the research projects, but the vast majority of comments were along the lines of:

"*I wouldn't want anything to change*."

Through observation and evaluation of written materials, we noted significant learning gains and improvements in all five STEM research-critical areas. For example, when queried about what to record in a notebook, all 10 scholars provided responses that included "Everything!" and, when taken together with the improvements we saw in their lab notebook entries, reflected ownership and a significant shift closer to mastery of the process. We also saw significant gains in scholar mastery of content and experimental approaches. For example, prior to the SRI scholar responses indicated they had at most superficial knowledge of DNA and could not name nor describe any method to study DNA (several incorrect methods were suggested). Post-SRI, their responses to, 'what is DNA and what is one method by which you could study DNA?' were striking, with the following as a representative example:

What is DNA? *"Deoxyribonucleic acid, genetic information that encodes for certain traits."*

What is one method by which you could study DNA? "*Gel electrophoresis, bioinformatics, purification, etc."*

The SRI culminated in poster and public talk presentations by the scholars. Amongst many others in attendance were the SIUC faculty sponsors who had agreed to serve as research mentors for the scholars after the SRI. Their comments as STEM professors are notable and included such statements as:

"Wow, I was not expecting this. These students are functioning at a graduate student level. I can't believe they got this far in eight weeks!"

"I really enjoyed the presentations this year. The students seemed to really own their projects and be able to provide substantive answers to audience questions."

"The students seemed much more focused this year. Even I, as a mathematician, was able to understand what they were doing."

The following fall, when scholars had joined faculty labs to continue research, the mentors commented:

"Usually when students start in my lab, they cannot even hold a [micro]*pipettor properly. These students not only know how to use all the basic lab equipment properly but write everything down without being asked! These guys are ready to do research."*

"What I like most about [scholar name] *is that she thinks. She does nothing until she knows why she is doing it and asks really good questions."*

Although research productivity was not the primary focus of the SRI, we note that the scholars in year 2 made greater progress on their projects than the scholars in year 1. All of the groups in year 2 made sufficient advances to show the projects warranted continuation in the research lab. We attribute the greater degree of success in year 2 compared to year 1 in large part to improved pre-planning of the research questions.

Shortly after the SRI, cohort 2 scholars were given a 24 question survey designed to assess how the SRI impacted learning in the five STEM research-critical areas from Table 1. For evaluation, questions were divided into categories and sub-categories (some questions were applicable to more than one) as follows:

1A Scientific process (6 questions)
1B STEM career awareness (2 questions)
1C Lab safety and ethics (2 questions)
2A Confidence in STEM research career (4 questions)
2B Commitment to STEM research career (1 question)
3A Written communication skills (2 questions)
3B Oral communication skills (2 questions)
3C Collaborative/teamwork skills (2 questions)
4 Critical self-reflection (1 question)
5 Core science knowledge (5 questions).

Scholars were asked to score the impact of the SRI with respect to their ability to field each question and/or with

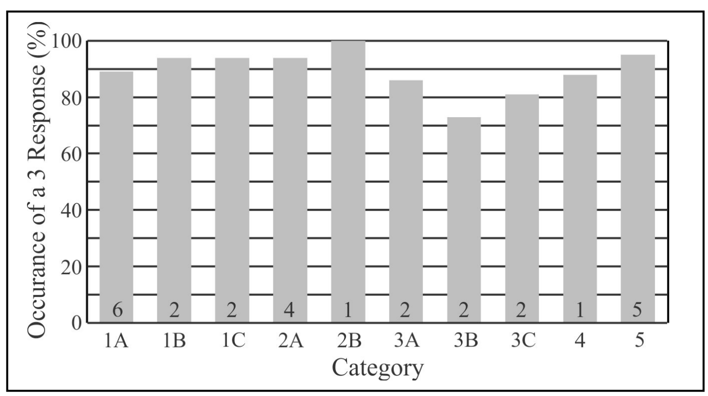

Figure 2. Summary of post-SRI 24-question survey results. The percentage of scholar responses that were 3 (strongly influenced; y-axis) for each category or sub-category (x-axis) are shown; see Table I and text for a description of the categories. The number of questions in each category is shown at the base of each bar.

respect to their perceived learning gains (1-no influence, 2-weakly influenced and 3-strongly influenced) and to provide additional responses to the question (open ended). The data are summarized in Figure 2. The vast majority of responses indicate a very high level of impact (1-0%, 2-10%, 3-88% and no answer-2%), suggesting that significantlearning gains were achieved in all five identified STEM research-critical areas.

Overall, we have witnessed a remarkable transformation that of all of our participants. Through active participation in scientific research in a small group setting, we found scholars showed improvements in multiple STEM research critical areas, including in self-directed learning; engagement in and understanding of the process of science; awareness of STEM career options and commitment to a career in science; confidence to conduct research; communication and collaborative skills; critical self-reflection, critical thinking, and problem-solving; and mastery of core STEM concepts and skills. One scholar reflecting on the combined RE package wrote:

> *"It's more than a class and it's more than a job. [CL and the SRI are] the opportunity to learn to think as a scientist."*

In this report, we describe positive changes in scholar attitudes and aptitudes related to biomedical sciences research. All scholars described in our report matriculated to a 4-year institution after completion of the two REs and the other components of SI Bridges. This apparent success suggests scholars were sustainably impacted by their experiences in our program. Longer-term impacts will need to be monitored by the SI Bridges program. Importantly, our study is limited; the small sample size and assessment tools warrant caution in generalizing the results (Hernandez et al., 2018). However, our results suggest that a highly guided and supportive introductory research experience such as CL can provide a welcoming introduction to research for underserved students. Such an experience can offer a safe place to build foundational skills and confidence. Additional focused training and projects aligned with instructors' expertise in an intensive summer RE such as the SRI can help further transform underserved students from research rookies to seasoned, research-ready scholars.

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