Board 149: Pioneering Pathways for High School Students in STEM Education (Work in Progress)

Mr. Adam W Davidson, Duke University

Adam is a seasoned educator and Senior Laboratory Administrator for the Electrical & Computer Engineering (ECE) department at Duke University's Pratt School of Engineering. With a degree in Technology Education from NC State University, his journey in education began as a Technology Education teacher at Penn-Griffin School for the Arts and later as a PLTW Engineering Instructor and Fab Lab Manager at Riverside High School and Technology Equipment Coordinator for Durham Public Schools. His contributions to the field have earned him recognition as an Ultimaker Pioneer, National Board Certified Teacher, STEM Educator of the Year, and PLTW Outstanding Teacher of the Year.

Adam's dedication to STEM education extends beyond the classroom. He has repeatedly presented at Construct3d conferences, and presented at the STEM in the Park Industry Summit. He's also a contributing author, sharing his expertise in self-regulated learning and performance. His passion for education has led to the establishment of makerspaces in Durham Public Schools and the early adoption of 3D printing technology in DPS classrooms.

Outside of his professional life, Adam is a gaming enthusiast, Lego builder, artist, and an ardent reader. He and his wife share their home with two disabled cats and a disabled dog.

Looking ahead, Adam is committed to enhancing undergraduate lab spaces and curriculum, facilitating the transition from secondary to post-secondary education in STEM, and improving Teaching Assistant (TA) training. His mentorship and guidance continue to impact individuals, educators, and STEM enthusiasts, solidifying his role as a leader in the field.

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Kip D. Coonley received the Ph.D. degree in Electrical and Computer Engineering from Duke University, Durham, NC in 2023, the M.S. degree in Electrical Engineering from Dartmouth College, Hanover, NH, in 1999 and the B.S. degree in Physics from Bates College, Lewiston, ME, in 1997. Following graduation from Dartmouth, he developed electronically controlled dimmers for fluorescent and incandescent lamps at Lutron Electronics, Coopersburg, PA. From 2001 to 2005, he was a Research Engineer at RTI International, where he designed high-efficiency thermoelectrics using epitaxially grown superlattice thin-film structures. Since 2005, he has been the Undergraduate Laboratory Manager in the Department of Electrical and Computer Engineering at Duke University, Durham, NC earning the doctoral degree in 2023. His research interests include undergraduate engineering education, energy harvesting, RFID, power electronics, plasma physics, and thin films.

Pioneering Pathways for High School Students in STEM Education (Work in Progress, Diversity)

Abstract

Our program aims to impact local high school students by highlighting engineering as a vital component of STEM education and building bridges to college life. A distinguished high school known for its robust engineering program serves as our partner, with a focus on underrepresented students. Our goal is to provide high school students with a taste of college-level engineering experiences and promote their interest in STEM fields. We successfully hosted 15 students, of whom 9 identified as underrepresented, including LGBTQIA+, women in STEM, and minority students. Most students enjoyed and highly valued their experience. Teachers were supportive and recommended expanding the program to other schools.

We adapted a college-level lab experience to make it more accessible to high school students and enhanced the campus tour to provide them with a holistic view of university life. We have found that the key takeaway from this initiative is the ease and success of the endeavor. Our program represents a new contribution to pre-college engineering education by providing high school students with hands-on exposure to engineering concepts and a glimpse into life as college students. Our future plans include making this an annual event, expanding it to other schools and student communities, and improving non-lab activities to further engage underrepresented communities.

This program aims to increase the diversity, equity, and inclusion of all students in STEM education, and we are committed to enhancing the experience for both students and teachers. By fostering early interest in engineering and STEM, we hope to encourage more students to pursue these fields and bridge the gap between pre-college and college education.

Keywords: STEM, PLTW, CTE, electrical and computer engineering, self-regulated learning, high school educators

Introduction

A call by professional organizations including the American Society of Engineering Educators (ASEE), the National Academy of Engineering (NAE) and others has been made to increase the participation of underrepresented students with new educational approaches that focus on early exposure through the integration of hands-on, interdisciplinary curricula, and socially relevant science, technology, engineering, and mathematics (STEM) aspects into school curricula [1, 2]. Furthermore, it has been demonstrated that the more students participate in hands-on problem solving, the more likely they will be to use what they have learned later on [3]. Also, research has shown that "[c]oordinated collaborations between schools, universities, industry, as well as engineering organisations[sic] and governments are needed to broadly expose and introduce young pre-college students to engineering" [4]. Finally, it has been recognized by the National Science Foundation (NSF) that teachers have an outsized influence in steering students toward an interest in STEM [5].

The breadth of outreach methods for K-12 students has included in-school programs, after-school programs, summer programs, on-campus programs, apprenticeships, and field trips [4, 11, 12]. Seminal work spanning two decades has discovered that a key to students' pursuit of STEM fields is to develop their interest at an early age. And that "themes such as the design of robots" provide effective strategies to develop this interest. Arduino microcontroller platforms, in particular, have been shown to encourage "tinkering," a broad term for making in which students apply their knowledge creatively and iteratively to a design task [13]. Project Lead the Way (PLTW) (http://www.pltw.org) is one such multiyear sequence of engineering courses that has shown strong, positive impact on mathematics and science achievement implemented in all 50 states in the US in over 12,000 high schools. This research adds to previous studies where PLTW work was similarly applied [12, 13]. Furthermore, offering these experiences free of charge and in a comprehensive manner such that not only cost but also transportation barriers are eliminated is imperative to participation success [4, 13].

This work reports on the initial results of a work in progress field trip with a local area high school where the school educator was deeply involved in the hands-on project selection to serve their existent 11th–12th grade engineering curricular cohort.

Methods and Data Collection

The field trip was offered free of charge to 15 students who are part of a PLTW certified high school engineering program. It was limited to a 4-hour university visit during the regular academic semester. Students worked in teams of two. A certified university instructor introduced expository and inquiry-based learning through a prepared Arduino robot experiment with four sensory options. Following this introduction, the student teams were guided by a trained and experienced university teaching assistant in the hands-on implementation of the experimental exercises. Activities were not graded. Learning from failure was encouraged.

Pre- and post-trip surveys were completed by students. Students identified their interests, the exercises attempted, and whether they liked or disliked them. They were asked to provide their overall comments and thoughts on improving the experience. The educator who attended the field trip also completed a post-trip survey and provided further feedback during a follow-up meeting two months later.

Project Context: An On-Site Laboratory Experience for High School Educators

Our outreach effort was made to Riverside High School (RHS), a Durham, NC Public School (DPS)-supported Career and Technical Education (CTE) pathway institution. RHS offers PLTW's Pathway to Engineering (PTE) and Computer Science (CS) curricula, emphasizing Science, Engineering, Technology, and Math (STEM) in all aspects of its engineering education. In an effort to focus on what the school educator most needed with the least impact on time, a pre-trip meeting was organized to 1.) identify which course completions and student cohort would benefit the most, 2.) select a rigorous but accessible laboratory (Appendix A) from the first year undergraduate-level Electrical and Computer Engineering (ECE) course at Duke University [14] 3.) determine that an interest flyer (Appendix B) and 4.) pre-trip survey (Appendix C) with targeted outreach would be implemented to advertise the experience and capture interest data.

Table 1 shows data from the pre-trip survey (Appendix B). It highlights students' year and breadth of PLTW course (Appendix D) experience, underrepresented group information, interests in STEM courses and areas, and interests in the experience. As can be seen in the *Yr.* column, of the 15 responses, 33% were 12th graders and 66% were 11th graders. From the *PLTW Courses* column, 93% completed or were enrolled in Introduction to Engineering Design (IED), 73% Principles of Engineering (POE), 53% Digital Electronics (DE), 53% Computer Science Essentials (CSE), and 20% Computer Science Principles (CSP). These encompass the foundational courses of the PTE and CS pathways. Additionally, 7% of the students completed or were enrolled in Civil Engineering and Architecture (CEA), an advanced PTE course. The *Group/Community* column shows that for the 9 students who identified as underrepresented, 33% indicated minority, 20% LGBTQIA+, 13% woman, and 6% neurodivergent.[1] Also, as shown in the *STEM Rank* column, the data also indicates that students were most interested in the engineering and math STEM fields. Finally, the *Field Trip Interest (FTI)* column indicates that students were most interested in the laboratory experience portion of the field trip by ranking it the highest.

[1] Note that one student selected *not listed* and wrote in 3 self-identifying communities: *LGBTQIA+, minority, and neurodivergent*. That data, therefore, appears in all 3 categories in Table 1.

Table 1: Participants Pre-Trip Survey Data

YR	PLTW Courses						Group/Community				STEM Rank				FTI Rank		
	PTE				CS		Min	LGBTQ	Female	Neuro	S	T	E	M	Lab	Tour	Food
	IED	POE	DE	CEA	CSP	CSE											
12	X	X	X		X			X			2	4	1	3	1	2	3
12	X	X	X		X		X				1	2	3	4	3	2	1
12	X	X	X		X				X		4	1	3	2	1	3	2
12	X				X		X	X		X	3	1	2	4	1	3	2
12	X										3	2	1	4	3	1	2
11	X	X	X				X				4	3	1	2	1	2	3
11	X	X	X								1	4	3	2	1	2	3
11	X	X	X					X			4	2	1	3	1	2	3
11	X	X	X		X	X					3	1	2	4	1	2	3
11	X	X									4	1	2	3	1	2	3
11	X	X		X	X	X					3	4	1	2	2	1	3
11	X	X			X						4	3	1	2	2	1	3
11	X	X				X			X		3	4	2	1	2	1	3
11	X				X		X				4	3	2	1	1	2	3
11			X				X				1	4	2	3	1	2	3
%	93	73	53	7	53	20	33	20	13	7	4	4	{1,2}	2	1	2	3
TOT	14	11	8	1	8	3	5	3	2	1	Modes						

Addressing the Need: The Field Trip Experience

The field trip consisted of 1.) the pre-approved laboratory, 2.) a tour of the engineering school, and 3.) a provided lunch. Upon arrival, participants were welcomed and sat around a large table in the middle of the lab where they encountered several pre-built Arduino robots. Sensors and displays were made available in the lab. Following introductions, the 15 students were split into two groups: Group A (8) engaged in the laboratory experiment first while Group B (7) was taken on the engineering tour first. This arrangement was mirrored at the 1 ½ hour mark. The laboratory experiment was led by a university-trained undergraduate teaching assistant. Students were told that they should try to complete at least one of the experimental exercises, but were encouraged to attempt as many as possible. Student learning was self-regulated: trying first and discovering the results. The tour was led by a trained undergraduate university student tour guide.

The Student Laboratory Experience: Results and Feedback from the Participants

Of the 15 student participants, 87% started the survey but only 47% finished. Table 2 shows participant experimental exercise ratings and feedback. It was noted during the self-regulated learning process that students hesitated until their first success, which lead to students sharing their success with other attendees during the field trip. Of the 15 students, 27% attempted the Hall effect & LED exercise with 3 liking it and 1 disliking it, 47% attempted and liked the Color Sensor & RGB LED exercise, and 33% attempted and liked the Thermal Sensor & Piezoelectric Speaker exercise, as well as, the RFID & 16x2 LCD exercise. Students also provided specific and overall comments on the lab exercises, which are abbreviated in Table 2.

Table 2: HS Students' Experimental Exercise Comments

Group	Hall Effect & LED		Color Sensor & RGB LED		Thermal Sensor & Piezo Speaker		RFID & 16x2 LCD		Overall Comments
	Like	Dislike	Like	Dislike	Like	Dislike	Like	Dislike	
	3	1[2]	7	0	5	0	5	0	
A			The color sensor was cool… the on-board RGB LED was also cool.		…speaker was super fun to code… rewarding when we were able to do what we wanted to with it.		…fun to get the text we wanted… to be shown		
A			…cool because we were able to coordinate it with our LED and LCD.		The LCD was my favorite because it displayed a message and played a song. We got it to play twinkle twinkle little star				
A			…code was provided… we could ask the teachers for help on segments we did not understand.				…code was provided… we could ask the teachers for help on segments we did not understand.		I wish we got to do another lab activity, other than coding
A	...fun figuring out how the pieces and the code… worked		...fun figuring out how the pieces and the code… worked						…I've already taken (DE). If I hadn't I would have probably broken something.
B		*Looking at the magnetic field wasn't my favorite… wasn't that interesting…*	...cool to see the… rgb that it picked up in different objects and hot it changed.		…fun to experiment with different object's temperatures and also the speaker's reaction				
B	…interesting… how the magnets changed the values…		…interesting… what colors were picked up…				…interesting… how one very common and important piece of technology functions.		
B			It gave us the RGB of any color		…just cool that is could detect different temp		It played super Mario brothers!		It was all great
B	We barely started to work with this sensor.				I like how accurate this sensor was and how it was able to detect the temperature every .5 sec		…favorite sensor… very cool that you could swipe… and it would print… on the screen…		

The Teacher Experience: Results and Feedback from the Educator

When asked to *compare this field trip to other university field trips* he informed us that this trip was "much better." During a follow up meeting, he elaborated by saying, "[other universities] have similar opportunities, but what [Duke University] did was more inviting and intimate for [the educator's] students." When asked to *quantify how much time and effort he put into planning and attending this field trip on a scale of 0 (none) to 10 (too much)*, he reported a 7. Despite a high score, he agrees that the trip was worth the time and effort and strongly agrees that we should offer it again in the future. He is willing to continue helping us develop this program and recommends we also reach out to other schools in the surrounding area. When asked to *provide details on ways we could have lessened the burden on [the educator] and what we could have done to make the field trip more worth the time and effort,* [the educator] explained:

"A lot of the troubles faced when coordinating this field trip were due to DPS, not Duke or its faculty, and thus the burden could not be lessened. Still, with all things considered, this field trip was enjoyable, informative, and gave students the opportunity to learn about Duke University and its engineering program. Prior to attending, I was all for [another local university] only for engineering, but now I believe that Duke could also be a strong contender for students interested in engineering. The complexity of the lab may have been slightly too difficult for some students,

[2] The single comment regarding dislike is *italicized* in the table for distinction.

but most all ended up with successful completions--or similar outcomes--where I do not believe much modification is necessary."

In response to, *were we successful with reaching underrepresented students? Are there other efforts we could have made to be more inclusive or to reach other groups of students in your school/program? Was there a benefit in seeking underrepresented students from your school/program for this field trip?* he writes:

"I believe more than underrepresented students wanted to attend the trip, but were saddened to hear it was targeted towards these populations which they did not identify with. If possible, multiple trips per school year (perhaps one fall, one spring) would help bring in more students. It is difficult to comment on benefiting underrepresented students, as Duke (as are most colleges) is expensive. Some students were attending simply to see what college life was like, while others may be specifically thinking about Duke as their post-secondary education. I believe those that identified as underrepresented students still found enjoyment and a 'place' with Duke, but more commentary on LGBTQ/minorities/Women in Stem and more ties to what Duke does to assist these demographics may further enhance their experience."

During a follow-up meeting with the educator, we discussed any impact this field trip had on his students' learning potential and what it meant for him as their educator. Although this information is anecdotal, we believe his insights will help us develop our field trip program further. The educator insisted that students currently in his DE course conversed positively about the field trip for days afterward. He highlighted that they were making connections between their DE course work and the laboratory work they completed. He also told us their conversations were as valuable as it meant they felt it was a value-added experience. When asked what limitations for the trip with which we could help, his response was surprising and yet encouraging. He suggested we alter our program to include transportation as this is often a costly and challenging aspect to secure for an overworked public-school teacher.

Conclusions and Next Steps

A focus of this work was to address the burden public school educators' face in organizing and implementing a college-level field trip. Often, public school teachers are overwhelmed with taking on the brunt of the work when collaborating with universities. This work has sought to lessen that burden and to instead offer a rich, hands-on, recurring engineering opportunity for interested teachers and the students in their curriculum. Results are self-admittedly initial and represent a work in progress. We plan to lessen the burden further by providing transportation and developing self-regulated laboratory content in line with the students' learning. In addition, expanding on the results from the surveys as well as the outcomes of the intervention are anticipated along with any longitudinal data.

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Appendices

Appendix A: The Laboratory Experiment

Duke University staff modified a laboratory manual and supplementary documentation used for the first-year Fundamentals of Electrical and Computer Engineering laboratory [15]. The version provided to attending students is located at the link provided.
https://bit.ly/42vFxb8

Appendix B: Field Trip Interest Flyer

Information about the field trip was provided to all students through a joint effort. Duke University staff created a digital flyer and a Qualtrics survey for interested students. The RHS educators included the flyer in a weekly newsletter sent to all students and families associated with the engineering program. The flyer instructed students to contact one of the DE educators if they were interested in attending, to which the educators provided them with a link or QR code to the survey and recorded their names for distribution of district mandated paperwork.
https://bit.ly/DukeInterestFlyer

Appendix C: Pre- and Post-Trip Surveys

The educator provided a pre-trip survey for students interested in attending the field trip, allowing the staff at Duke University to gather information intended to help them tailor the trip for the population. Below are links to copies of both surveys.

https://bit.ly/Pre-Trip_Survey

https://bit.ly/Post-TripSurvey

Appendix D: Project Lead The Way (PLTW) Course Descriptions[3]

Course		Description
Introduction to Engineering Design	IED	Students use engineering tools and apply an engineering design process to solve engineering problems. They learn to plan, document, communicate, and develop professional skills through an activity-project-problem-based (APB) pedagogical approach. This APB work is completed individually and in teams, considers material selection, human-centered design, manufacturability, assemblability, and sustainability. They use CAD to create prototypes, and develop testing protocols. They apply computational methods, developing algorithms, performing statistical analyses, and creating mathematical models to inform their solutions. They collaborate in teams to study project management, peer review, environmental impacts, and ethical issues.
Principles of Engineering	POE	Students explore disciplines/careers. They design and solve real-world engineering problems, creating solutions with 3-D modeling software, hands-on prototyping equipment, programming software, and robotics. They use the engineering design process to solve problems in mechanical engineering, robotics, infrastructure, environmental sustainability, and product design/development. They use the APB approach to complete structured activities and open-ended projects/problems requiring technical documentation, critical thinking, collaboration, communication, and ethical reasoning.
Digital Electronics	DE	Students use combinational and sequential logic design, teamwork, communication methods, engineering standards, and technical documentation. Using the APB approach, students analyze, design, and build digital electronic circuits while rigorously developing professional skills/creative abilities, and understand the circuit design process.
Civil Engineering and Architecture	CEA	Students use STEM skills to understand aspects of building and site development while creating residential and commercial projects requiring documentation of their work using a 3D architectural software. This is a specialized course that builds skill sets introduced in IED and POE.
Computer Science Principles	CSP	Students develop in-demand CS skills such as, computational thinking and coding fundamentals while using computational tools to foster their creativity. They gain an awareness for the demand of computer scientists and computational thinking skills. They are encouraged to consider creativity, socially responsible choices, and ethical behaviors when solving problems.
Computer Science Essentials	CSE	Students are introduced to coding fundamentals through a block-based coding language to create apps, transitioning to a text based Python programming language

[3] www.pltw.org

Appendix E: Photos from the Field Trip