Engineering Resilience through Research Mentorship: Manufacturing Pathways to Careers

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Without comprehensive systems change, the entrenched stratification of engineering by race/ethnicity and gender will not be meaningfully remedied [1, 2]. The STEM labor system continues to entice and attract underrepresented groups and communities to invest energy and time into fields that have been and continue to resist change, argue Scott and Elliot [3]. Pawley [4] interrogates the engineering education research base to assert the importance of shifting to an intentional centering of the voices and experiences of women and underrepresented groups, to be more effective in achieving field, national, and programmatic equity goals. This paper draws on the systems knowledge of an interdisciplinary team (sciences in industrial/mechanical engineering plus sociology of higher education). More specifically, this paper reports on the collaborative examination of a testable and scalable ten-week summer intervention to enhance undergraduate students' material science learning and commitment [5]; notably, this student population is predominantly Black and nearly 50% female.

Why does it remain both essential and difficult to attract diverse students to engineering research and industry? McGee and Robinson [6] argue the traditional discussion for diversifying STEM positions minoritized people of color as replacements in the mostly White STEM professoriate and workforce. They critique the common claim that underrepresented minorities are an untapped resource to improve capitalism as it ignores other reasons such as personal and professional efficacy. Building on their past research, they provide the following example to illustrate the experience of a Black engineering student in the United States:

> *"…as a student, if you have a bad experience and you don't feel like your presence is even wanted, never mind improving the situation, you want out of the environment, because it's toxic. So take a person like me – I could do a lot of good around here. I don't want to be here. Not because I don't want to do any good, [but] because this has been damaging to my psych."*
>
> -*Samuel* (pseudonym; *as cited in* McGee & Robinson, 2020, p. 4)

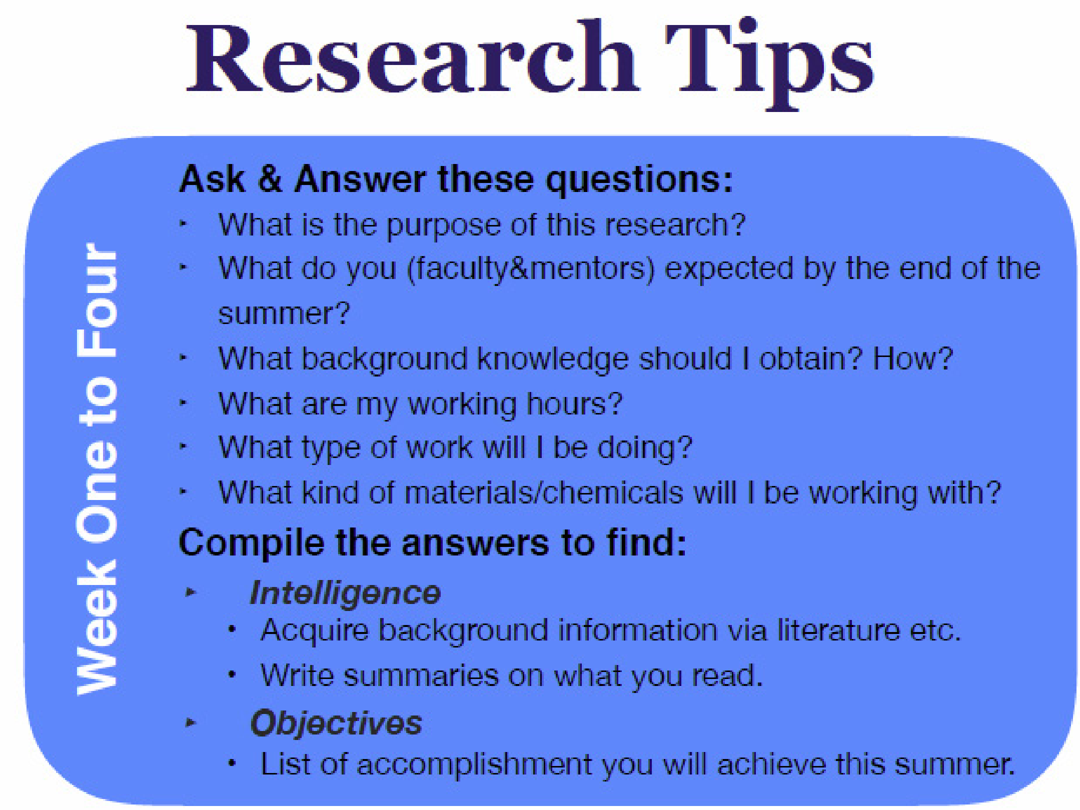
Despite projected growth in engineering jobs, corresponding degrees earned among Black women have remained strikingly and persistently low, even as compared to their male peers. Although most research on women in engineering focuses on predominantly white institutions, recent research suggests women of color might have more success in Historically Black Colleges and Universities (HBCUs) [7, 8]. This manuscript develops an evidence base for *engineering resilience* among students of color pursuing undergraduate research in materials, undergoing intensive mentorship and training in how to become material scientists.

Such training may be especially important for students of color – and women of color specifically – because the difficulties and frustrations inherent in scientific research may be especially fraught for already marginalized students who have had to work so hard to belong and be seen as legitimate scientists and engineers [9]. *Resilience* refers to a student's ability to overcome challenges and setbacks, such as they might encounter in an intensive summer research program [10-12]. As a concept, resilience is typically referenced as a trait consistent with self-determination; a combination of skills, knowledge, and beliefs that enable self-directed and self-regulated achievement of goals [13]. Some argue resilience is malleable rather than an inherent trait, and can be trained [14, 15]. Ability-related beliefs have been shown to matter for persistence in race- and gender-segregated mathematics-intensive fields like engineering, and this may be particularly the case for Black men and women [16].

Importantly, undergraduate research has been found to be a high-impact practice, as is the mentoring often associated with it [17], predicting student success [18, 19]. Indeed, students with mentors have higher GPAs, greater retention rates, and more courses completed on time. This paper builds on a mixed methods evaluation study of a series of funded undergraduate research cohorts, with a focus on a comprehensive ten-week research and training intervention in the summer of 2019. This intervention enrolled a predominantly underrepresented minority cohort of undergraduate students in material sciences research – chemical, industrial, and mechanical engineering – based at a "Southeastern HBCU." While Chemical Engineering (CE) is less gender-segregated than other engineering fields [20], fewer women within CE pursue materials science specializations. Industrial engineering and mechanical engineering, in particular, have especially low rates of women nationally. We examine whether resilience could be engineered through structured and intentional mentored research. Using a mixed methods evaluation strategy to assess inputs, environment, and outcomes [21], qualitative inquiry drew on 1) an affirmation writing exercise and 2) individual interviews with undergraduate mentees. Quantitatively, we draw on the results of pre- and post-test surveys at the start and end of the summer, measuring learning, science identity, and intent to persist in STEM fields.

METHODOLOGY – INTERVENTION AND DESIGN

Eleven students mostly new to mentored undergraduate research as well as the HBCU research setting were selected to participate in a paid undergraduate research summer program. They were primarily rising juniors and seniors in college. At the start of the summer, students were given time to tour and explore campus research labs in multiple sites, with groups focused on materials science research. They were each assigned material-driven projects to train on, with clearly defined deliverables monitored regularly by the faculty directors of the program, with structured checkpoints over the course of the summer. These projects were bounded by the summer session but allowed opportunities for students who were local to continue into the academic year and for all students to resume work if they applied and were accepted to the institution's graduate school programs. In addition to their stipends and living costs (for those not in residence), undergraduate students participating in the program were offered free course training from the investigators and/or colleagues in advanced characterization, robotics, data-sciences, entrepreneurship and industry training. The figures below detail the strategies and flow of the training.



Mentored supervision was structured such that students received ongoing formative feedback through peer supports, graduate and postdoc mentors, and their faculty/investigator mentors (via weekly progress meetings). In the context of this intervention, mentoring was provided through structured feedback to further students' research designs and presented work – both oral and poster presentations. Students received formative feedback from these periodic reviews of their presentations to program faculty and students, using presentation templates that included a Penta chart and quad chart, widely used in top-tier institutes. The structural presentation and provided guidelines were intended to help undergraduate students become immersed in and develop their project in a timely manner. Further, this design aimed to provide a clear evaluation baseline for the whole group to see each students' progress with milestones. To prepare students for graduate school applications and readiness, students were also invited to participate in training workshops for fellowship applications and a paid GRE exam prep course.

Two formative, predominantly qualitative assessments were given mid-summer. First, an Engi-resilience training workshop run by the external evaluator was held in June 2019, including affirmation intervention on skill-career fit, drawing on best practices and published research [22, 23]. After a presentation and facilitated discussion, the eleven summer REU students were asked to "write a paragraph about how you are uniquely well-suited for success in materials science. It can be about your skills, interest, experience, perspective, values, or anything else." Individual interviews followed the subsequent week, between the developmental, research preparation and conceptualization period and the latter half of the summer, focused on execution.

From weeks five through ten, students were tasked with executing their projects, under the hierarchical mentoring teams of their graduate student and faculty mentor teams, which at times included postdocs and additional, peer undergraduate students. Developmental tasks for weeks five through seven consisted of the following: continued learning through literature review, documentation and validation of early findings, communication with mentors, motivation, and commitment to meeting their objectives. In weeks eight to ten, students were asked to provide more data and documentation, including visuals, polish their result description and discussion, including theoretical synthesis, and send drafts of their written report and final presentations to their mentors for feedback and revision –resembling a foundational learning scheme. The summer experience closed with a final presentation that is judged by a panel of academic engineers and industry professionals.

Pre- and post-surveys consisted of a series of items ranking confidence that they "can master the following subject matter" on a scale of 1 (least confident) to 10 (most confident). Subject matter for mastery was identified by the materials science team and included the following clusters: mathematics, applied and engineering sciences, materials application, product design and development, process design and development, manufacturing process applications and operations, product system design and development, equipment/tool design and development, automated systems and control, quality and customer service, manufacturing management, and personal effectiveness. Additional background characteristics were queried as well, with a focus on learning goals and science/engineering identity. Factor analysis synthesized the engineering and materials science learning items into constructs.

Original data collection and analysis employed two sets of pre- and post-surveys assessing engineering learning, identity, and career commitment. In between the pre- and post-surveys, the evaluator observed students' participation in intensive materials research mentored by more senior scholars of color, led an affirmation training and writing intervention, and conducted and coded individual semi-structured interviews with all participants mid-summer. These 30-minute interviews were transcribed and inductively coded for themes, using open coding. T-tests were used to assess variation between students in the pre- and post-test means.

RESULTS

Learning gains and limitations. Students were surveyed before the start of the summer as well as at the end of the summer, about their level of knowledge and skill in a series of areas relevant to material and manufacturing science. Given limited space with a mixed methods study, we report here only significant findings. Overall, the pre- and post-means were not significantly nor meaningfully different, although students' reported mastery of science and engineering skills did descriptively trend higher in most instances at the end of the ten weeks. The most significant differences, with positive t-test effects (of at least $p<.10$, given the small n), tended to be in practical areas around industrial engineering, entrepeneurship, and management – key intentions of the program's base department. Specifically, these included tool and equipment selection (pre=7.91, sd=2.55; post=8.64, sd=1.43; 1-tailed sig<.09), power systems mechanics (pre=7.30, sd=2.54; post=8.00, sd=2.75; 1-tailed sig<.01); inspection test validation (pre=7.91, sd=2.63; post=8.37, sd=2.16; 1-tailed sig<.06); fabrication processes (pre=7.19, sd=2.36; post=8.73, sd=1.01; 1-tailed sig<.02), CAD application (pre=7.91, sd=2.67; post=8.46, sd=2.66; 1-tailed sig<.03), simulation engineering (pre=7.64, sd=2.62; post=8.82, sd=1.33; 1-tailed sig<.03). No significant differences were found in a negative/declining mastery direction.

[INSERT TABLE 1]

In a few cases, there were modest but statistically insignificant decreases, such as with knowledge of welding (pre=7.73, sd=2.69; post=7.45, sd=2.54) and heat transfer (pre=7.54, sd=2.54; post=7.09, sd=2.59). These mostly null and occasionally declining patterns in confidence likely reflect increased awareness of the field, and their limited experience compared to the graduate student and faculty mentors. While the author team observed their displays of confidence at the end of term presentations and the students did indeed present and move towards publications on the results of their research findings in regional and national presentations following the summer research, their awareness of the depth of the fields they were entering did appear to increase, as several discussed in the formal individual interviews as well as in more informal discussions and observations with the students.

Notably, in the initial pre-test surveys, students' open-ended responses about their intended learning gains tended to be quite broad. Responses ranged from the general "I hope to enhance my research knowledge and additive manufacturing knowledge, and I am to be able to present a research poster to the best of my ability" to the most specific being "I want to learn how to use various software like CAD, lean, 5s, how to be able to understand systems to optimize them. I hope to network with the young minds here and with the faculty and mentors to broaden my experience." It seems that while their mastery of materials science and engineering grew from a limited baseline at the start of the summer research experience, the setbacks and challenges they encountered in the lab and the depth of knowledge they discovered in their courses and literature review might have adjusted their interpretation of what it takes to master one of these areas. We observed this in past cohorts of this program's summer research experiences and adjusted accordingly, structuring the program to allow for initial weeks focused on learning and qualitative, formative reflection before being fully immersed into independent but mentored laboratory research.

Resilience. At the end of the summer, in addition to the surveys assessing learning gains in specific engineering areas, we also inquired about how they overcame challenges and about their future plans in relation to further study in areas adajacent to materials science. During the June 2019 Engi-resilience workshop, students indicated alignment between their identity and their engineering interest. The following responses were selected to represent the range of their perspectives. Given research evidence on the efficacy of such affirmation exercises, a pre-test was issued before this intervention and a post-test was issued at the end of the summer, showing gains in most areas of learning as well as in their engineering identity, particularly in how it aligned with their identities as students of color, women, and/or in fitting with their interests and formative experiences.

Notably, a consistent theme was resilience. These were not students who had consistent and early exposure to engineering knowledge and training – none of the 11 students interviewed and surveyed self-identified as having childhood training and passion for engineering as a specific career field or discipline of study. Two example narratives are included below.

African American female student: inquisitive and 'unyielding drive':

> "I have always liked building things and taking them apart. I always ask 'why' questions which tend to lead down rabbit hole of knowledge.... I am self-motivated to succeed and have worked hard with a clear goal in mind. I am a determined to write my own destiny. I push boundaries and ask whys, until I understand the answer. I relish in opportunities that provide stepping stones and have been continually, successfully, setting myself up for the future in every step. I have to do this, to dream and to take with me all of these experiences. What makes me different is my unyielding drive."
>
> *Underrepresented male student: self-confidence, hard work, and validation.*
>
> "I'm uniquely equipped for a career in material science because of my [recent] background in [*redacted*] engineering. This is predicated on experience with using biocompatible polymers and is the thing that I've worked the hardest on in my life. This past year I've been pushing myself outside my comfort zone of [natural science] into engineering and I'm seeing my hard work come to fruition. It all came from my believing myself, and I would have never made this much progress without believing myself. I have CEO's and world famous scientists telling me that I have a good idea and that's something I would have never dreamed would happen."

Across the qualitative component of the study, students reflected on motivation ability to push themselves "outside of their comfort zone" and – when present – family and community supports as key factors to their short-term and intended longer-term engineering success.

STUDY SIGNIFICANCE

This multi-method evaluation study sought to examine engineering resilience among students of color during a ten-week summer intervention program. Using a series of qualitative and quantitative approaches detailed above, we examined the experiences and learning gains of a cohort of intersectionally diverse HBCU engineering students. As noted earlier in this paper, there has been debate in the research literature about the degree to which resilience is a static trait versus a malleable one that can be trained and developed through mentored support [14, 15]. We measure resilience through individual interviews with students halfway through a summer intervention using mentorship and undergraduate research – two high-impact practices – and through the measured gains in their assessments of their ability in topical areas of manufacturing science, as measured by the results reported in Table 1. As noted earlier, these assessments of ability have been shown to matter especially for the success of Black men and women in engineering and other mathematics-intensive fields [16]. While we do not have a comparison case with which to directly assess the contribution of the diverse and rich communities of support as found in HBCUs, where our study was situated, case studies comparing sites which intentionally serve diverse students would further advance the field of knowledge on STEM resilience among students of color. As such, our research findings suggest the value of validating, affirming, and fostering the skill development and confidence of HBCU students pursuing materials science and engineering, manufacturing a resilient and robust engineering workforce.

***Table 1.* Student Self-Assessment at Start (Pre-Test) and End (Post-Test) of Summer Intervention**

	Pre-Test		Post-Test				
	M	*SD*	*M*	*SD*	*t*	*p*	Cohen's *d*
T1. Tool and Equipment Selection	7.91	2.55	8.64	1.43	0.71	.09	0.49
T2. Power Systems Mechanics	7.30	2.54	8.00	2.75	-2.69	.01	0.58
T3. Inspection Test Validation	7.91	2.63	8.37	2.16	-1.61	.06	0.65
T4. Fabrication Processes	7.19	2.36	8.73	1.01	-2.42	.02	0.04
T5. CAD Application	7.91	2.67	8.46	2.66	-2.21	.03	0.63
T6. Simulation Engineering	7.64	2.62	8.82	1.33	-2.20	.03	0.29

- T# - Topic Area of Interest

References

[1] L. Perez-Felkner, "EDITORIAL: Surpassing STEM's Gender Limitations: Structures, Interventions, and Systems Change," *International Journal of Gender, Science and Technology,* vol. 11, no. 3, pp. 1-4, 2020-01-31.
[2] L. Perez-Felkner, "Conceptualizing the Field: Higher Education Research on the STEM Gender Gap," *New Directions for Institutional Research,* vol. 179, pp. 11-26, 2018.
[3] K. A. Scott and S. Elliott, "STEM Diversity and Inclusion Efforts for Women of Color: A Critique of the New Labor System," *International Journal of Gender, Science and Technology,* vol. 11, no. 3, p. 9, 2020-01-31.
[4] A. L. Pawley, "Shift the default in "broadening participation" in STEM equity research," *International Journal of Gender, Science and Technology,* vol. 11, no. 3, p. 9, 2020-01-31.
[5] S. Margaret, M.-D. Micah, O. O. David, and I. O. Okenwa, "NSF-Retaining Engineers through Research Entrepreneurship and Advanced–Materials Training (RETREAT)," in *American Society for Engineering Education*, Indianapolis, Indiana: ASEE Conferences.
[6] E. O. McGee and W. H. Robinson, "Diversifying STEM: Multidisciplinary Perspectives on Race and Gender." New Brunswick, NJ: Rutgers University Press, 2020.
[7] L. W. Perna *et al.*, "The Contribution of HBCUs to the Preparation of African American Women for STEM Careers: A Case Study," (in English), *Research in Higher Education,* vol. 50, no. 1, pp. 1-23, 2009/02/01.
[8] R. T. Palmer, D. C. Maramba, and M. Gasman, "Fostering Success of Ethnic and Racial Minorities in STEM: The Role of Minority Serving Institutions." Routledge, 2013.
[9] E. O. McGee and D. B. Martin, ""You Would Not Believe What I Have to Go Through to Prove My Intellectual Value!": Stereotype Management Among Academically Successful Black Mathematics and Engineering Students," *American Educational Research Journal,* October 21, 2011.
[10] C. S. Clauss-Ehlers, "Sociocultural factors, resilience, and coping: Support for a culturally sensitive measure of resilience," *Journal of Applied Developmental Psychology,* vol. 29, no. 3, pp. 197-212, 2008.
[11] C. O'Connor, "Black Women Beating the Odds From One Generation to the Next: How the Changing Dynamics of Constraint and Opportunity Affect the Process of Educational Resilience," *American Educational Research Journal,* vol. 39, no. 4, pp. 855-903, December 21, 2002.
[12] E. O. McGee and L. Bentley, "The Troubled Success of Black Women in STEM," *Cognition and Instruction,* vol. 35, no. 4, pp. 265-289, 2017/10/02.
[13] M. V. Izzo, A. Murray, S. Priest, and B. McArrell, "Using Student Learning Communities to Recruit STEM Students with Disabilities," *Journal of Postsecondary Education and Disability,* vol. 24, no. 4, pp. 301-316, 2011.
[14] J. A. Schmidt and L. Shumow, "Testing a mindset intervention as a resilience factor among Latino/a students in science," *Journal of Latinos and Education,* pp. 1-17, 2018.
[15] D. S. Yeager and C. S. Dweck, "Mindsets That Promote Resilience: When Students Believe That Personal Characteristics Can Be Developed," *Educational Psychologist,* vol. 47, no. 4, pp. 302-314, 2012/10/01.

[16] S. Nix and L. Perez-Felkner, "Difficulty Orientations, Gender, and Race/Ethnicity: An Intersectional Analysis of Pathways to STEM Degrees," *Social Sciences,* vol. 8, no. 2, pp. 1-29, 2019.

[17] Z. S. Wilson *et al.*, "Hierarchical Mentoring: A Transformative Strategy for Improving Diversity and Retention in Undergraduate STEM Disciplines," *Journal of Science Education and Technology,* vol. 21, no. 1, pp. 148-156, 2012/02/01.

[18] A. Finley and T. McNair, "Assessing Underserved Students' Engagement in High-Impact Practices with an Assessing Equity in High-Impact Practices Toolkit," Association of American Colleges & Universities, Washington, DC, 2013, Available: https://www.aacu.org/sites/default/files/files/assessinghips/AssessingHIPS_TGGrantReport.pdf.

[19] M. C. Linn, E. Palmer, A. Baranger, E. Gerard, and E. Stone, "Undergraduate research experiences: Impacts and opportunities," *Science,* vol. 347, no. 6222, p. 1261757, 2015.

[20] National Science Foundation, National Center for Science and Engineering Statistics, "Women, Minorities, and Persons with Disabilities in Science and Engineering: 2017," Arlington, VA. Special Report NSF 17-310, 2017, Available: www.nsf.gov/statistics/wmpd/.

[21] A. W. Astin and A. L. Antonio, *Assessment for Excellence: The Philosophy and Practice of Assessment and Evaluation in Higher Education*. Rowman & Littlefield, 2012.

[22] A. Miyake, L. E. Kost-Smith, N. D. Finkelstein, S. J. Pollock, G. L. Cohen, and T. A. Ito, "Reducing the Gender Achievement Gap in College Science: A Classroom Study of Values Affirmation," *Science,* vol. 330, no. 6008, pp. 1234-1237, November 26, 2010 2010.

[23] G. L. Cohen, J. Garcia, V. Purdie-Vaughns, N. Apfel, and P. Brzustoski, "Recursive Processes in Self-Affirmation: Intervening to Close the Minority Achievement Gap," *Science,* vol. 324, no. 5925, pp. 400-403, April 17, 2009.