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BOOSTing preparedness through engineering project-based service learning

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BOOSTing Preparedness Through Engineering Project-Based Service Learning

Our College of Engineering, Computer Science, and Technology at California State University, Los Angeles is proud to serve a student body rich in first-generation college students and underrepresented Latino (74%). However, the 6-year graduation rate, while on the rise, is still at 38%. There is currently a 33% equity gap in 6-year graduation rate between underrepresented minority (URM) and non-URM students. An engineering design service learning based summer bridge was developed, with support from the National Science Foundation (NSF), for engineering majors in between their freshman and sophomore years. The goal of Bridge Opportunities Offered for the Sophomore Transition, better known as BOOST, was to help the engineering students at Cal State LA capitalize on their potential for engineering innovation and social capital.

During BOOST, teams of rising sophomores, with mentorship from faculty and near-peers, spend six weeks of their summer innovating and working collaboratively on Engineering projects which serve one of four highly impactful local community organizations. BOOST students experience the engineering design process from concept through to delivery, as well as peer mentorship and faculty interaction, while working on engineering projects, which serve their local community. The potential to meaningfully serve their communities while developing their engineering expertise inspired teams of rising sophomores, along with junior- or senior-level peer mentors to spend six weeks of their summer innovating, creating, and working collaboratively on multi-disciplinary Engineering projects, such as a portable stage for foster children to perform rock concerts at their residential campus, and computer games to teach fractions to 5th graders at a neighboring elementary school. BOOST was designed to help students identify more with engineers who care about their community, think critically and persevere to deliver engineering projects which serve their community. We present results here that indicate that we are beginning to meet those goals.

Service Learning in Engineering Design and During Freshmen-sophomore Transition

Most universities recognize that the transition from high school to college requires extra support and therefore offer college summer bridge programs. However, the transition from the freshman to sophomore year is a critical formational period and yet often neglected in student success initiatives [1-3]. The sophomore year is a defining moment in the college career, and also a time that is filled with uncertainty and a sense of losing support students had in their freshmen year [2, 4-6]. We recognized the need for students to strengthen their motivation, resolve, and capability to persevere through the challenges that tend to hit them particularly hard when they reach their first engineering courses, typically in their sophomore year. We hypothesized that service learning projects during the students' freshman-to-sophomore transition would address these needs and thus build engineering identity and improve their academic performance in their sophomore year, especially for students who start with low academic integration, which are typical Cal State LA students matriculating in engineering majors as freshmen. First generation college students make up 59% of our Engineering student population, and Hispanic students make up 61%. Studies have shown that the lack of academic integration of first-generation students is correlated with their lower persistence rates than those of non-first generation college students [7] and that academic integration, particularly through faculty interaction, is often lacking but can have a significant positive impact on persistence [7, 8].

Through the service projects, BOOST students gain practical exposure to engineering and experience the engineering design process. Furthermore, they are rewarded by seeing the benefit their work can bring to their community. Studies in non-STEM fields have shown that the focus on giving through service learning leads to academic success by addressing the sense of aimlessness and student disengagement that negatively impacts their education [9-11]. Ironically, until recently a vast majority of the service learning literature was in non-Engineering fields, such as sociology. The literature shows some very impactful service learning programs in Engineering, such as Prof. William Oakes' EPIC program at Purdue University, but which do not specifically target the freshman-to-sophomore transition [12, 13]. We therefore created a program that begins in the last term of the participants' freshman year, with a service learning Engineering Ethics and Professionalism course, and allows students to work on service learning projects for a local community organization in the summer. The design projects, with their inevitable need to revisit design choices, teach students to build grit and learn from mistakes through the iterative process of design, build, and test. It also builds their engineering identity, as they see themselves more as real-world problem solvers. The service learning aspect enables students to see the impact of their engineering abilities on their local community and motivates them to persevere through the challenges and rigor of engineering degree programs. The teamwork, peer mentorship, and faculty interaction required to carry out these service learning projects all contribute to building social capital which in turn enhances students' ability to thrive, especially for first-generation college students [14, 15]. Participation in service learning projects increases academic integration by building the students' identity as engineers, and helps students to see the impact their work could have on their community and how they could contribute to their team's success and morale.

BOOST Program Design and Overview

The BOOST program was designed to provide students with engineering design experience applied to serving their community. During the Fall semester, BOOST faculty recruited community organizations to "host" design projects for our students. We visited the community partners and together defined projects that would be of service to them and require engineering design.

Table 1 provides information about the partnering organizations and their missions, the projects BOOST students designed and implemented for the respective community partner clients, and other activities built into the program to engage students with community. Each project was assigned a faculty mentor and a peer mentor, who was a junior or senior majoring in the Engineering discipline which would be most applicable to the project.

Table 1) BOOST engineering design projects overview.

Partner Org.	**Mission / Focus**	**BOOST Design Projects**	**Other community engagement activities**
Rancho Rehabilitation	Provide affordable treatment and care for mobility impaired patients, and research in rehabilitation engineering.	* portable hand cycle frame for individuals in wheelchairs to exercise at home	* community wheelchair basketball tournament. * field trips to tour wellness center, discuss ideas, and try out prototype subsystems with clients
El Arca	Care for developmentally disabled adults.	* retractable patio garden cover * solar power system to power computer lab	* gardening with El Arca students under the BOOST retractable cover * playing games on BOOST solar-powered computers
Kennedy Elementary	Primary school education for a low-income, 99% under-represented minority community	* computer games to help 5th graders learn fractions * model of solar system with rotating and revolving bodies	* playing fractions games with the students * demo of moon phases with the BOOST model
Hillsides	Provide safe, caring environment for vulnerable youth.	* portable, collapsible stage for concerts and ceremonies * mobile app for special ed phonics exercise	* rock concert using BOOST stage * volunteer at "carnival" fundraiser for Hillsides

During the Spring semester of their freshmen year, BOOST students enrolled in a special section of Engineering Ethics and Professionalism, which is required for all Cal State LA Engineering majors. In this course, students learned about codes of ethics and moral frameworks which frame engineering design decisions. The course also provided an opportunity for students to get to know about the community partners and be introduced to the project. We took field trips to the community partner organizations and students were asked to share reflections on needs they identified, and hypothetical case studies were created out of the BOOST projects. The students also learned to communicate and interact professionally with the community partners. Students were assigned to project teams and met with the faculty mentors to begin forming team bonds and brainstorming conceptual designs, and discussing potential ethical issues that would influence their decisions. Since the Summer program was only six weeks, this preliminary phase during the Ethics course was very important to the program because it provided students with a good understanding of the partnering organizations and projects before the Summer session.

The main design and implementation component of the BOOST program took place during the first 6 weeks of the Summer session. A glimpse of a typical week during the BOOST summer session is given in Table 2. Because physics principles were applied in all of our BOOST projects and our students' performance in Physics is usually low (average DFW rate, or rate of Ds, Fs, and withdrawals, = 33%), time was allocated each week for solving a physics problem and/or a brain teaser. Faculty mentors also ran workshops on tools they would be using, including machine shop, SolidWorks, Arduino microcontrollers and breadboarding, and Simulink. Once a week, the teams gave oral presentations to update others on their progress and practice for the final presentation.

Table 2) A typical weekly schedule during the main (6-week Summer) BOOST component

<table>
<tr><th>Time</th><th>Mon</th><th>Tue</th><th>Wed</th><th>Thu</th><th>Fri</th></tr>
<tr><td>12:30 - 14:00</td><td rowspan="2">Analysis/ Problem Solving ET C18</td><td rowspan="2">Engineering tools workshops ET C254</td><td>Comm. / Presentation Workshop ET C159</td><td rowspan="2">Engineering tools workshops ET C254</td><td rowspan="2">Analysis/ Problem Solving ET C18</td></tr>
<tr><td>14:00- 14:30</td><td rowspan="2">Projects ET C159</td></tr>
<tr><td>14:30 - 15:00</td><td rowspan="3">Projects ET C159</td><td rowspan="3">Projects ET C159</td><td rowspan="3">Projects ET C159</td><td rowspan="2">Projects ET C159</td></tr>
<tr><td>15:00 - 16:15</td><td rowspan="2">Outdoor / Recreation</td></tr>
<tr><td>16:15- 16:30</td><td>Reflections</td></tr>
</table>

BOOST was piloted in 2016 and has run for a total of 3 summers. We present here the results obtained thus far from the first two cohorts. Assessment results on the 2016 cohort indicated that students greatly benefited from participating in design projects, providing service to their community, working in teams, peer mentorship, and interaction with faculty advisors. Most noticeably, the first cohort of BOOST students' engineering innovation and creativity scale increased by 50% (n =18, p<.01) according to pre-post-BOOST comparisons on Ragusa's ECPII validated scale [15]. In addition, BOOST students became more STEM-focused after BOOST than their matched control counterparts, and the BOOST experience provided some immunity to the typical "sophomore slump", in that the BOOST group's GPAs dropped from pre-BOOST (first couple terms of freshmen year) to post-BOOST (last term of freshman year through first term of sophomore year) by 49% less than their matched control group's average GPA (see Table 4). We are seeing similar trends from results of Cohort 2.

<u>Engineering Design Exposure</u>

Students were involved with the design and development of projects from tasks ranging from identifying needs and brainstorming designs to analyzing tradeoffs between design options, constructing, coding, and debugging. After brainstorming ideas and conducting a tradeoff analysis between their top design options, students iterated through a process of communicating their design to a designated project liaison from the community organization, receiving feedback from the liaison, and incorporating that input into an improved design; and students presented their final work at an event concluding the 6-week summer program. This correspondence and interaction with the community partner provides the students with an opportunity to practice professionalism and increases the professional manner in which they interact with their clients.

Table 3 gives several examples showing the engineering skills they developed, tools with which they gained experience, and the competencies that were utilized and developed in carrying out the respective project. Figure 1 depicts the type of design experience obtained by participating in BOOST. We outline the design process for the El Arca solar powered system project because we ended up expanding it to a 2-year project. The 1st year consisted of designing, sizing, and installing the system to power 4 computers in their computer lab. The next BOOST cohort improved the design by developing an automated switching system to detect the battery voltage and switch between the utility line and solar powered battery accordingly.

Table 3) Tools and engineering competencies related to each project

Project	**Tools**	**Engineering competencies**
Solar powered system	Solar panels, batteries, oscilloscopes, multimeters, breadboards, power supplies, etc. (i.e, electrical measurement and prototyping equipment), machining and drilling for the adjustable support frame, CAD, Simulink to test their calculations.	Framing problem as math / modeling; integration to compute energy supply and demand. Breadboarding, soldering, electrical measurements, debugging,
Automated photovoltaic – utility line power switching circuit	Power meter, electrical measurement and prototyping equipment, Arduino microcontrollers and boards, CAD for the circuit housing, orCAD, and PSPICE	AC, DC power, voltage protection, optoisolators, transistors, detection and thresholding, microcontroller programming, circuit schematics and layouts
Computer game to teach fractions	Adobe ActionScript, Scratch programming, flow charts	Planning program, abstract thinking, programming concepts – conditionals, loops, arrays, functions, call backs, objects, inheritance
Portable, collapsible stage	Bandsaw, drill press, sander, CAD / SolidWorks	Dimensioning, statics
Model of phases of the moon	SolidWorks, Arduino, construction tools, 3D printing	Motors, AC and DC power, microcontroller programming, gears, dimensioning

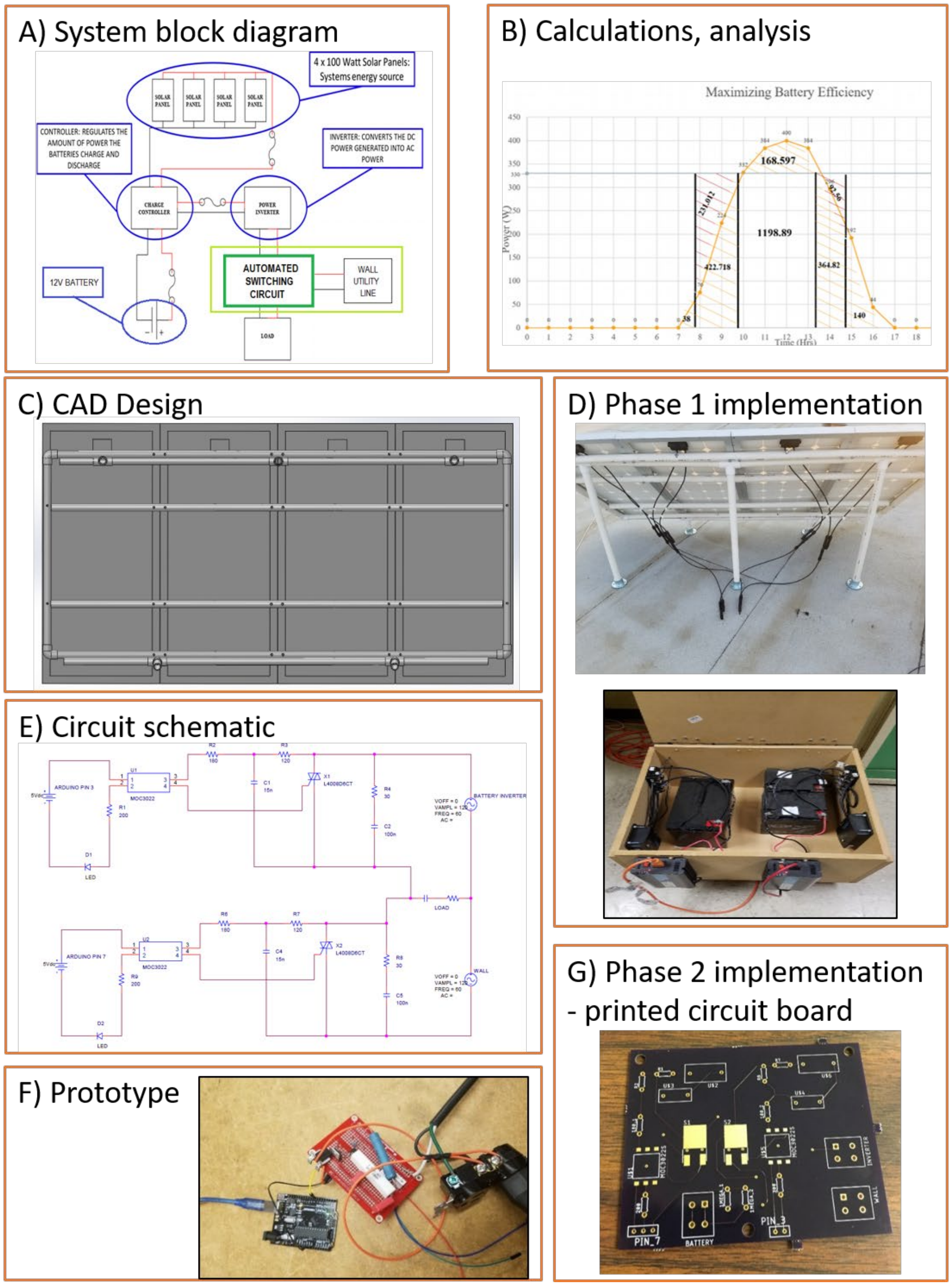

Figure 1) Example of the engineering design experience that BOOST students gain. The design process begins with conceptualizing the system with a block diagram (A), they perform calculations needed to carry out trade analyses to select the appropriate battery and number and type of panels (B), they carry out more detailed design, such as CAD drawings of the adjustable frame they must build to support the panels at the optimal angle (C), and then the students build the frame, wire up the inverters and battery, install and deliver the whole system (D). The second year, the students modify the system block diagram to incorporate their concept of the automated switching circuit, they iterate through many versions of circuit schematics (E) and prototype breadboarded and perf board circuits (F), and they finally build the circuit on their final printed circuit board version of the circuit (G).

The students gave an oral presentation at the conclusion of the 6 weeks to liaisons from our community partner organizations, faculty and staff in our College, including the Dean, and some members from industry who have partnered previously with our College in one form another. Many audience members expressed how impressed they were with our students' achievements and how much exposure they had to engineering design. One BOOST participant stated in an unsolicited email: "*I want to thank you for allowing me to be a part of the BOOST program again to increase my engineering skills in the real world. I have learnt so much especially learning how solar panels work. It is amazing how a group of students can make such an impact to our community and change lives. This program has been amazing and would recommend every incoming sophomore student to take advantage of this opportunity.*"

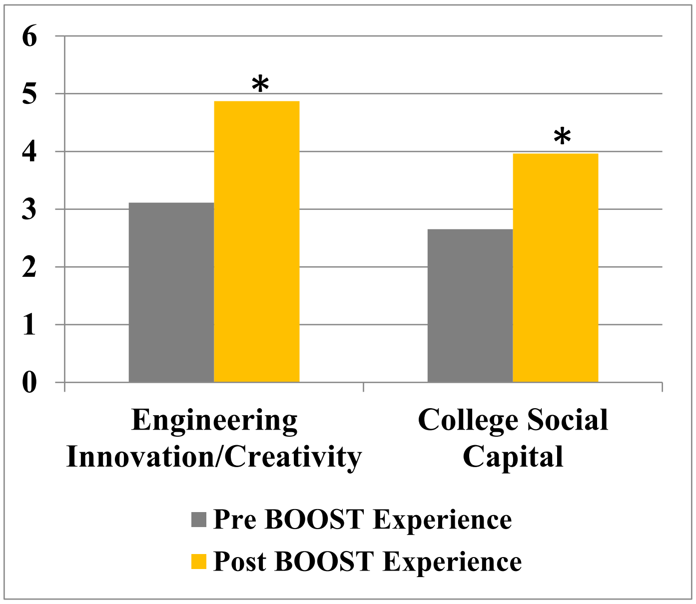

Figure 2) BOOST students scored significantly higher on validated scales measuring Engineering Innovation and Creativity (average 56% increase) and College Social Capital (average 49% increase). * $p < .01$

This and other similar comments made by BOOST students in casual encounters after the end of the BOOST program reinforce the quantitative survey data obtained. We administered a questionnaire on a validated scale (Ragusa) which tested their engineering innovation and creativity, college social capital, and engineering global preparedness. The students took the questionnaire before the BOOST summer component and 6 weeks later after their final presentations. The results revealed statistically significant increases after BOOST on all 3 scales, but the increases were most dramatic in engineering innovation and college social capital, as depicted in Figure 2.

	Su '16		Su '17
	Yr 1	Yr 2	Yr 1
	F '16	F '17	F '17
BOOST	-0.35	-0.17	-0.40
CONTROL	-0.69	-0.82	-0.96

Table 4) Changes in STEM GPA from before BOOST (during freshmen year) and after BOOST (during sophomore "Yr1" post BOOST and into junior year "Yr 2" post BOOST).

We also analyzed grade data. GPA in STEM (math, physics, and engineering) courses were calculated for BOOST students as well as matched controls. Control group students were selected based on a stratified propensity matching approach carried out by our Institutional Research office. In general, we aimed to have the same distribution of majors and ethnicity. A certain number of students to match students in these categories in the BOOST group were randomly selected from the cohort matriculated at the same time as the BOOST students were randomly chosen from that category – e.g., if there were 4

Hispanic Mechanical Engineering majors in the BOOST group, we randomly selected 4 Hispanic ME majors from the same freshman cohort. After the selection was done, we compared other demographic information. The control group had only 18% females as compared to 47% in the BOOST group, 58.8% first generation compared to 52.9% in BOOST, and an average Math SAT score of 539 vs. 493 in the BOOST group. Table 4 reveals that while our students generally suffer a "sophomore slump", or drop in GPA after their freshman year, BOOST students appear to have some immunity to this drop in GPA. The BOOST students' STEM GPA exhibited a 49-79% greater change from pre- to post-BOOST than the Control group.

Community Engagement

The impact of the BOOST experience went beyond their own academic achievements. The impact BOOST students had on their local community was undeniably positive. Here is some unsolicited feedback from our community partners:

"*We truly appreciate the partnership with CSULA. Thanks for exposing our students to their future!*" - Pete Preciado, Categorical Program Advisor/Targeted Student Population, Kennedy Elementary, after project delivery.

"*Thank you so much to you and your team for your hard work in building the stage. It is awesome!!*" –Robert Wherley, Education Specialist and Band Director, Hillsides, after project delivery.

"*Above and beyond what engineering experience you [BOOST students] are gaining… the long-term value is what you're doing for the community... for folks with developmental disabilities. This has turned out to be a great, great project. It's giving [adults with disabilities] the ability to build up more self-esteem, and giving them a vocational skill…. This is something that you really can't place a value on…. The Cal State LA students were awesome*". – Mr. John Menchaca, President & CEO, El Arca, Inc. at the BOOST final presentations.

Taken together, the quantitative results and the qualitative feedback provided by the community partners indicate that the BOOST experience helps students to identify better as engineers and to attain the intrinsic motivation and innovativeness that breeds successful engineers.

We were privileged to work with such passionate and caring community organizations. We repeatedly hear from BOOST students that one of the most rewarding aspects of their BOOST experience is being able to give back to their communities. BOOST students delivered projects which serve their community, and through presentations at the University and other outreach events, have raised awareness of various community needs, and of the specific community organizations with whom we partner, to a broader community. Meanwhile, BOOST students are motivated by having a real client they want to serve. They have therefore been willing to persevere through the challenge of engineering design. As one student put it during a focus group interview at the end of the summer "*The project [is] not just for us, but we were able to use what we learned to help other people*."

An open-ended focus group was conducted within a week following the conclusion of the program. According to the frequency of the classification of students' responses (Table 5), students felt they most benefited from BOOST due to team experiences, engineering design, application of engineering and technical skills, engaging with their community, mentorship and faculty guidance, and application of ethical principles.

Table 5) Frequency of focus group interview responses

Category	Yr 1	Yr 2	Yr 1+2	Example responses
Team Experiences	14	12	32%	"Our mentors they are like telling us, you guys need to work in groups, and I understand cause me as an electrical engineer, I cannot do the stuff that civil or the mechanical would do."
Engineering Design	9	7	20%	"It was really great to work with the professor designing things and building from designs." "I really liked the design time that we had.." "I think the design part was just right. Because, I mean the mentors explained to us when you're doing engineering, your first design isn't always going to be the right one. And that way we kind of got to see you know it's a process. You're going to have to make adjustments."
Application of Engineering Technical Skills	9	7	20%	"The best part was the workshops cuz we got to use what we learned classes to build and test our work ." "I call this engineering with a purpose,; my technical still s really got me far with the programming we did" "It's good cause uh just like what she said we are able to uh experience the hands on engineering project. Cause you know um in other classes we just did like in inside the classroom. " "I haven't even taken physics yet, but we're.. I'm learning it through the hands on process, and you get to learn um… kind of how the information you're learning in class is going to be applied in to the real life situation."
Service Learning/Community Experience	7	4	13%	"The look on people's faces when they saw your completed product. I will never forget it!." "You are really helping people and you see immediate benefits from your work. Especially team work. " "The project it's not just for us but, we were able to use what we learned to help other people." "Right, it's a cool place to work. You can see that you can really help people."
Mentorship/ Faculty Guidance	5	3	10%	"if we're like stuck on something. Like they'll take their time to actually explain every step by step. Making us

				feel like we're all on one team.“ “I really enjoyed seeing our students' faces when they got close to their finished products. It is something I will never forget.” “I plan to talk about mentorship in my job interviews.” "if we're like stuck on something. Like they'll take their time to actually explain every step by step. Making us feel like we're at home.”
Ethics	2	3	6%	"You have to be people first in designing things and listen to your customers.” "You have to consider others, safety and what their needs are in your design.” “Ethics is something that I am going to need to consider in the workplace. I got to try this first hand.”

Conclusions

A majority of BOOST students are first-generation college students, and almost no BOOST student had any previous engineering design experience prior to participation in the program. Yet, the first two cohorts of BOOST students completed seven substantial design projects which were all very well received by the community partners, and have already shown academic gains compared to a matched control group. Results from 2 cohorts (in 2016 and 2017) based on grades, a questionnaire measuring engineering innovation and social capital on a validated scale, and focus group interviews indicate that BOOST can help us work toward closing the achievement gap. Comparisons of BOOST participants with matched controls indicate BOOST students had higher pre-post changes in STEM GPA (-0.35 vs -0.69 for Cohort 1, and -0.40 vs. -0.96 for Cohort 2), and that BOOST encouraged students to persist through the challenge and rigor of the Engineering program.

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