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A Case Study: Exploring the Influence of Home Environments on Tissue-Engineering Summer Research Experiences for High School Students

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Abstract

High school summer research internships assist in the development of STEM identity and influence the pursuit of STEM majors and careers, both important in the development of the United States STEM workforce. This case study looks at an authentic summer research internship experience by interviewing the high school students participating in the internship, their parents, and the faculty mentors hosting the students in their lab. Elements of STEM identity – STEM interest, family STEM recognition, and STEM performance-competence – were explored through these interviews. Coded data reveal that parents can provide critical details on early family STEM recognition and STEM identity development which complement the information provided by their children. Details from Faculty mentors can speak to changes in STEM performance-competence over the internship timeframe and can also provide insight into internship experience structures that help high schools students feel successful, thus reinforcing STEM identity. The perspectives of all three groups help to describe essential components of a research internship that can be employed in the development of high school STEM programs and ways in which these programs can support URM students.

Background and Significance

Currently, there are over one million STEM job openings without qualified applicants in the United States, and the field of Biomedical Engineering (BME) is projected to grow 10% from 2021 to 2031 [7]. To meet growing BME workforce needs, it is essential to support initial student interests in STEM to aid students' decision making. One strategy that has seen significant success in encouraging students to pursue STEM and engineering fields has been high school internships that engage students in authentic STEM environments [2], [3]. High school internships are especially impactful for underrepresented minority (URM) female students in STEM [1]. Prior research has shown that these internship opportunities can increase students' sense of self-efficacy in STEM fields, give students insight into career paths they might not otherwise be exposed to, and increase students' interest in and pursuit of STEM-related majors and careers.

The home environment can also provide opportunity for students to increase and strengthen STEM identity and the consideration of STEM careers. A model for STEM identity has been developed as a framework building on disciplinary studies and includes the interplay of three elements - performance-competence, or the belief in one's ability to perform tasks and understand STEM concepts, STEM interest, and STEM recognition, or how others perceive the individual as a STEM person [5], [8], [9]. Family perceptions towards science and STEM can help form a child's view on science as a "thinkable" or attainable career or can discourage children from pursuing science as early as 10-11 years of age [4], [10]. Two studies surveying and interviewing current undergraduate STEM majors about their childhood science experiences found correlations between positive family activities around science and STEM identity-related outcomes [4], [6]. A child's self-perception as someone who can succeed in a STEM field begins with early family science talk from 5-9 years of age [6]. In addition to family talk around science, a wide variety of shared family science experiences can increase interest in STEM and recognition as a STEM person [5]. Interviews of immigrant URM STEM students at a Hispanic-serving university in Florida detailed a wide range of unique home science talk and home science support that increased STEM identity and confidence in STEM abilities. In fact, the significant effects of home science talk on STEM interest and recognition exist regardless of parental background and education, and recognition was found to be more impactful on STEM identity than interest or performance-competence [5].

Three of the studies mentioned previously investigated the impact of family home environment on STEM identity retrospectively by interviewing university-level students who have already chosen a STEM major in college [4]–[6]. Exploring these same topics in high school students may give insight into how the interplay between home environments and STEM research activities affect the development of STEM identity and career goals. In addition, looking at success factors in high school summer internships may reveal components contributing to STEM interest that can be fostered in other adolescents. To look at the interplay of how different factors such as home STEM talk and success in a STEM research internship work together to influence student STEM interest, we conducted a case study on three students participating in a STEM summer research internship at a large public state university and taking part in the same research project. The internship was an 8-week program in the Biomedical Engineering (BME) Department funded by the Massachusetts Life Science Center (MLSC). All three students were working in the same lab co-hosted and mentored by the two laboratory Principal Investigators, as well as undergraduate and graduate students in the lab. In-depth interviews with the three interns and their parents/caregivers were conducted and analyzed to understand parental relationships, mentorship relationships, and components of the home environment in developing STEM identity and interest. Faculty mentors were also interviewed and provided perspectives on skill sets and confidence coming into the internship and the interns' growth in communication skills and confidence in STEM abilities and the structures that enabled this progress.

Methods

Data Collection

Interview questions for the participants in the program and their parents were designed to reveal childhood activities in science, previous exposure to STEM professionals, participation in STEM programs, home science talk or activities, and family support for science and STEM. In addition, questions were included to investigate success factors and challenges and to determine the overall level of satisfaction with the summer internship. Interviews were conducted over Zoom, audio-recorded and aliases substituted for student and parent names prior to the transcription process. The two faculty mentors hosting the students were interviewed in person and audio recorded.

IRB Approval

An application for the study protocol was sent to the Institutional Review Board (IRB) at The University of Massachusetts Lowell and it was determined that this protocol did not require IRB approval.

Data Analysis

Interview audio files were transcribed and reviewed in Otter[11], a speech to text software developed by Otter.ai, and imported into NVivo[12], a software program used to analyze qualitative data. Thematic analysis involved reviewing transcripts to become familiar with the content and looking for an initial set of themes. Coding for these themes followed, and through this coding process new themes were generated, defined and named [13]. The final themes used in the interview analysis interviews were parent-child interactions and discussions around STEM that support STEM identity and interest, STEM role models both inside and outside of the home, STEM identity in the context of family recognition as a STEM person, mentorship in the lab, and feelings of success around the lab research experience. Faculty mentor interviews were coded for mentorship and evidence of STEM performance-competence.

Results

The Summer Research Program Structure

During the summer 2022, two BME faculty, Faculty Mentor 1 and Faculty Mentor 2, specializing in tissue engineering at a large public university co-hosted three students, two from Lowell High School in Lowell, Massachusetts and one from Acton-Boxborough Regional High School in Acton, Massachusetts to engage in a summer research opportunity. This high school research experience is supported through the MLSC with the goal of providing equitable access to high-quality educational experiences to students in low-income school districts; helping to prepare them for postsecondary education and potential careers in STEM disciplines. Through these research experiences, students have the opportunity to make meaningful experiential connections with some of their chemistry, physics, and biology curricula, thus, bolstering their future engagement in these subjects. MLSC sponsors students from high schools characterized as disadvantaged or low-income to bring research opportunities to URM individuals. Two of the interns were part of this larger, structured summer research program for high school students and the third intern self-advocated for a summer research internship by emailing Principal Investigators, attending some of the summer internship activities.

The 8-week summer research experience in the tissue engineering lab was organized in two unique phases. In the first four weeks, students shadowed undergraduate and/or graduate students during research activities and were trained in basic laboratory skills, cell culture techniques, biomaterial processing, as well as multi-well microelectrode array recordings for electrophysiological data analysis. In the last four weeks of the program, the high school students were asked to independently develop an experimental procedure for an alginate-based cell bioink.

Defining Success

To evaluate the student experience data, we first needed to explore how success is defined in high school research experiences. There is a wealth of literature characterizing the benefits and successful outcomes of Undergraduate Research Experiences (UREs) and course-based undergraduate research experiences (CUREs). In a report containing a comprehensive review of educational studies on UREs, research spanning several studies on undergraduates participating in UREs shows increased retention for African Americans, increased persistence, an increase in GPA or a higher academic performance, decreased attrition and shorter degree completion timeframes, and an increased likelihood to pursue a STEM career [14].

At the high school level, there are few studies clearly characterizing successful outcomes of summer research-based internships, but indicators of success were found by broadening the search to include any STEM summer high school experience. A recent study looking at a high school apprenticeship program called Work with a Scientist employing a constructivist learning environment, which includes interactive group work based upon student knowledge, reported increased student agency and breadth of scientific knowledge as measures of success [15]. A shadow summer internship experience for URM high school students called Doctors of Tomorrow evaluated success in terms of increased student enthusiasm and satisfaction with the experiential learning approach [16]. One study of a high school STEM camp defined a successful outcome as an increased awareness of STEM fields, increased interest in STEM, and an indication to pursue STEM careers [17]. In keeping with the limited work at the high school level and the goal of our study, this work will define success as an increase in STEM identity, student- and parent-reported satisfaction with the research and/or internship, increased student interest in pursuing a STEM career, and increased student confidence in their ability to succeed in STEM-related tasks.

Participants and Setting

Participants were the three high school students interning in the BME lab and fathers of two of the students (See Table I). The parents of the third student declined to be interviewed. The three high school students interviewed were non-white, one was female and two were male. Intern Patricia attends a large, diverse public school and Intern DP graduated from the same high school as the class valedictorian and now attends a large, public state university majoring in a STEM field. The third intern, Intern Sid, attends a top-rated public regional high school[18]. Both parents of each child are living, and 5 of the 6 parents are currently in a STEM career, with the exception of one parent who owns a convenience store. All three sets of parents immigrated to the United States. Intern DP self-identifies as being in the Indian community, and the parents of Intern Sid immigrated from India, as reported by Parent SN. Intern Patricia self-identifies as a first-generation immigrant from Kenya and is of a cultural background recognized as an underrepresented minority in STEM [19].

The two faculty mentors interviewed are research scientists in Biomedical Engineering and Assistant Professors in the Biomedical Engineering Department of the host university. Both faculty members have established labs with undergraduate and graduate student researchers as well as a staff scientist.

Table I – Participants family and academic background.

Intern (Alias)	**Self-identifies**	**URM in STEM**	**Parent Interviewed (Alias)**	**Parents' Careers**	**Part of MLSC**	**School System**
Intern Patricia	First generation immigrant from Kenya	Yes	None	Father – RN Mother LPN	Yes	Public, low-income
Intern DP	Second generation immigrant from India	No	Parent Prashant	Father - engineer Mother - convenience store owner	Yes	Public, low-income, but attended public STEM-focused elementary and middle school
Intern Sid	Second generation immigrant from India	No	Parent SN	Both parents are engineers	No	Public, in top 20 in state ranking [18]

STEM Role Models

Results indicate that all three students grew up in a household that was supportive of science and STEM with STEM talk occurring in all three families. Two of the three interns have significant access to STEM role models outside the home and family STEM talk around education and careers in science and STEM (Table II).

Table II – STEM interest, activities, and role models

Variable	Intern Patricia	Intern DP	Intern Sid
Early STEM interest and/or activities	No	Yes	Yes
Parental support of STEM pursuits	Yes	Yes	yes
STEM role models in the home	Yes	Yes	Yes
Access to STEM role models outside of the home	No	Yes	Yes
Self-reported successful internship experience	Yes	Yes	Yes

Interns DP and Sid both discussed an extensive network of doctors, engineers, business owners, and labs – i.e., STEM role models outside the home - that provided many opportunities for mentorship, research, and conversations. Intern Patricia stated that her parents had friends that were nurses but did not elaborate as to specific influences or opportunities provided by any STEM mentors or professionals outside the home, saying "I don't know anyone personally that is like a doctor or anything like that."

Family STEM Recognition, STEM home support and Confidence in the Lab Experience
All three interns reported significant support for STEM pursuits. Two of the interns, DP and Sid, self-reported an early interest in STEM, which was confirmed by parents, whose comments reflected a strong sense of recognition of their child as a STEM person. Parent Prashant commented "All his achievements [in STEM were] from kindergarten or pre-k" and "…so it was in kindergarten… he had written up…I want to be a doctor."

Parent SN displayed recognition, support, and expectations around STEM for Intern Sid when he explained, "Both me and my wife are in STEM fields. So, we expect a lot from him, and he understands that, but fortunately, his interest and our interests are aligned."

All three students reported a desire from their parents to enter a STEM field. Intern Patricia said "…my dad does, like, want me to go into the medical field."

Student DP mentioned his father's wishes: "I know, definitely, he wanted me to go into engineering probably before, but…[I] got excited with medicine."

Intern DP and Intern Sid both reported multiple experiences of school-sponsored and -supported events and clubs that enabled early (elementary school and/or middle school) participation in STEM activities and competitions. Intern Patricia became interested in STEM with a science and engineering class in freshman year of high school. Parental recognition and support continued into the UML research internship for Intern DP and Intern Sid. The parents of these interns recalled frequent conversations about the internship and the day-to-day experiences of their children in the lab.

It is likely these prior STEM experiences and early family STEM recognition manifested in the day-to-day of the research internship for Intern DP and Intern Sid. Both faculty mentors recognized the initial and continuing confidence displayed by both interns in comparison with Intern Patricia. Faculty Mentor 1 described the dynamic of the interns as follows:

> [Intern DP] was…quietly confident, would always stand closest to whoever was speaking or teaching him something…Intern Sid was the most talkative and had the most questions

> and was also note taking and…peering at everything that was going on…[Intern Patricia] would be behind the wall of [Intern Sid and Intern DP]"

Faculty Mentor 2 agreed, saying "[Intern Patricia] was generally very excited and interested…" but "…would barely talk at the beginning…with the three of them [together], they would…overpower her."

Faculty Mentor 1 and Faculty Mentor 2 detailed further examples of STEM performance-competence for Intern DP and Intern Sid when compared with Intern Patricia. Both faculty mentors reported making frequent attempts to engage Intern Patricia in the conversations and to elicit her opinions. It was reported that by the end of the summer, Intern Patricia was talking and interacting more in the group when faculty were present. Faculty mentor 1 noted "[Intern Patricia] was more comfortable…and was taking a much more active role in what was going on."

Defining a Successful Research Experience – Parent and child evaluations and faculty mentor intentional planning

All parents and children reported feelings of satisfaction and success when talking about the research internship experience. The three interns mentioned the hands-on experiences as being the favorite part of the internship, highlighting "…going into the BSL II lab and working with [the cells]," and "…being able to learn hands-on techniques…taking care of the IPSCs [a type of stem cell] was my favorite…it was amazing." Two of the three students described troubleshooting the 3D Bioprinter difficult and "frustrating" but one of their favorite summer activities. All three students alluded to the strong mentoring relationships offered by Faculty Mentor 1 and Faculty Mentor 2, as well as other lab members, as a significant contributor to their feelings of success. Intern Patricia commented:

> "I was paired with by [Faculty Mentor 1] and [Faculty Mentor 2]. And they're absolutely amazing… our professors kind of gave us like more hands on things to do. The undergrads that worked…under them were like, so helpful. And it just…felt like a close-knit family in a way."

When Intern DP spoke about the parts of the internship that helped him learn, he recognized the contributions of the faculty mentors on the structure of the experience:

> "The way that [they] kind of planned out this internship was very, very, very smart. [It] helped us stay on track and focus on what we're doing. [I] definitely worked with [Faculty Mentor 1] a lot."

The planning alluded to by Intern DP became clear when interviewing Faculty Mentor 2. In her interview, she elaborated on the design of the research experience and how she developed and distributed a calendar detailing shadowing assignments, experiment information, and scheduled time for lunches and breaks (see Figure 1). In addition to the schedule, Faculty Mentors 1 and 2 set aside time for one-on-one meetings with the interns each week, creating a space for the students to share not just science interests but to “see how they were doing…” and talk about “…their life in general.” The interns also took part in journal clubs, during which one member of the lab presented a summary of a primary research paper related to the focus of the lab or larger field of research.

Figure 1. – Student schedule of experiments and activities in the lab for Week 1 of the internship

	Monday	Tuesday	Wednesday	Thursday	Friday
	06/27/2022	06/28/2022	06/28/2022	06/30/2022	07/01/2022
Morning 10am – 12pm	iPSC MEA Recordings	iPSC medium exchange	iPSC MEA recordings	Tissue Culture and Cell Thawing	Scratch Assay
Afternoon 1pm – 4pm	mDRG recordings (2-3pm)	Axogen Nerve Segment – Clearing/Staining	Microbiome Experiment – Bioreactor Set Up	IL-8 ELISA Assay	Axogen Nerve Segment – Confocal Imaging
		Journal Club			

Faculty mentor interviews indicated an overall willingness to allow the interns to experiment without fear or consequences of failure. For example, Faculty Mentor 1 gave each intern several cultures of cells, telling them “You all have to take care of them. And then we'll see whose rows survive the longest” which became a playful competition between the interns in the lab. Taking care of the cells was so impactful that all three students mentioned the cells in their interviews, and during the interview, Intern DP was scrambling to find his cell images, wanting to share them with the interviewer. This culture of open inquiry and experimentation was carried through to the final project when the interns were asked to troubleshoot the 3D Bioprinter.

When parents were asked about the success of the internship, lab skills and the faculty mentorship were described. Both parents expressed that the experience helped their children gain skills in a wet lab. However, they emphasized training on a piece of equipment or a lab technique, as opposed to involvement in a research question or working collaboratively to troubleshoot a protocol. Parent SN said, “I didn't expect him to like work on the research problem… [just] get acquainted with the machinery.” In fact, neither parent seemed aware that their children were given experiments with cells or challenged as a group to get the 3-D Bioprinter working.

In terms of mentorship, both parents were in agreement that the summer program provided an opportunity to develop relationships with professors. Parent Prashant mentioned that this is important because in college …" You got to have…[a] good relationship with the professor to go further and get more opportunity on the research side." Parent SN said that after this summer internship, his son can now build on the skills foundation and "I'm expecting him to…take a problem and collaborate with professors and like, make progress or headway on these problems like your research." Both parents mentioned a desire to learn more about the lab experience and wished they had been able to visit the lab or attend the student poster session at the end of the summer.

Parents and children differed on their perceptions around the ease of transportation to and from the internship. All three students said transportation "wasn't really an issue." But both parents mentioned having to give their children rides to and from the internship, with Parent SN describing the multiple arrangements that he and his spouse had to make to support Intern Sid with transportation, stating, "it was challenging, but somehow we made it work."

Discussion

Many studies on STEM identity have focused on students at the undergraduate level with data collection restricted to the undergraduates themselves [1], [4]–[6]. In addition, no studies were found that involve parents and the research mentors in the interviews. This case study looks at the development of STEM identity in high school students before, during and after a summer research experience in a university lab. In this study, three students, two parents, and two faculty mentors were interviewed to give multiple perspectives on the summer research experience, the structures of the program that led to feelings of success, and the qualities of mentorship that affected STEM identity.

The research of Dou and Cian (2022) quantitatively determined the significant contribution of home support in self-recognition as a STEM person and in the development of a STEM identity in URM undergraduates [5]. In this study, the qualitative analysis of interviews from three high school student interns, two parents and two faculty mentors reflect what is seen at the undergraduate level - authentic science lab experiences result in an increase in STEM identity and interest. The positive influence of direct faculty mentorship in a research experience also mirrors what is seen in UREs. Two unique themes emerged from this study – the importance of the parent perspective in evaluating STEM identity and family STEM recognition, and ways in which the hosting faculty mentors can evaluate STEM performance-competence and give insights into the academic and social-emotional growth of the high school students.

The recognition of others as being "a STEM person" or being "good at STEM" can be more impactful in developing STEM identity than either interest in STEM or performance-competence in STEM classes or activities [5]. While all three interns mentioned parental support for their

STEM pursuits, both Intern DP and Intern Sid specified being interested in STEM as early as 4th or 5th grade. Interviewing the parents of Intern Sid and Intern DP substantiated this early STEM interest and participation in activities, the anecdotes reflecting parental STEM recognition as early as pre-kindergarten. This means that the parents saw their children as STEM individuals from a very young age. Perhaps this early encouragement and recognition reinforced STEM interests for Intern Sid and Intern DP, which in turn further developed their STEM identity. Multiple attempts were made to interview the parents of Intern Patricia to explore her childhood experience as both an immigrant and a URM in STEM and were unsuccessful. We do know that she reported that her interest in STEM did not begin until 9th grade in high school.

Faculty mentor viewpoints contained information on degree of pre- and post-internship STEM performance-confidence, an indicator of and an important contributor to STEM identity [8], [9]. Previous lab, job shadow, and STEM activity experiences allowed Intern DP and Intern Sid to begin the lab experience with confidence noticed by both faculty mentors. While Intern Patricia began the research program quiet and standing back in the group when with faculty mentors, she did exhibit more assertiveness near the end of the summer. This suggests that the summer research internship positively affected her STEM performance-competence.

As mentioned in the introduction, URM STEM females are significantly impacted by high school summer research experiences in authentic lab spaces [2]. The interview with Intern Patricia reinforces this. When asked if her career choice changed after completing this research internship, she responded that coming into the internship, her possible career "…wasn't like STEM-based like biochem, it was more like public health. And…when I did the internship, that's when I was like, oh, maybe I should be like, more STEM because I really liked this." Intern Patricia also talked about the responsibility she felt toward the choices and sacrifice her parents made by coming to the United States, saying "You feel like you need to…kind of succeed…to…make how your parents came here worth their while." Further research is needed at the high school level to explore both male and female URM experiences in STEM summer research internships, the responsibilities and pressures they may carry with them into these career explorations, and the most impactful aspects of these internships in guiding STEM career choices.

The strong and effective faculty mentorship was highlighted by both interns and parents as key to the success of the internship. For the interns, this translated into the time spent explaining protocols, training on equipment, "long discussions about science," and the graduate and undergraduate peer mentorship. From the parent perspective, professors "having that kind of trust in the students" to use expensive equipment and materials and "being so open" with the students meant that their internship goals for their children were met.

Many components of the mentor relationship may have contributed to the success of the high school interns' experiences – the schedule, the one-one-one weekly meetings, the presence of near-peer undergraduate mentors, and the openness of the faculty mentors in creating intellectual and emotionally-supported space for the interns to experiment and troubleshoot with their own materials. These elements were intentionally designed by the two hosting faculty mentors. Faculty Mentor 2 mapped out experiments weeks in advance and provided calendars for the students each week (Figure 3). Additionally, both faculty met with each student one-on-one every week for discussions focused on social-emotional well-being and building the mentoring relationship. Research shows that predictable routines and the opportunity to build meaningful relationships with mentors can promote deeper learning in students of all backgrounds, and especially those with complex trauma [20], [21] and should be part of any program aiming to support URM students. Future surveys and evidence of intern work can help qualify and quantify which of these elements may be impactful to URM students.

This case study of a high school summer research internship adds to the evidence that research internship experiences contribute to STEM interest and identity. However, the data here reveal that interviewing parents can give additional details on home STEM talk and can supply crucial evidence of early family STEM recognition, a powerful element in the development STEM identity. This study also indicates a role for parental involvement in the design of STEM high school research experiences, as their participation may initiate and/or reinforce family STEM recognition. In addition, faculty mentorship and hands-on skills involving authentic lab techniques, protocols and problem-solving challenges all contribute to feelings of a successful internship for both parents and high school students. Importantly, future work researching challenges and success elements for URM high school students in these internships is essential in developing a path to diversity in the United States BME workforce pipeline.

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