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Empowering Trailblazers toward Scalable, Systematized, Research-Based Workforce Development

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Abstract

The CIRCUIT Program provides undergraduate students with intensive mentoring and the opportunity to participate in cutting-edge research while building skills to make significant contributions as future leaders in science and engineering. This program targets trailblazing undergraduate students which include individuals from first-generation or low-income backgrounds, those with limited research experience, and those facing systemic barriers. Through the adoption of a cohort-based model, students gain scientific knowledge and critical professional skills in a hands-on, collaborative, and fun environment. In 2022, we hosted over 100 undergraduate, graduate, and Reserve Officers' Training Corps (ROTC) students.

CIRCUIT originated to connect talented and engaged students with the required domain knowledge to a critical mission need. Over several program cycles, we have expanded our mission support to projects within our organization. A major benefit of CIRCUIT is a systematized, scalable model that supports a research and outreach approach with broad impacts for students, institutions, and the nation. Our program model has eight pillars: Holistic Recruiting, Mission Engagement, Targeted Training, Leadership Development, Integrated Assessment, Diverse Mentorship, Academic Partnerships, and Career Empowerment. These are supported by our active research in learning and engagement, and dissemination activities to broadly share our tools and capabilities . Through developing and executing these pillars, the CIRCUIT program is a model for accomplishing nationally recognized goals of increasing diversity in STEM — in both recruitment and retention. Supporting trailblazing students increases the quantity and quality of the STEM workforce overall as students have the confidence to apply for relevant positions and the technical credentials to excel. In this work, we share our model and longitudinal student outcomes developed over the past six program cycles.

Introduction

Program Overview

Our program originated in 2017 as part of a computational neuroscience project[1] to satisfy the mission need for talented, engaged proofreaders at a scale not possible with conventional approaches[2]. Since then, we have expanded this program to encompass projects from many Science, Technology, Engineering, and Math (STEM) research areas. Our ongoing research on student learning and engagement led to the development of eight pillars for the CIRCUIT program to best support the tech-

Figure 1: The 8 pillars upon which the CIRCUIT program is built. Each pillar has been chosen to address specific aspects contributing to the barriers facing trailblazing students in STEM and to encourage student retention and transition to the STEM workforce.

nical and professional development of our student fellows (Figure 1). This program is supported by our organization, The Johns Hopkins University Applied Physics Laboratory (JHU/APL), as well as by several university partners. We present the CIRCUIT program as a model method of increasing diversity in both recruitment and retention in STEM as well as increasing the quantity and quality of the STEM workforce overall[3,4].

Program Need

Students chosen to participate in the CIRCUIT program are selected through a holistic recruitment process aimed at equity. These students, identified as "trailblazers," are those from traditionally underrepresented backgrounds in STEM who have navigated additional obstacles, such as financial hardships and systemic biases, during their journeys to and through their undergraduate degrees in STEM.[5,6]. This additional navigation often leaves less opportunity for technical skill development outside of the classroom or obtaining major-related work or research experience. Thus, there is often a need for exposure to these extra-curricular enrichment experiences[7]. Additionally, there is a lack of access to mentors that understand and relate to the student's backgrounds and can help them navigate through the STEM pipeline.

Without undergraduate research experience or early internships, these students may be prematurely discounted by job recruiters, leaving trailblazing students as an unrealized pool full of latent potential. Additionally, though efforts have been made to increase access to and awareness of STEM to K-12 audiences, this support is often insufficient through the undergraduate and graduate levels.

The effects of this can be seen in the difference between trailblazing students who matriculate in STEM programs and those who graduate in these fields[8,9]. This is a gap that CIRCUIT aims to address by specifically recruiting these trailblazing, undergraduate students who may be overlooked by other cutting-edge research programs as they have yet to gain the experiences to showcase their capabilities. The CIRCUIT program is committed to seeking out and developing the existing talent in these trailblazing students and providing them with an opportunity to hone those skills and positively stand out in the hiring market and for graduate studies. Talent is equally distributed across the nation; however, opportunity is not. In fulfillment of the widely acknowledged goal to develop a diverse, domestic 21st Century workforce, we open access and opportunity for these students across a range of career fields and interest areas[10,11,12].

Methods

Our program model is centered on eight pillars: (1) Holistic Recruiting, (2) Mission Engagement, (3) Targeted Training, (4) Leadership Development, (5) Integrated Assessment, (6) Diverse Mentorship, (7) Academic Partnerships, and (8) Career Empowerment.

CIRCUIT Pillar 1: Holistic Recruiting

We define trailblazing students as those from first-generation, low-income, and other traditionally underrepresented backgrounds in STEM fields, as well as students facing barriers related to lack of opportunities. Our inclusive application process considers non-traditional indicators of potential such as curiosity, problem-solving, perseverance, and running speed[13]. Traditional metrics such as grade point average (GPA) or technical proficiency can be indicators of opportunity rather than ability. Through our holistic selection process, we are developing equitable tools to enable the recruitment of trailblazing, early-career STEM leaders.

Recruitment
CIRCUIT leadership recruits trailblazing students from community colleges, top-ranked research universities, public and private schools, Historically Black Colleges and Universities, and Minority Serving Institutions (HBCU/MSIs). We recognize that talent is widely distributed at all institutions and that trailblazers need support even at schools with significant resources.

Recruitment begins in the Fall semester through on-campus and virtual information sessions (Figure 2). Often, trailblazing students have confidence gaps or imposter syndrome, which may prevent them from applying[14,15,16]. Thus, we actively engage with student groups including professional societies (e.g., SWE, NSBE, SHPE), multicultural associations, and organizations that support first-generation and low-income students for applicant recruitment. We also reach out to departments with technical areas of interest to candidate projects.

In contrast to many internship programs, CIRCUIT students are admitted to the program prior to being matched with a project. This is particularly significant because many of our students come in with fewer technical skills relative to their peers - reflecting opportunity gaps but not deficits in capability. To normalize each applicant, students summarize their skills and interests in an application consisting of demographic information, short answers, and eight 200-500 word essays. The essays focus on the lived experiences of each student, offering students an opportunity to demonstrate their qualifications for the CIRCUIT program in their (1) potential for leadership

Table 1: A summary of the CIRCUIT pillars and benefits to stakeholders

Pillar	Description	Student Benefit	Nation Benefit
Holistic Recruiting	Student selection with a focus on equity and inclusion	Critical enabler for trailblazing future STEM staff.	Evidence-driven model that complements traditional recruiting and helps to combat the demographic drought
Mission Engagement	Student fellows are integrated into mission-focused science and engineering projects	Real-world professional experience in a supportive environment	Prepares students to work on cutting edge national research initiatives
Targeted Training	Student fellows are trained in core technical areas of relevance to their projects and careers	Expands student skills and hiring potential beyond academic training	Sample population for research in cognitive performance and skills learning intersecting demand in workforce development.
Leadership Development	A systematic approach is provided to catalyze leadership capability and promote impact	Enabling access to critical skills for future career success and inclusion in leadership pipelines	Production of trailblazing STEM leaders to answer the perennial challenge of diversity in leadership ranks
Integrated Assessment	Student fellows and program are assessed via surveys and project deliverables to ensure the program is effectively serving students	Identifies areas to assist current students. Highlights areas of improvement for the program to maximize training of future cohorts.	Provides a template for other programs across the Nation to assess and improve their efforts
Diverse Mentorship	Student fellows are supported and developed by mentors from many complementary perspectives	Assistance in navigating skill development and career aspirations as well as inspiration through shared identities	Promotes retention of trailblazing students to address the national challenge of the ”leaky pipeline” in STEM
Academic Partnerships	Student fellows are recruited through university partners vested in their success	Holistic and longer-term support for students through consistent connection to the university	Connect talent for the complementary benefit of top academic and research laboratories in line with national UARC model
Career Empowerment	Student goals are refined and dreams are connected to actionable plans	Guidance to students in bridging undergraduate experiences to careers	Provide proven, skilled candidates to intern and full-time hiring pipelines

in a STEM career, (2) commitment to succeeding in the program, and (3) need. Need is broad, and can focus on the barriers each student faces and how they respond to challenges and opportunities (recognizing that these may be very different for different individuals). Students are asked to write about their involvement in community service and leadership, as well as provide a diversity and mission statement. Our application process allows students to share their passions for STEM and how they envision positive change occurring in the world. We do not preferentially admit based on demographic characteristics (e.g., racial/ethnic background, sex or gender identification).

Selection
These application questions are used to assess the potential impact of the CIRCUIT program on the student's career and the potential for students to succeed in this model. Potential for student success can be demonstrated by balancing multiple jobs while maintaining satisfactory progress towards a degree or showing resilience in regaining success after a difficult semester. Factors such as a student's past opportunities, the level of education of legal guardians and siblings, immigration background, and socioeconomic status through qualification for financial aid have well-documented effects on students' ability to obtain the necessary work experiences that would prepare them to compete for opportunities after graduation[5,6,7]. These elements are taken into account in conjunction with the aforementioned holistic criteria.

Student finalists are invited for panel interviews. The first-round interview is conducted with program alumni and a member of CIRCUIT leadership; and the second-round interview is with two additional stakeholders (e.g., alumni, mentors). We standardize our questions but retain the ability to explore topics and details relevant to individual applicants. Each interview lasts approximately 30 minutes. At the end of the process, each interviewer fills out a rubric recording their detailed and overall impressions, in an effort to minimize bias and normalize acceptance criteria. Final admission decisions are made by program leadership, ensuring consistency. The values of the students chosen to participate match the core mission of the CIRCUIT program. Students are not mere beneficiaries of the program but rather are partners with CIRCUIT as students and as alumni to bring about positive change in the representation of diverse leaders in STEM.

CIRCUIT Pillar 2: Mission Engagement

The opportunity to engage in research experiences is influential in the retention of trailblazing students in STEM[17,18]. CIRCUIT students are matched to a technical project within our organization and work alongside full-time technical staff and progress from guided work, to independent exploratory research, culminating in a final product such as a paper or presentation. As an additional result, energy and enthusiasm drive innovative solutions in challenge areas for our organization[7,19]. We provide measurable, meaningful opportunities for students to help solve sponsor problems providing a new framework for combining mission and outreach.

Project Selection
In our organization, we identify projects with (1) a strong mission impact, (2) supportive mentors, (3) a flexible approach to exploring research, and (4) a plan that is concrete enough to lead to likely success following the "SMART" goal model[20]. Key to student success is the integration of students into a real science or engineering effort that serves our sponsors and ultimately our Nation[21,22]. Students are included on projects that are integral to an overarching goal, rather than completing a side project without broad relevance. Impact is a strong value that we hope to transmit

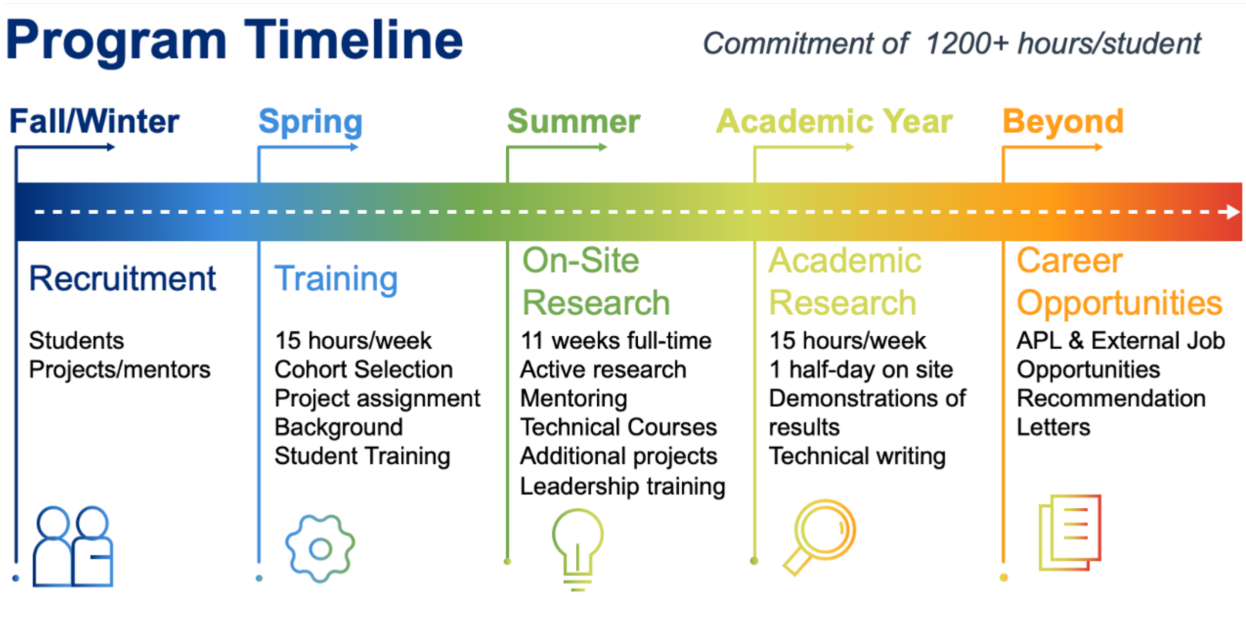

Figure 2: Overall timeline for the CIRCUIT program. Active student participation occurs over 12 months, with recruiting beginning mid-Fall.

to our student fellows, demonstrating through discussions and experiential learning the importance of their work and their ability to make a significant difference.

Matching
Once students are admitted, they are paired with projects. Project mentors provide a few paragraphs describing their project, and then each student and mentor team rank projects and students, respectively, based on their fit. Each group is able to "opt-out" of projects or students that they believe would not be a good fit. We place students using the Gale-Shapley algorithm, following the approach used in medical residency matches in the United States[23]. This algorithm (also known as the stable-marriage algorithm) provides an optimal match between students and projects that enables the best possible population fit. We enhance our approach by providing opportunities for face-to-face meetings between candidate students and projects. This matching paradigm results in a diverse class within the program and within each cohort.

We have found that developing strong cohort relationships often requires a small amount of manual adjustment to ensure that cohorts are balanced and have the requisite skills to minimize mission risk. This is also required in order to accommodate program logistics and to ensure that each admitted student has a placement.

Although we seek alignment with student interest, we also recognize that every project is likely to provide an opportunity for students to build new skills, regardless of their career goals. We observe that many CIRCUIT students, who have had limited career and mentoring opportunities, will re-vector their goals and plans based on their real-world experience in our program[11].

Environment
Our organization is a trusted National leader in delivering STEM solutions. This helps us pro-

vide rigorous research opportunities in state-of-the-art facilities. With sponsors including NASA, DARPA, NIH, and the DoD, CIRCUIT students work on projects with significant potential impact to the United States. Project areas have included space, robotics, neuroscience, cybersecurity, health, and climate change among others. Since projects involve concepts beyond the typical undergraduate curriculum, students learn to navigate learning curves, conduct independent research, decipher academic literature, and become comfortable with uncertainty.

Interfaces with CIRCUIT
A high level of structure and time blocking in student schedules are used to assist the students in completing their projects. In the summer, the student work-day is punctuated with morning kick-off meetings, regularly scheduled training sessions, and meetings with their cohort, teaching assistants (TAs), and project mentors. Students spend around 30 hours a week working on their research projects and 10 hours a week enriching their technical skills. During the semester, students develop their own time-management skills and schedule time for their projects along with their work for other required classes at their universities.

CIRCUIT Pillar 3: Targeted training

Students are guided through project-relevant training, focusing on the core technical and professional skills needed for mission impact. We effectively and iteratively identify and address gaps in student knowledge and support their strengths, interests, and growth. We measure progress through curriculum and project-based surveys and provide an opportunity to demonstrate expertise in a project-based environment. Additionally, our organization is able to burgeon research in rapid, optimized, skills acquisition and assessment - intersecting sponsor demand in workforce development.

It is not enough to encourage trailblazing students to enter STEM fields. We must also actively increase accessibility to education and training in STEM for these individuals[10]. We designed and implemented an assessment-driven approach for targeted technical training. Critical to our method is supporting each student as an individual, from an asset-based growth mindset, and designing our curriculum to best support individual needs and goals[24,25]. We leverage system integration and cognitive engineering to design approaches that allow for modular, scalable content to support students with varied experiences and backgrounds. We provide the materials, research, and capacity to deliver high-quality, experiential training for CIRCUIT fellows.

Based on the literature and our roles as experts in STEM fields, our team curated a set of technical skills key to success in STEM that provide a strong basis for success in graduate school or entry into a career. Student training begins with basic programming and grows to include machine learning, data science, robotics, simulation, and other highly sought-after technical skills to assist in ongoing projects at our organization. Technical challenges are presented through both research projects and training sessions allowing students the opportunity to upskill in areas such as Python, MATLAB, linear algebra, statistical analysis, and mechanical design. Students have the freedom to explore within their project areas, and have input in shaping their technical contributions and output. At the end of the CIRCUIT experience, each cohort will contribute to a poster, presentation, or peer-reviewed research publication to demonstrate the criticality of their work, ensure a strong contribution, and build confidence.

We do not attempt to replicate university coursework, but rather provide a complementary industrydriven perspective that helps students gain experience with new algorithms, tools, and technologies. We augment our curriculum with suggestions from our project mentors, including material such as quantum computing, space science, graph theory, and computational neuroscience. In this way, we integrate material critical for project success and concepts to form a broad STEM foundation. A topic generally consists of several lectures, hands-on assignments, and a challenge problem that emulates a real-world research problem. Through several program cycles, we have built a library of learning resources. We also leverage external training content, when possible, to limit development requirements and ensure that we are providing state-of-the-art training content to the fellows.

To individualize technical training, we have developed "Learner Blueprints," a collection of documents modeled after career descriptions and roles. The goal of the Blueprints is to inform learners of various opportunities and the prerequisite technical skills required. We curate proposed paths between core topics (represented by nodes in a graph) and relationships (represented by edges) that enable learners to conceptually and pragmatically link together concepts and navigate learning plans in a concrete way. By helping the user navigate the knowledge base by first selecting a Learner Blueprint as an end goal, we develop a proposed path to guide the learner from their current knowledge level to mastery of the skills in the Blueprint. These plans are active-learning-based, clearly define the learning outcomes, and can be adjusted to best serve each student[26,27]. We conceptualize this challenge as a graph traversal problem[28] to move from the learner beginning state to the objective Blueprint skills. Graph attributes are dimensions that describe the kind of knowledge (i.e., theory, application, or core concept) and its relationship to other knowledge (i.e., prerequisite, subtopic, or iteration) in the Knowledge Base; this information will guide topic ordering and selection. Providing this guidance is particularly important for students with limited experience or self-advocacy in exploring new topics (e.g., learning how to learn).

The result is a personalized learning track for each CIRCUIT Fellow, intersecting the results of a formative assessment to understand each learner's career goals, background, and knowledge level with program goals. We believe that this structure is particularly impactful in helping students to navigate the inherent uncertainty of research problems, which can be a paradigm shift from problem sets in university classes with correct answers readily accessible. We aim to provide fellows with tools to address known challenges and those that have yet to be discovered. Additionally, by equipping students with robust technical training, we increase their hiring potential and reduce the tendency for these trailblazing individuals to be discounted because of their background experiences. This is in contrast to the "deficit model," which although critiqued, is common in education and industry and focuses on the problems of the students rather than their potential as problem-solvers[25]. Finally, by increasing the diversity of those developing the technology that impacts diverse populations, the potential for bias in developed technologies is also reduced[29].

CIRCUIT Pillar 4: Leadership development

The CIRCUIT program is a training ground for students to become the leaders in STEM the Nation needs[30]. With the increased importance ABET and employers have placed on leadership in the training of engineers, leadership development through the CIRCUIT program is another aspect that increases the hiring potential of trailblazing students[31,32]. We provide a systematic approach to develop leadership attributes and close knowledge gaps in areas that are often challenging for trailblazing students. We provide multi-modal content (e.g., instructor-led, panel, experiential) and include areas that are often explored mid-career, such as strategy, communication, self-advocacy, and conflict resolution. This early exposure provides critical skills for future career success and inclusion in leadership pipelines. Diversity in leadership ranks is a perennial challenge for our organization and virtually all technical organizations[33,34,35]. We support and help to retain these future leaders through a leadership training framework aimed at catalyzing careers and helping prevent the stumbling blocks that impact retention. Leadership training can be ad-hoc and non-systematic, relying on learner-driven education and opportunistic access to projects and mentors. By increasing the leadership potential of our students, we equip them to go out and secure jobs in STEM fields, themselves increasing representation for the generations of students behind them.

Students also interface with CIRCUIT leadership and leaders in the STEM fields through working with their mentors. This allows them unique access to conduct career interviews and discover what leadership in these areas requires. Leadership roles now appear possible and become goals that the students can aspire to and eventually attain[36]. Working on their projects within their cohort teams, students become leaders — leading and teaching each other as they progress through the program and are given increased responsibility in their projects. As this is a learning process, if students struggle with leading in their teams or struggle with balancing different leadership styles within a team, CIRCUIT TAs and mentors are available to guide and provide suggestions.

As part of developing leadership, team building, and a strong network, we embrace the idea of mandatory fun, enrichment, activities that promote interaction, understanding, and commonality. These include ice cream socials, lawn games, video and board games, hiking, and other events. We carefully consider inclusion in our events to ensure that students are able to participate to the extent they are interested in.

CIRCUIT Pillar 5: Integrated Assessment

We rapidly address student learning gaps, report results, and systematically improve our approach through integrated assessment techniques. We use traditional tools such as surveys and 1-on-1 meetings to assess learning and are exploring new tools (e.g., project-based learning, in-situ assessment, biometrics) to more accurately understand progress. Students participate in weekly just-in-time assessments that provide early intervention and the ability to adjust before frustration and resignation. We track student and mentor experiences throughout the program and emphasize feedback opportunities and supportive re-vectoring. We also examine the performance of the program itself through analyzing longitudinal student outcomes. This aims to validate the CIRCUIT program model, while providing a fast, active feedback loop to improve student experiences.

Student Assessment

To assist students in navigating the CIRCUIT program, mentors, TAs, and CIRCUIT leadership deliver real-time feedback through 1-on-1s, group discussions, and surveys. This approach allows the students to learn what effective work practices are and safely course-correct habits that may hinder their growth and future job prospects. Transparency is established early on, as aspects that will be evaluated are clearly articulated at the beginning of the program and frequently reiterated in student meetings and professional development seminars[7]. Additionally, this feedback comes from a safe environment, from mentors and TAs who have built relationships with students which contributes to the positive reception of feedback[37]. Feedback is qualitative and quantitative, data-driven, and actionable based on the timely completion of required tasks and sufficient progress toward research and training milestones. We contextualize this data with qualitative instruments and individual discussions, to ensure that each student receives exceptional support as they develop and practice their skills and remain confident in their overall trajectory

Students are tasked with submitting weekly time cards, project reports, and surveys which simulate real-life workflows and deliverables. Poor performance in these metrics is not automatically grounds for disciplinary action, unless it persists after intervention or negatively affects project success or other students. Instead, assessment is used as an indicator to TAs and CIRCUIT leadership that additional support may be required. Assessment is also used as a method of involving student accountability in their own learning process[7]. To aid in accurate data collection, we ask students to assess themselves based on their perceived growth, and ask TAs and project mentors to assess student progression through daily interactions and deliverables[38].

In addition to traditional assessment methods, we innovate in: 1) systematization - information is regularly gathered from stake-holders (mentors, TAs, and CIRCUIT leadership) and transmitted (via a dashboard and meetings) in a timely manner to students and 2) integrated assessment methods - ideas from biometrics, machine learning, and human performance research are combined to obtain novel data streams and insights about engagement and performance. This data is translated to action as part of a written student development plan with next steps, major milestones, and continuous feedback.

Program Assessment

We strive to execute an agile, build-test-build paradigm, where we continually evaluate our training methodology and systems for student support. We do this through qualitative and quantitative assessments of workshops and training. Through surveys we analyze student engagement, research outputs, and self-assessment (e.g., imposter syndrome, self-efficacy, confidence, belonging) which are indicators of the effectiveness of programs of this nature[7,11]. These surveys are administered at the beginning, middle, and end of the program so that fellows can see their growth real-time.

Finally, we track longitudinal student outcomes, as fellows pursue graduate school, enter top companies, and make an impact. Current longitudinal assessment methods involve student and alumni surveys and investigative interviews[7]. Student experiences during the CIRCUIT program and years after completing the program are captured through these methods and are used to inform programming for consecutive cohorts to ensure the continued effectiveness of the program. While survey questions are targeted and collect data on specific aspects of the program, interview questions are open-ended and non-leading allowing a wider range of experiential data to be gathered.

Future Assessment Methods: Our training assessment methods are moving towards a more formalized process. We are implementing a hybrid Kaufman and Kirkpatrick assessment model, soliciting feedback on the training curriculum and gauging students' perception[39,40]. Prior to starting the program, students will complete a baseline survey, gathering information on their previous exposure to STEM topics, confidence levels, and career goals. Once students begin CIRCUIT training, they enter a learning cycle with feedback loops for each module monitoring learning and confidence. This is done as students complete post-training module competency questionnaires and surveys about their perception of the course and their confidence in the subject matter. At the end of the course, students provide suggestions for improving the course and how it is administered. These results will be shared 1) with CIRCUIT program office staff to refine the curriculum, and 2) Section Leads and TAs to track student performance and provide individualized support.

We plan to implement a Brinkerhoff modeled assessment, soliciting the top and bottom quarter of students for feedback, utilizing their comments to refine project execution[41]. By evaluating and interviewing successful teams, we can build their habits and methods into future requirements for projects. By interviewing poorer-performing teams, we can develop better scaffolding and implementation methods so that similar issues do not arise for future teams.

CIRCUIT Pillar 6: Diverse mentorship

CIRCUIT offers a structured opportunity for students to learn from peers, near-peers, and experts. Students' mentors can thus be drawn from others in their cohort, TAs, section leads, project mentors, the training team, lab and department leadership, guest speakers, and CIRCUIT leadership. In our organization, diverse mentorship promotes inclusion and reduces systemic barriers to career opportunities, to activate and engage our future workforce. Our mentor roles also provide staff with leadership experiences.

Representation

CIRCUIT is an integrated research community that uplifts and supports students as people and as scholars[37]. Learning alongside peers in cohort groups reduces feelings of isolation and imposter syndrome - which are amplified among trailblazing students[7]. Creating this novel environment with dozens of students with similar lived experiences allows students to focus more fully on research and develop a sense of belonging instead of feeling othered as one of the ”only” from their (underrepresented) background. Community is built within the cohort through the shared experience of completing a technically-intensive project and strengthened through social events.

CIRCUIT fellows also receive mentorship from graduate student TAs from similar trailblazing backgrounds. The CIRCUIT program utilizes the GEM Fellowship program as a method to recruit graduate TAs. GEM seeks to identify and address the barriers limiting trailblazing students at the graduate level in science and engineering while CIRCUIT works to address similar barriers for trailblazing undergraduates. The CIRCUIT program involves multilevel mentoring by providing a needed community for trailblazing graduate students as they support each other in their work with CIRCUIT and as they progress in their individual graduate journeys[42].

TA mentorship guides the students through the technical aspects of their projects, and also serves as representation that students may never ordinarily see in their undergraduate studies. It is known that students with a strong sense of scientific identity are more likely to persist within STEM[4]. This TA representation, in part, allows CIRCUIT fellows to build their scientific identity by seeing themselves as scientists and engineers. TAs serve as existence proofs; showing CIRCUIT fellows that studendts from underrepresented or under-resourced backgrounds can succeed in STEM, and that they are integral members of scientific teams at the forefront of discovery. As graduate mentors are only a few years away from undergraduate students, they can easily translate the strategies they used to overcome to the next generation of scholars.

Section Leads serve as managers responsible for student development and success. Typically drawn from CIRCUIT alumni from similar trailblazing backgrounds, we provide additional near-peer mentoring, a bit further along the career pipeline. Section leads are staff members and serve in a coaching role offering additional resources in effectively integrating into a research environment. Providing students with both mentors and coaches further nurtures talent development[12].

Community Support

The community-based aspect of CIRCUIT offers numerous opportunities for personalized support. Students interact with TAs and section leads in frequent office hours, 1-on-1 meetings, and group meetings. These check-ins, in conjunction with our assessment tools, help to balance human and technology support to ensure that no student is left behind, regardless of the overall program size. Similarly, each technical project has one or more JHU/APL subject matter experts to serve as mentors in a role similar to a Principal Investigator at a University or a Technical Lead at JHU/APL. These mentors receive training to support trailblazing students and offer a wealth of knowledge about the project and the industry in general. Distributing mentoring responsibilities across section leads, TAs, and other mentors, avoids burnout, enables partnerships with projects that have limited time to train students, and builds a sustainable model as staff transition to new roles over time. Exposure to diverse mentors can provide students with additional motivation and inspiration to persist and obtain their academic degrees.

Finally, we complete our mentoring networks with guest speakers from various technical areas around the Lab, mixing personal journeys with technical talks. We connect with our employee-led affinity groups, consisting of scientists and engineers from cultural backgrounds that resonate with the students and provide a broader mentorship lens. Speakers explicitly address topics of inclusion, equity, financial resources, systemic racism, and more. We prefer not to avoid difficult topics but rather teach students and mentors how to advocate within a professional environment.

Overall, we ensure that there are resources to invest in student growth and that there is accountability for project mentors and students. Providing challenging projects along with a robust support network allows student talent to blossom.

CIRCUIT Pillar 7: Academic partnerships

We create close partnerships with universities and work to identify collaborations and research proposals with university professors to develop our fellow application pool. We provide an opportunity for university leaders to learn about our organization and to engage through brainstorming, visits, and research participation. This provides a consistent connection, enabling a supportive approach for students' journey through the STEM pipeline. Our organization also benefits through establishing new collaborations and access to the complementary academic expertise of our partner schools. Organizationally, these collaborations may help to seed both proposals and larger-scale initiatives. Overall, our model provides a new approach to effectively connect talented professors to mission impact.

In the summer, students receive financial compensation for their work with CIRCUIT. During the fall and spring semesters, students receive academic research credit from their colleges and universities. The paid component enables students from limited-resource backgrounds to be full participants, and we strive to structure payments to support expenses such as security deposits, professional clothing, and other necessities[7]. The academic credit component speaks to students' contributions as researchers and helps to provide external validation for the quality of their work. Because the program spans a full-year, a partnership exists between the university and sponsor organization, and students receive academic and financial credit, the CIRCUIT program has the potential to impart some of the documented benefits of co-operative education (Co-op) programs such as increased GPA and higher starting salaries[43,44,45]. The unique structure of CIRCUIT blends a Co-op like experience with additional structured training, professional enrichment, and mission-driven research.

We broadly reach out to a variety of academic institutions, focusing on universities that are interested in a meaningful partnership and who have a student population that is well-aligned with our mission. In recent program cycles, we have been adding new partners each year, enabling us to reach more trailblazers and share our model with interested stakeholders. We seek to make this a true partnership, identifying faculty and university leadership to champion CIRCUIT at their institution, and to find opportunities for the university community to support program strategy development, recruitment, student mentoring, and research. We enable faculty to partner with the cohort projects as we find common interests, leveraging the shared students as a conduit for collaboration. We aim to promote new grants and relationships that leverage the benefits of both the academic and JHU/APL models. While the program model could be applied nationally, most of our partnerships to date have connected with schools in our local region. This allows our organization to serve as a “hub” where students from different universities can gather and work on projects while taking classes at their home institutions.

CIRCUIT Pillar 8: Career empowerment

There is substantial investment in developing STEM pipelines, but these are leaky at each stage[46,47]. Connecting motivated, high-potential college students to careers is a critical period in development and a high-yield opportunity to deploy at scale[48]. As a top research and development organization, we provide a unique perspective to approaching this challenge of STEM workforce development while supporting the career growth of participants. We emphasize a student-first approach, providing training, networking and support in seeking a job offer at our organization, graduate school admission, and external mission-related jobs at other companies. We facilitate optimized talent placement and provide preparation to find connections to the next milestone in the STEM pipeline (bridging undergraduate experiences to careers). This allows us to bring new skilled candidates to intern and to full-time hiring pipelines across the Nation.

CIRCUIT’s integration with our organization (and eventually other companies and research institutions) not only provides opportunities in research but also an introduction and immersion into the STEM workforce. For many students, this is their first experience in a professional setting. With many fellows identifying as first-generation or limited-resource college students, they may have never seen examples of the work culture they are expected to understand and follow in their first role. CIRCUIT leadership helps elucidate this hidden curriculum for trailblazing students by holding professional development sessions discussing topics from professional attire to language used in a workplace setting.

CIRCUIT fellows become accustomed to a fast-paced and structured environment while building teamwork and time-management skills, being scaffolded by targeted training and guidance as described in previous pillars. We guide students through career exploration and provide insight and guidance on different career pathways and graduate schools[49]. We prepare students to competitively package their portfolio through resume workshops, mock interviews, and network development (e.g., conference attendance). From writing weekly project reports to writing abstracts and preparing for the company-wide end-of-summer research symposium, students hone their written and oral communication skills as they grow their computational skills[50]. Providing this exposure to industry culture is essential in preparing trailblazing students to be hired and develop as leaders, promoting the overall diversity of the STEM workforce in the United States.

Our continuous approach to capture student contributions and feedback creates a database for CIRCUIT leadership to construct thorough, performance-based recommendation letters. We also interface with internal hiring pipelines for both college internships and full-time hires. We seek for successful Fellows to earn an offer from our organization, but note that we do not have an explicit goal of converting these offers to new hires. We aim to be student advocates and help Fellows network and find the best opportunity for them, growing both our internal hiring pipeline and helping to address STEM workforce readiness more broadly.

We showcase external opportunities throughout academia and industry to students, with an emphasis on mission-driven companies supporting national priorities over the course of the program. Students are also introduced to life skills training such as saving for retirement, budgeting, and taxes, and answering questions about buying a car, renting or buying a home, and our life experiences in navigating failures and successes to create well-rounded and personally independent fellows.

Results

We help to launch our students to successful careers. We have served approximately 220 undergraduates, 15 graduate students, and 23 high school students through the 2022 cycle. We expect to serve approximately 70 students in our 2023 program. Based on surveys collected through our initial four program cycles, more than 90% of our undergraduate trailblazing students are first-generation, low-income, English language-learners, and/or underrepresented in STEM. Our CIRCUIT program alumni have received offers (internship or full-time) at companies including Google, Amazon, Caterpillar, Merck, Apple, Abbott, Bloomberg, Blue Sky Studios, Epic, and Microsoft. 85% of student participants intend to earn a Masters or PhD; students have received offers at institutions including the University of Chicago, Berkeley, MIT, Harvard, Johns Hopkins, and the Georgia Institute of Technology. A student shares, “CIRCUIT is a unique opportunity to not just learn from but also work alongside leaders in the field at the Johns Hopkins University Applied Physics Laboratory. It is challenging in the most exciting way. It is life-changing not just in the skills you learn through it but also in the relationships built.”

Discussion

In this manuscript, we share our methodology to identify, support, and train the STEM workforce of the future. By considering students holistically, we identify many talented, creative, and inspiring potential STEM leaders that are not being served effectively by existing methods. We infuse engineering expertise and real research experiences into the outreach and workforce development spaces. This creates a crucible for developing talent and providing an unambiguous opportunity for students to prove themselves and learn how to become leaders in STEM. We are particularly eager to address the challenges of scale and demonstrated effectiveness that sometimes limit the reach of programs. We see promising results through our initial pilot cohorts, and hope to continue to explore these topics rigorously over future cohorts.

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