

Empowering Undergraduate Student Researchers Through Inclusive Research Learning Systems

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Abstract

Research provides opportunities to develop critical thinking and problem solving capabilities. Intervention programs such as the Louis Stokes Alliance for Minority Participation (LSAMP) and the Multicultural Academic Opportunities Program (MAOP) also place value on research as a mechanism to attract, retain, and prepare underrepresented minority students for successful graduate careers, and these programs have achieved notable success. Yet, as a discipline, engineering continues to see limited growth in the number of underrepresented minorities who enroll in the major, graduate, and achieve advanced degrees. While research opportunities continue to expand for these groups, gaps in undergraduate and graduate degree attainment continue. We posit that research could be viewed as an inclusive learning system to impact underrepresented students' agency, self-efficacy, and empowerment in engineering by providing opportunities to acquire research skills and knowledge aligned with values of social responsibility. By centering on the creation of an Inclusive Research Learning System (IRLS) focusing on equity in societal benefits and other inclusive concepts, students not only grow intellectually, but also develop an empowered intellectual perspective. We discuss the IRLS concept, and highlight challenges and opportunities related to inclusive research.

Keywords

Inclusive research, inclusive curriculum, undergraduate research, graduate research, engineering education, research bias, research equity, culturally-responsive research

1. Introduction and Background

1.1 Underrepresentation in Science and Engineering

In the USA, the underrepresentation of ethnic minorities, women, and persons with disabilities is well known. Much has been written and many programs have been conceptualized, implemented, and evaluated. But, the much-hoped-for increase of underrepresented minorities (URMs), especially in engineering, has not yet been realized. Using data from the American Society for Engineering Education (ASEE; Yoder, 2016), from 2007 to 2015, students enrolled in engineering programs at the bachelor's level has remained stable, with the exception of Hispanic students, whose percentages rose steadily from 6.2% in 2007 to 10.7% in 2015. African American student enrollment remained between 3.5% and 4.9% and has steadily decreased from a high of 4.9% in 2007 to 4.0% in 2015. Asian American

student numbers ranged from 12.2% to 13.4% with decreases between 2009 and 2013, followed by gains in the past two years. ASEE combined Hawaiian, Pacific Islanders, American Indians/First Peoples, and those identifying as “two or more races” under the same category indicated as “other.” This group ranged from a low of 1.2% in 2010 to 11% in 2009, although some of the values are artifacts of the classifications used by ASEE. White students enrolled in engineering programs have declined from 67.3% in 2007 to 64.9% in 2015. Within all ethnic groups, women remain underrepresented as well. Enrollment in graduate programs among U.S. citizens show the same lack of growth, and for some engineering disciplines, a decline. In contrast, graduate degree enrollment among international students (non-residents) continues to increase (Yoder, 2016).

As a discipline, engineering is only as inclusive as the lived experiences engineers bring to design, analysis, and evaluation. When a subset of lived experiences dominates engineering practice, outcomes will be influenced by the cognitive fixity or biases resulting from limited subsets of lived experiences. These biases lead to technologies with benefits that do not disseminate equitably to all groups, which will be describe later in this paper.

1.2 Benefits of Undergraduate Research

In this paper, we focus on practices that might account for successful engineering degree completion with a specific focus on the role of undergraduate research. Initially, we focus on and scope the concept for success of African American students in engineering. While many other factors are at play, undergraduate research has drawn more attention as a means to engage students in engineering and sustain interest and persistence in the discipline. Some of these practices might generalize to underrepresented students at Predominantly White Institutions (PWIs) as these universities seek to expand the diversity and inclusion. While Historically Black Colleges & Universities (HBCUs) also struggle with challenges of building diverse and inclusive climates, the historical contexts and missions of HBCUs support more clear precedents and processes to be successful in this regard.

In describing the experience of undergraduate research, May and Chubin (2003) wrote:

One of the most effective approaches for motivating students to pursue advanced degrees and research careers in science and engineering is a fruitful research experience as an undergraduate.

May and Chubin suggested the academic benefits of undergraduate research arise from the opportunity for more personal mentoring, more depth and quality of faculty engagement, opportunities to network, and confidence-building activities such as presenting at conferences. Other researchers have connected retention and persistence as indirect outcomes of an undergraduate research experience. It is also suggested that opportunities to participate in a learning community, gain independence of thought, and be guided and mentored in a cognitive apprenticeship impact student persistence and engagement in STEM disciplines (Bauer & Bennett, 2003; Jones, Barlow, & Villarejo 2018; Lopatto, 2006, 2010). Bauer and Bennett conducted studies with alumni who had an undergraduate research experience and, when compared to alumni who graduated without participating in undergraduate research, those having undergraduate research experiences reported higher satisfaction with the university and with their overall experience as an undergraduate student. These alumni were also more likely to have attended graduate school.

Evidence exists supporting the importance of undergraduate research. But, merely participating in a laboratory and conducting certain types of research projects may not always have the same level of positive impacts among all undergraduate students. For instance, some African-American students in engineering seemed to be highly motivated by the extent to which their engineering knowledge could meet personal goals of social responsibility, mentoring and giving back to the African American community, as well as upward mobility in order to better serve their communities (Moore, Madison-Colmore, & Smith, 2003; Smith, Fleming, Moore, Burris, & Bornman, 2014). Similar findings have been indicated by Kim (2002) and Wolf-Wendell (1998). Undergraduate research enhances this motivation.

The question remains as to how to structure an undergraduate research experience to ensure the impacts and outcomes to each student are equitable and beneficial. Our focus has been to find ways to improve the climates of undergraduate research experiences for African American students by conceptualizing undergraduate research opportunities in engineering as inclusive learning systems.

2. Inclusive Research Learning Systems

2.1 Definition and Concept

First, we define an inclusive research learning system (IRLS) as a sociotechnical system consisting of environments (labs, fields, communities, virtual environments), an organization (the culture and climate of the institution and faculty micro-units), personnel (undergraduate students, graduate students, postdoctoral scholars, faculty, and others), and the technologies of use as well as those under study and the knowledge bases underlying them (software, computer workstations, cyber-environments, instrumentation and other lab artifacts). IRLS should be designed to support shared goals of the research enterprise, while also balancing the needs of stakeholders, including the institution.

Specific to students, successful IRLS, as a sociotechnical system, should value the diverse attributes students bring to the research setting. These attributes are depicted in Table 1 and are based on Thomas and May (2010; in Morgan & Houghton, 2011, p. 9), with some modifications based on the authors own interpretations and experiences. Educational attributes describe the former and current preparation of each student in terms of access to high quality education, learning experiences, capabilities (strengths, weaknesses), and skills and habits (studying, work organization). Dispositional attributes relate to individual differences at the idiographic level, or as one might describe it, the personality of each student. Circumstantial attributes are those that arise from situational factors that are both individual and arising from social stratification and other societal structuring. Cultural attributes refer to the nomothetic level of the individual, and consists of those attributes that comprise values and beliefs of groups with which the student identified. All students are essentially multicultural with both nomothetic (group cultures) and idiographic or dispositional attributes intersecting in ways that determine their ascribed minority or majority status, cultural capital, and social privilege at any given moment within any given social context. The interdependencies of these four characteristics should help to organize understanding of the dynamic personas students might bring to the research experience. These personas also influence and are influence by equally intersecting attributes of each faculty member and other research stakeholders (e.g., team members, communities to be served, target groups, human subjects, conference attendees, co-investigators at other institutions). A successful IRLS recognizes, appreciates and organizes programming to support participants with diverse attributes.

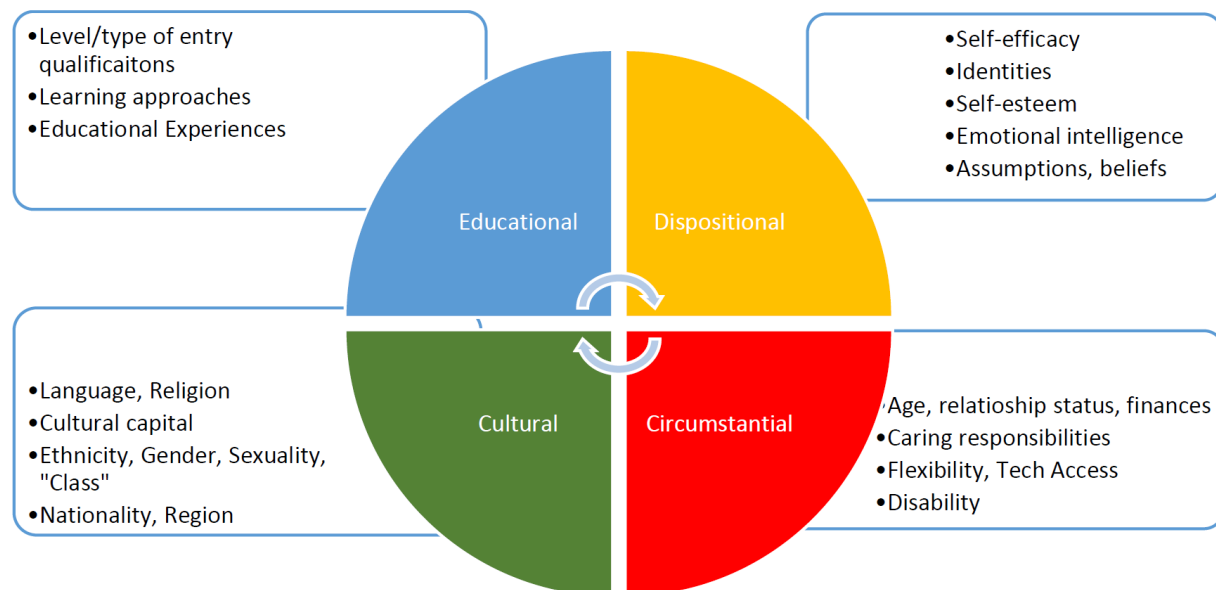


Figure 1. Classification modified from Thomas and May (2010).

2.2 Importance and Implications for Using IRLS

Student needs and characteristics provide a basis for the establishment of IRLS as a means to enhance research quality, rigor, equity, and fairness arising from university research. Disparities in research outcomes and consequences have been attributed to researchers who failed to consider differences of the intended beneficiaries. Such factors as social stratification, ethnicity, gender, socioeconomic status, sexuality, sexual identity, religion and many others have found to account for differential impacts of research and technologies, including those arising from STEM research and innovation (Grusky, 1994; McLeod, 2010; Schieman, Whitestone, and van Gundy, 2006). Every individual, regardless of culture, is impacted by a confluence of factors that may not be addressed as effectively without the involvement and intellectual capacities of researchers with personal lived experiences and inclusive perspectives. Because of the complexity of next generation social and sociotechnical systems, the social construction of technology and research (Pinch & Bijker, 1989) contributes to enabling majority and privileged groups to benefit from research more than other groups. At times, inequity in benefits might yield disadvantages that produce negative and even dangerous outcomes, such as facial recognition systems that fail to “see” darker-skinned individuals, software applications that inflate insurance premiums for African Americans living in certain neighborhoods, etc. (see O’Neill, 2016; Wachter-Boettcher, 2017).

Algorithmic bias, gaps in knowledge of inclusive data science approaches, inequities in usable access, and limited understanding of differential impacts of advanced technologies continue to challenge computing, information systems, and engineering. The National Academies, including the Institute of Medicine, The National Academy of Science, and the National Academy of Engineering, also articulated these concerns, remarking that “*America needs to draw on all of its talent, especially the growing population of minority students who continue to be under-represented in STEM fields* (Institute of Medicine et al., 2007, p.13). The target users of engineered systems and products are increasingly diverse. Unfortunately, proportionately fewer African American engineers are effectively represented as thought leaders in innovation or research. While many have been, African American engineers are still underrepresented as CEOs and entrepreneurs of leading engineering organizations.

3. A Proposal

3.1 Potential Impacts of IRLS

To confront inequities resulting from biases in engineering applications and a lack of awareness of social impacts of biased engineering practices, African American engineers must gain agency (the capacity to lead and act) and provenance (a sense of historical ownership) in the profession. We suggest that an established IRLS context would positively impact student experiences at HBCUs, and, with localization considerations, any other type of institution. Agency and provenance are fundamental to the development of an engineering identity. Numerous studies reveal a distressing systemic pattern of a lack of engineering identity among African American students who express interests in engineering or who are pursuing engineering majors (Aschbacher, Li, & Roth, 2010; Gilmartin & Aschbacher, 2006; Do & Schallert, 2004; Moore, Madison-Colmore, & Smith, 2003; Oyseman, Bybee, & Terry, 2006; Tate 2005). It is no surprise that engineering provenance and agency are not integrated in the developmental progression of African American high school students, especially class minorities. These students report a sense of disempowerment throughout their STEM high school preparation, and, at some universities, the sense of separation from the engineering profession grows more salient. We have failed to integrate students’ experiences and perspectives to an extent that would allow them to express their expertise, wisdom, and knowledge in an engineering context. We have continued to teach engineering as if it were “color-less” or accurate in its fundamental Euro-centric world view.

Engineering is socially-constructed; this is obvious when one reviews almost any introductory engineering textbook. The practice, tools, and knowledge domain were constructed by dominant majority social groups using theories, methods, and applications that are attributed to primarily European foundations. Students don’t learn about Ethiopian algorithms used to compute values quickly and with a high degree of accuracy. It is well known that most students are not taught the Arabic and African roots of algebra and calculus. One will not find a mention of engineers who used contextual disadvantage in communities to drive the engineering process --- Garrett Morgan (creator of the modern gas mask and traffic light), Madame C.J. Walker (a leading African-American entrepreneur, philanthropist, and political/social activist), and Jan Matzeliger (inventor of machinery to greatly reduce the cost of footwear). While not recognized in their time as “engineers” these researchers and inventors used lived experiences in context and used

their own sense of self or identity to create, prototype, and evaluate innovative technologies to enhance quality of life and equitable access. In sum, they reconciled the advancement of technology with a narrative identity grounded in the need to give back, save lives, and enhance quality of life. These “inventors” used a sense of provenance of context and agency within society to engineering solutions important to various populations. We hypothesize that this provenance and agency can be cultivated in all African American youth and may serve to motivate and sustain interest and passion for engineering.

To select and persist in engineering, African American students need opportunities to reconcile narrative identities that conflict with biased value systems introduced by the social construction of engineering. IRLS can provide these opportunities. Currently, the value proposition of engineering is not aligned with what is of value to African American students. Many examples in the classroom indirectly communicate values of individualism, advancement of certain groups over others, and outcomes that are beneficial to advantaged subsets in the population. Second, these students need tools to assert academic equity in majority-dominated engineering ecosystems to shape the discipline and profession to be more inclusive and equitable. This “acquired status of privilege” requires an effort to enhance agency and provenance by focusing on academic self-efficacy and narrative identity. IRLS might help to confront the problem of *leaky pipelines* or *failed pipelines* through the expansion and integration of new ways of understanding engineering.

4. IRLS Design Requirements

Recall IRLS as a sociotechnical system with four primary features: environment, personnel, technology, and the organization. Thus, there are design requirements for IRLS to facilitate effectiveness and continue the research community’s exploration, further study, and hypothesis generation. IRLS should be designed to support academic mastery in engineering by using research training, mentoring, and advising as tools or “social technologies.”

Combined with the aforementioned persistence factors of social responsibility and mentoring, empirical studies of high school students reveal several experiences associated with persistence and academic mastery relevant to science and engineering careers among under-represented high school students (Bogue, 2012; Borman, Stringfield & Rachuba, 2000; Johri & Olds, 2011; Neumeyer, Chen & McKenna, 2013). Important “push” factors to build a science and engineering identity and academic self-efficacy include:

1. Encouragement from families and counselors;
2. Successful application of and reinforcement of knowledge to solve meaningful problems of immediate impact on their communities (such as repairing broken appliances in households, bias in the criminal justice system);
3. Academic climates supporting safe spaces to question biases and terminology in conventional STEM knowledge and practice;
4. Reinforcement of science and engineering identities in multiple communities: school, family, extracurricular activities, religious organizations, etc.;
5. Skills to successfully navigate stereotype threat and academic micro-aggressions; and
6. Opportunities to experience STEM concepts as affirmations of service-centered values and self-integrity (aligning engineering problem solving with personal values).

There is also a basis to assess and evaluate all students who participate in an IRLS to further improve the undergraduate research experience. The following National Academies concepts (National Academies, 1991) could be used as metrics and indicators to determine whether the IRLS facilitated provenance and agency among student researchers. These include whether students:

1. Understand the potential of engineering to uphold the dignity of humans and society;
2. Comprehend the need to avoid negative side effects and by-products from inequitable engineering practices;
3. Express belief in the need to avoid perpetuating systems that already introduce inequities rather than continue to try to improve these systems through incremental solutions (Bugliarello, 1991);
4. Communicate perceptions of minimized stereotype threat as an African American engineer; and
5. Express a desire to engage in the social construction (or reconstruction) of the engineering profession.

4. Conclusions

While our exploration of IRLS is in the early stages, the time is ripe to go beyond our anecdotal knowledge and experience and test the short and longer term impacts and effectiveness of this model. Engineering-focused learning communities across multiple sites will be useful in developing new theories and approaches, as well as in assessing differential impacts on students while also continuing to broaden inclusive practices.

Some caveats are important to note. African American students, like any other social grouping considered, are not homogeneous across the categories in Figure 1. All social groups have embedded multicultural identities and forms of intersectionality. They are all unique and hold attributes that are not reproducible on the individual level. This adds layers of complexity, but does not undermine the prospective benefits of IRLS. This heterogeneity also shows promise to benefit many other students from many other backgrounds, including majority group members as well.

Another caveat: anyone can learn to develop and implement an effective IRLS. While lived experience matters in terms of the quality and rigor of research, any researcher can learn and understand social attributes and their role in engineering research. Researchers without the lived experience may not acquire in-depth understanding of the nuances, but other researchers (students, faculty) with lived experience will provide the expertise. This take on using lived experience as an element of expertise redirects the frames of engagement that often underpin perceptions of underrepresented students, and particularly African American students, from a social deficit or inferiority status bias. Lived experience is an element of expertise, and should be viewed as assets to improve the quality of research and technological innovation.

One final caveat is that IRLS, as discussed here, have been framed within a national, USA-centric perspective. While one of the authors has eight years of experience living abroad, she has only experienced academic research climates originating from the perspectives of the USA. Of interest would be the replication of IRLS in countries other than the USA, which also have social stratifications driven by many of the aforementioned attributes (cultural, circumstantial, dispositional, and educational). These countries may also struggle with inequities arising from ascribed minority and majority status of specific groups. Some practices may be generalizable, but it is likely that some will not be generalizable, and will require significant modifications to localize an IRLS.

IRLS should evolve and improve as institutions and faculty increase their cultural competence. Unit climate (department, college/school, lab, center, etc.) is essential, and follows from institutional culture. Organizational culture (or what we say) espouses the values and beliefs of diversity and inclusion expressed through core values, mission statements, strategic plans and other communications. But, organizational climate is what we actually do; our actions that demonstrate an authentic commitment to what we have said. IRLS can only work successfully if BOTH culture and climate are consistent with diversity and inclusion. A useful organizing framework is provided by the Association of American Colleges and Universities (AAC&U; Figure 2).

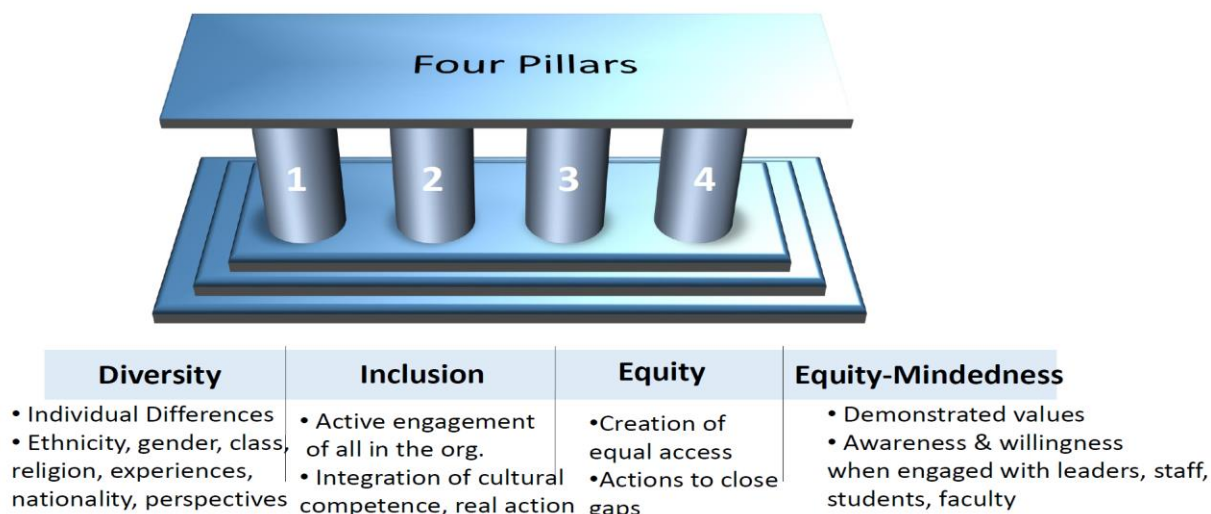


Figure 2. Four pillars to organize the establishment and assessment of climate (AAC&U).

There are many areas that have to be addressed using these four pillars as assessment opportunities to improve the overall context in which IRLS might be designed, implemented, and evaluated. A list for further thought is provided here.

- 1) College preparation and recruiting programming
- 2) Admissions
- 3) Advising
- 4) Curriculum
- 5) Town-Gown relationships
- 6) Housing and Residence Life
- 7) Experiential Learning
- 8) Job Search and Professional Development Support
- 9) Staffing
- 10) Alumni Relations

Just as IRLS cannot be fully or appropriately implemented without consideration of the sociotechnical classification system introduced in Figure 1 that helps to define participants, it also cannot be fully or completely implemented in an organization that is not ready for inclusive excellence. All of the entities, activities, and constructs that appear in the list above, from college preparation and recruiting, from matriculation to graduation across all of the functions that touch the lives of students, to on-going alumni relations with graduates, must be fully prepared to embrace difference. Unless the four pillars of diversity, inclusion, equity, and equity-mindedness are present across all of the various endeavors that make up modern universities, IRLS will not find the fertile ground that it needs to fully flourish. The journey that we are recommending is not a simple one, but the strong benefits of IRLS to minority students appear to provide sufficient cause to undertake the journey. The destination may be one in which our increasingly diverse nation and world can take advantage of contributions from previously marginalized groups to advance society in ways that may not have been previously possible. This seems to be a journey worth taking.

Acknowledgements

Some of this work is based on an action learning project through the Center for the Advancement of STEM Leadership (CASL), which was supported by the National Science Foundation through the Historically Black Colleges and Universities Undergraduate Program (HBCU-UP). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Thanks to Katherine McGraw, the writing coach supported by the CASL project who provided feedback on the abstract for this paper, and Goldie Byrd, who served as the CASL coach and mentor during the development of the inclusive research excellence concept, which is embedded in the Inclusive Research Learning System concept.

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