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Framework to Enhance STEM Education for Community College Students

Abe Zeid and Claire Duggan

ABSTRACT

Community colleges (CCs) play a critical role in advancing the education of all learners. Approximately 40% of first-time college freshman begin in Community Colleges. The proposed framework seeks to support and excite CC students to persist in their STEM education to increase the pipeline for the STEM workforce. Its vision is to provide CC students engineering skills and to excite them about engineering research. The framework enables students to spend 10 summer weeks at Northeastern University to increase skills, confidence, and learn firsthand about research. Each student will join a research lab, working with faculty and graduate student mentors. Also, students will be mentored after summer to further support their successful graduation and/or transfer to a 4-year institution and beyond. The site is guided by two of the grand challenges of the National Academy of Engineering: personalized learning and scientific discovery. Unique aspects of the proposed framework include: a hands-on short course in engineering topics and software tools; formal mentor training including modules for mentoring CC students; daily student meetings with mentors; extensive professional development seminars; formal research training including daily reflection journals, poster presentations and technical writing with a faculty member; and recruitment from a unique pool of highly talented URM students.

Keywords: Four-year Universities, STEM Education, Two-year Community Colleges, Undergraduate Research Experience

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I. Introduction

The National Science Board (NSB) Vision 2030 (Boroush, 2020) makes "A Case for Urgency" to support and expand the Science and Engineering ecosystem. Outlined in the report are three movements that threaten the nation's prosperity and future. These are 1. Globalization of Science and Engineering; 2. Growth of Knowledge and Technology Intensive Industries and 3. Demand for STEM Talent.

Worldwide there is an increased demand for talented Science and Engineering professionals. Opportunities span across geographic boundaries. By 2026 it is estimated that Science and Engineering jobs will grow by 13% compared with the 7% growth in the general workforce. (Boroush, 2020) Although the need for STEM expertise continues to be of critical concern, our rate of progress addressing challenges facing students, especially those underrepresented in STEM fields is slow. The growth of these jobs has far outpaced any progress made to bring more students into the engineering pipeline. For the U.S. to effectively address this gap, the NSB states for the Science and Engineering workforce to be representative of the overall population by 2030. Therefore, we must double the number of women, more than double the number of Black or African Americans and triple the number of Hispanic or Latinos entering the Science and Engineering workforce. We must radically improve the successful transition of underrepresented students from Community Colleges to either join the STEM workforce or transfer to 4-year institutions to further their education. Current data indicates 1:12 black students successfully navigate transfer and degree completion in comparison to 1:5 of their white peers. The Aspen Institute raised the question, "How can the U.S. increase STEM skills and opportunities for all Americans? The proposed framework is one model that seeks to address this issue. Building on the collaborative expertise of faculty and administrators engaged with multiple prior NSF grant efforts, we seek to implement and scale best practices supporting the engagement, graduation, and/or transfer of CC students to 4-year engineering institutions.

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In the context of the foregoing, the proposed framework engages multiple stakeholders: graduate mentors, faculty, administrators and partners to support of participants prior, during and after participation in summer research experience. Research engagement has been cited to be of significant influence on students underrepresented in science and engineering, particularly on their graduation rates and overall academic performance resulting in increased persistence. (Chand *et al*., 2014) Also, providing students the opportunity to build and expand their social and professional support networks also contributes greatly to their long-term success. The framework is designed to address three separate national critical needs:

- The low percentage of underrepresented students pursuing and persisting in STEM programs; (Jacobs, 2001)
- The national shortage of underrepresented students entering the STEM workforce. (NAE)
- The low rate of Community College (CC) students transferring to 4-year institutions in STEM fields; (Jacobs, 2001)

The framework will provide Community College (CC) students with a 10-week summer research experience working with faculty affiliated with the College of Engineering, engaged in research on topics pertaining to the National Academy of Engineering (NAE). The framework will focus on skills development to support long term success of CC students whether they join the workforce after they complete their CC education or continue their education by transferring to 4-year colleges to earn higher degrees. The main field of the research of the framework is Smart Engineering with four sub-fields of research: (1) AI/Machine Learning; (2) Smart infrastructures; (3) Smart materials; and (4) Smart health.

The intellectual focus of the framework is to provide 10 students annually, over 10 week summer session, with a comprehensive engineering research experience, seminars, lab experiments, and mentoring. The first week offers a workshop focused on building student's *engineering skillset.* Week 2 – 9 further support the students through continued weekly sessions, research presentations, and field trips in addition to opportunities to engage directly with University students that have successfully transferred from local Community Colleges. The 10 weeks are designed to provide tools and resources to support students long term academic and career success. The framework seeks to engage students in pre, during and post programming specifically designed for them to: (1) learn and develop new skills beyond what they typically learn at their home institutions; (2) increase their chances to join the workforce; and (3) engage them to think about transferring to four-year institutions.

II. Student Activities

Student activities are designed to maximize and customize the learning experiences of participating students. The activities are divided into two sub-activities: (1) working on a research project in a research lab, and (2) working on an open-ended engineering design project in the First Year Engineering makerspace lab. Students will indicate the research project they are most interested in working on in their application and confirm after introductory presentations by participating faculty. In addition, students will develop their own engineering design project.

Participating faculty and supporting graduate students who will interact with CC students have extensive experience working in a culturally competent manner, dealing directly with undergraduate students, as many previously have worked with Community College students. All faculty and graduate student mentors will participate in an introductory workshop on Diversity, Equity and Inclusion. A similar workshop will be also offered to all program participants.

III. Student Recruitment

Students will be recruited from local CCs. Program information will be distributed through electronic postings, direct mail and through workshops, and classroom visits to partnering CCs throughout the fall semester. CC partners faculty will also help in recruiting applicants from their respective institutions. Students will prioritize their research selection in their application and confirm after final introductory research presentations.

Recruitment for the 10 students will be from the partner institutions (see Table I) and other local community. Priority will be given to students from partner institutions. There will be an emphasis on the identification and recruitment of students underrepresented in STEM fields including but not limited to female, low income and first-generation college students.

TABLE I: Student Demographics of Partnering Community Colleges, as of Fall 2019

MA Comm. Colleges	Total Enrollment	Male	Female	African American	Hispanic
Northern Essex	5,233	39.0%	61.0%	4.0%	43.0%
Bunker Hill	11,769	43.0%	57.0%	25.0%	27.0%
Massbay	4,048	46.0%	51.0%	14.0%	20.0%
Middlesex	10,957	39%	61%	7.9%	17.1%

Source: Massachusetts Association of Community Colleges web site accessed August, 17 2020 (https://www.masscc.org/about-mcceo/fast-facts)

IV. Student Selection

Along with the standard CISE common application (Anderson-Rowland, 2016) that will be utilized for this program, applicants will submit two letters of recommendation from faculty members and/or advisor and a position statement outlining their long-term interests in engineering. Applications will be reviewed by the Selection Committee of faculty and staff. CC faculty will serve on the Selection Committee. The committee will take into consideration a student's entire portfolio by examining course grades, extracurricular activity, leadership skills, letters of recommendation, and student essays

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V. Objectives of the Framework

The framework has the following objectives:

- Engage participants in an introductory workshop that introduces/enhances foundational engineering skills/competencies essential to long term student success in engineering.
- Expand the mentoring ecosystem developing at the host institution (Northeastern University) and integrate programmatic supports that foster persistence of students underrepresented in the engineering field. (skill development, support and motivation, mentoring and advising) (Stolle-McAllister, 2011) and (Stolle-McAllister, 2011)
- Strengthen relationships with local community colleges to enhance the pipeline of students completing engineering degrees to join the STEM workforce or transfer to 4-year institutions. The program will leverage the CISE Toolkit (Anderson-Rowland, 2016) for pre- and post-program surveys, and to assist in the identification and recruitment of potential students.
- Enhance and support mentoring practices at host institution, including sessions that will build cultural competencies and increase understanding of the diverse population of students during their academic course of study in a community college.
- Utilize partnerships with industry and government research facilities to enhance the summer experience of participants. Presentations and site visits have been offered by, but not limited to, representatives from NASA, GE Aviation, Reebok, Mayflower Wind, Goldman Sachs, Wayfair, and Google.
- Expose students to research in their academic experience to increase persistence in STEM.

VI. Details of Summer Program

Activities throughout the summer program focus on building research skillsets, mentoring careers in engineering, fostering a social cohort, and motivation of persistence in research and degree completion (Table II).

TABLE II: Schedule of Activities for Summer Program

Activity	Frequency	Dates
Design Project		
Introduction to SparkFun inventors kit, Makerspace lab	4 Days	Week 1
Design project work	Weekly	Week 2 – Week 10
Research Project		
Research Presentations by affiliated and other Faculty	weekly	Week 2 – Week 10
Focused research activity: 9 – 12/ 1 – 4:30 p.m.	Daily	Week 2 – Week 10
Poster Presentation	1 event	Week 10
Write research contract	1 event	Week 1
Prepare final abstract	1 event	Week 9, 10
Optional: Publish review paper with lab team	as needed	Fall and Spring Semesters after REU
Mentoring and Student-Faculty Interaction		
Individual Meetings with Research Professor	Weekly	Week 2 – Week 10
Lab Meetings with Mentor (graduate student)	Daily	Week 2 – Week 10
Group networking Meetings: homeroom and/or lunchtime	Daily	Week 2 – Week 10
Research Reflection Journals and weekly status reports	Weekly	Week 2 – Week 10
Careers and transfer to 4-year colleges	Through program	Week 2 – Week 10
Poster Session/Final Presentation	Last Day	Week 10
Field Trips/Industry visitors	Through program	Week 2 – Week 10
Optional: Transfer Mentoring	as needed	Following academic year

The program activities are shown in Table III. We will cover two distinctive areas during the 10 weeks: technical and social. The technical area includes conducting research and developing design projects. The social area includes developing communication skills, personal growth, networking, and ethics. As such, Week 1 is designed to focus on SparkFun learning required to conduct design projects and use makerspace lab during Week 2 – 10. Week 1 is also designed to acquaint students with the host institution and help them connect/network with faculty and students mentors.

Weeks 2 – 10 will focus on developing social skills, in addition to research and engineering. "soft" skills" weekly sessions are planned during these weeks. Sample topics covered in these sessions include DEI, Ethics, Guaranteed 4.0, graduate school workshop, updating your LinkedIN profile and resume, preparing final presentations, and developing a poster, to name a few. Participants will also have additional research seminars they will be invited to over the course of the summer in collaboration with other programs.

We will utilize a weekly status report/powerpoint throughout the summer program. This format has worked very well with past students. It allowed students to build their presentations as the weeks progress.

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TABLE III: ACTIVITIES OF WEEK 1 WORKSHOP

Day 1	A.M. – Overview of Engineering Lunchtime – introduction of research partner faculty P.M. – Intro to SparkFun kits (installing Arduino on laptop, circuits, setting up RedBoard & breadboard, basics of Arduino, SparkFun Tutorial Circuit 1A: Blinking LED light)
Day 2	A.M. – SparkFun Circuits 1B & 1C: Potentiometer; Photoresistor Lunchtime – Networking lunch – peer mentors P.M.- SparkFun Circuits 1D & 2A: RGB Night Light; Piezoelectric Buzzer
Day 3	A.M. – SparkFun Circuits 2B & 2C: Digital Trumpet; Simon Says game Lunchtime - session with research mentors P.M. – SparkFun Circuits 4A & 4B: LCD Hello World, Temperature Sensor.
Day 4	A.M. – data sampling with SparkFun (modify Project 4B Temperature Sensor) Lunchtime – Lunch with peer mentors & data collection around campus P.M. – SparkFun Circuit 3B: Ultrasonic Distance sensor, "smart" museum security system
Day 5	A.M. – Laboratory Safety presentation; Research Contracts Lunchtime – Networking lunch with faculty/research mentors P.M. – STEM Social Event with faculty/research mentors/students and peer mentors

VII. SAMPLE RESEARCH PROJECTS

We have selected 10 research projects in contemporary cutting-edge research area of Smart Engineering. Research projects focus on such areas as AI and ML (Machine Learning), smart health, smart materials, and smart infrastructures. sample four projects are listed below. The first project in AI and ML and the second project is in smart health, the third in smart materials, and the fourth in smart infrastructures. These projects are conducted and led by active research faculty with prior experience of guiding and mentor CC students. The faulty host and mentor the students in their research labs, with the help of their own graduate students.

Project (1) – Analog Computing Simulation Tool for Machine Learning Inference in Edge Biomedical Devices (Zaeimbashi, 2021) and (Zhang , 2020)

Project Description: Wearable and implantable biomedical devices continue to disrupt healthcare through the development of continuous sensing and monitoring, timely medical intervention, efficient and tailored drug delivery, and reduced medical cost. However, a significant technological gap exists when it comes to adopting ML (machine Learning) based solutions for wearable and implantable biomedical devices. Power consumption and hardware requirement make it challenging to integrate ML solutions in existing mobile health technologies. This project aims to develop ML based hardware solutions for mobile health technologies.

Learning Objectives: (1) develop basic understanding of basic ML algorithms; (2) develop software coding skills with the development of Matlab codes; (3) develop skills in technical writing and presentations.

Role of the participating student: (1) Model and evaluate analog computing circuits to be used for ML network; (2) Model and evaluate nonidealities in analog computing and its impact on network performance.

Expected Learning Outcomes: (1) learn about the use of Machine learning to conduct simulation analysis; (2) apply Machine Learning in mobile healthcare applications; (3) gain basic coding skills in MATLAB.

Project (2) - Endothelial Mechano-Biology Research (Mensah, 2020) and (Harding, 2018)

Project Description: We seek to define endothelial cell and glycocalyx mechanisms of blood vessel regulation by solid-fluid mechanics. The project tests the hypothesis that fluid (blood) and solid (blood vessel wall) forces cooperate to regulate endothelial cell behavior via the glycocalyx, a sugar complex that is anchored to and coats endothelial cells and can convert fluid and solid force stimuli into cellular responses. Endothelial cells lie at the vascular fluid-tissue interface and play an essential role in maintaining blood vessel health. An incomplete knowledge of endothelial cell mechanobiology mechanisms results in limited vascular disease prevention and treatment efficacy. This project will address this critical knowledge gap.

Learning Objectives: (1) Characterize glycocalyx architecture; (2) Link glycocalyx structure to cell molecular mechanisms; (3) Clarify how molecular stimuli evoke an endothelial cell response that impacts production of nitric oxide, a vasodilator.

Role of the participating Student: (1) design and conduct rigorous research in the areas of bioengineering and endothelial mechanobiology: (2) collect and access relevant data; (3) create written and oral presentations of study results.

Expected Learning Outcomes: (1) apply interdisciplinary fields to research; (2) design of experiments and data interpretation; (3) responsible and ethical conduct of research; (4) technical communication

Project (3) – Relating Carbon Nanotube Network Structure to Mechanical and Viscoelastic Performance (Liu, 2015) and (Hill, 2014)

Project Description: Vibration damping by structural materials is a critical requirement for creating a comfortable consumer experience and for protecting everything from soldiers to bridges. In particular, we need stiff, strong, lightweight materials that also dissipate energy effectively through viscoelastic deformation, but current materials are largely an either/or compromise between load bearing and vibration damping. This research project involves mechanical characterizations over a range of loading frequencies, amplitudes, and temperatures plus structural characterization coupled with deep learning to reveal the structure-property relationships.

Learning Objectives: (1) understand how mechanical testing elucidates energy dissipation; (2) predict the effects of network structure on energy dissipation; (3) predict the effects of network structure on storage modulus.

Role of participating student: (1) evaluate how energy dissipation varies with loading amplitude; (2) evaluate the dependence of storage and loss moduli on network structure through dynamic mechanical analysis testing.

Expected Learning Outcomes: The student will (1) gain knowledge of carbon nanotubes; (2) know how to conduct mechanical testing; (3) evaluate mechanical properties of carbo nanotube network structures.

Project (4) – Designing Sensor Systems that Support Smart Operations of Environmental Infrastructure (Snuffer, 2019) and (Mueller & Hemond, 2016)

Project Description: The Environmental Sensors Lab is actively engaged in research thrusts related to stormwater, wastewater, aquaculture, and coastal environmental protection. Water chemistry is important in all of these scenarios, to ensure that infrastructure and anthropogenic activities do not adversely impact surface water quality. A major research challenge is designing sensors that operate correctly in these very different and sometimes chemically challenging environments. This lab is working on (1) design of novel printable nutrient sensors, and (2) developing advanced data analytics approaches that can integrate expert knowledge (for instance, about water chemistry) with sensor measurements to report usable information to city managers and citizens.

Learning Objectives: (1) learn about experimental design as applied to studying the environment; (2) gain experience in lab work; (3) understand how to integrate and compare datasets with different sampling rates and levels of uncertainty.

Role of participating Student: (1) participate in lab and field testing of sensors and sensor arrays in stormwater sewers; (2) collect physical water samples, (3) perform lab analysis of samples; (4) compare results of lab analyses with sensor readings.

Expected Learning Outcomes: The students will acquire these skills: (1) use smart sensors; (2) conduct sampling collection and analysis; (3) use advanced data analytics methods.

VIII. Post Program

Participants will be invited to open seminars on participating institution campus in addition to continuing several meetings each semester with their peer-mentors. Faculty/mentors will also schedule visits to CC partner classrooms throughout the academic year. CC partner faculty will also advise participants from their home institutions.

IX. Mentor Training

Northeastern University Center for Advancing Teaching and Learning through Research (CATLR) provides multiple workshops throughout the academic year to faculty and graduate students. In addition, our ADVANCE office, will facilitate several sessions utilizing resources developed through the Center for the Improvement of Mentored Experiences in Research (CIMER) and informed by best practices (National Academy, 2020). Collaborating faculty and their affiliated graduate students will attend an introductory workshop that will outline program goals and expectations. Bi-weekly networking meetings will take place to allow for further discussion and reflection of their mentoring experience.

X. Mentoring Participating Students

Continued and sustained contact with CC students is essential to support their academic and career success. (Shapiro, 2017) In addition, it is essential that mentees be guided to outline their short- and long-term goals and learn strategies to make the most of the mentoring experience. Participants will meet daily as a cohort with program leadership and peer mentors in addition to meeting directly with their research mentor. They will meet with faculty weekly through attendance at research team meetings. We will also create a LinkedIn Group for participants to join to facilitate continued interaction between students, mentors and faculty.

XI. Evaluation of Framework

We will provide formative and summative evaluation of the framework on the extent to which it is effective at achieving its near- and longer-term objectives and goals. We will operationalize outcomes, construct a logic model, develop sampling frames, adopt or adapt assessment instruments drawn from the CISE Toolkit (Anderson-Rowland, 2016), and implement data collection procedures and data analysis strategies. Using the CISE resources, we will identify resources most germane to the target constructs and revise these resources to tailor them to the proposed framework. The CISE "a la carte" tools to be used to measure the framework target constructs will be those focused on self-efficacy, intentions to continue in engineering, participant growth in research skills and knowledge, and the value of formal mentoring and social learning. Suitably anonymized data using these tools will then be available for inclusion in cross-projects analyses by the CISE team.

Key evaluation research questions include:

1. How meaningful do the participating students find their lab-based work and how readily are they able to access critical support resources?
2. Do participating students actively participate in the many project activities? What value and meaning do the students attribute to their lab and other related experiences?
3. Do participating students who are better connected to their mentors and others in the Pathways community report better outcomes?
4. What are the prospects for the transfer of learning back to the home institutions?
5. How are the participating students' future study and careers affected by their university experience?

6. Are some groups more strongly affected than others? What are the enduring effects attributable to the research experience?

Reporting will occur with every wave of data collection. All reports will include a clear explanation of methods and findings, along with recommendations for the project to consider. These data collection efforts and reports will strictly follow the university IRB policies and will meet the funding agency requirements

XII. CONCLUSION

This paper addresses the need for future workforce that is better trained in the emerging areas of smart engineering. Community colleges (CCs) main mission is to serve as the pipeline to the workforce. Students graduating from CCs must keep up with the emerging technology and labor market needs. This paper addresses the need by presenting an innovative framework where CCs work with higher education institutions to train CC students. Three local CCs have teamed up with a local R1 institution to implement and test the proposed framework.

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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