Engineering Outreach: Project-Based Learning for Elementary and Middle School Students

Abstract: Parents have sought out engineering preparatory programming for their children who have expressed an interest in the field as a college major and as a career. The supplemental educational industry which has arose to train the hard and soft skills required to prepare students continues to grow and transform the way elementary and middle school engineering education is shared. The cost of these supplemental programs is a future investment in that they provide an entry to engineering concepts, exploration of first principles, and project based learning. New additions to this market such as Ad Astra/Astra Nova and Synthesis have sought to teach communication and team building skills alongside problem solving to students interested in STEM. Other organizations such as Future Engineers and Rube Goldberg encourage students to become active learners. Access to these skills at a young age will help strengthen the skills set of future engineers.

Introduction

The emerging industry associated with prepping elementary and middle school students for engineering careers is bridging gaps that exist between what is learned through traditional means, and what is actively taught through early Project Based Learning opportunities with engineering mentors. The rise in online and in-person supplemental engineering programming for students is beneficial and strengthens and diversifies the field by attracting students at a young age to engineering.

By introducing Project Based Learning (PBL) at the elementary and secondary level, students are exposed to engineering concepts and critical thinking skills that would otherwise not appear on their educational radar until much later in high school or college. PBL combined with collaborative problem solving training increases the knowledge of potential engineering candidates when integrated with traditional coursework. This paper will overview several of the online and in-person PBL models focused on introducing engineering to young students. Exposure to engineering skills such as CAD, robotics, AI, 3D Modeling, experimental design at an early age allows for future knowledge to compound, and the potential for mastery and innovation to be more likely.

Young Students, Problem Solving, and PBL

For many children educated in a traditional school setting, engineering and innovation is not a daily class offering. By the time students reach the pre-college years of high school, the opportunity to teach concepts that would make for a strong engineering candidate may have already been missed. Li Tan concluded in "Using random forest analysis to identify student demographic and high school-level factors that predict college engineering major choice" that it is crucial to attract more students to college engineering programs that are prepared to successfully complete the degree [1]. While there are no metrics to assess the efficacy of whether introducing young children to engineering through PBL will increase the number of students completing an engineering degree, one assumes teaching critical thinking reinforces a respect for the scientific method and innovation.

Although the United States places importance on STEM, students need to firmly understand the basics of mathematics to advance to higher levels of study in these disciplines. The inability to complete rigorous math and science courses can be a factor in engineering students dropping the program and choosing to study something else. Early intervention in addressing math and science inequities in education is crucial. The disparity in public school offerings among affluent and depressed socio-economic areas is well-known. Engineering outreach programs seek to introduce these concepts at a young age to the widest and most diverse audience possible.

To introduce the concept of engineering to the spectrum of students, engineers volunteer as mentors and participate in outreach organizations. These programs can open doors to innovation, internships, and increase the visibility of the profession. When presented through a PBL framework, engineering concepts do not initiate a pre-conceived notion of difficulty, inaccessibility, or bias. After school PBL programs provide project kits and assist in prepping for national engineering challenges. Emphasis is placed on producing a project that students can take home after completion. Engineering mentors make the field more attractive for youth just as they enter the years where science and math get increasingly more complex.

PBL Laboratories for Youth and Critical Thinking

Supplementing traditional class-based methods of acquiring the first principles of engineering broadens the discipline and attracts new problem solvers. For instance, students compete for coveted spots at the Massachusetts Institute of Technology (MIT) to learn from the profession's best engineering, math, and computer science professors. Popular introductory computer science classes have had students seated outside watching on screens as the classrooms are crowded. The availability to access has been a mission of the EDX community, which many parents have used for supplemental engineering education.

In Grasp: The Science Transforming How We Learn, MIT's Professor of Mechanical Engineering, Dr. Sanjay Sarma challenges institutions to refresh their methods to find the next generation of Albert Einstein's [2]. As the head of Open Learning at MIT, Sarma studied the history of education and looked at some less traditional approaches. He traced the methods used by John Dewey in his 19th century laboratory school, all the way to the system-disruptive laboratory school Ad Astra which was located on the SpaceX Campus in California.

Ad Astra (now Astra Nova) [3] was a laboratory school born out of Elon Musk's interest to create a different type of PBL education for his five sons. He hired his son's teacher, Josh Dahn, to develop a fresh approach to education. Parents are obviously not equipped with such financial resources to build a school environment from the ground up; however, such a disruptive approach has resonated with many who feel PBL is the best way to engage younger students.

When asked about the major benefit from creating a new school from the ground up, Dahn shared: "The power of starting with the question 'why school.' The first principles approach is deeply embedded in SpaceX culture and the justification of doing something at Ad Astra merely 'because someone else does it this way' was out of the question. At Ad Astra we had a fabrication lab far more advanced than anything I had in a traditional school environment, but what makes Ad Astra/Astra Nova unique is the emphasis on decision making and finding opportunities for connection and application to the wider world [4]."

By employing nontraditional teaching methods, students were motivated and inspired to mature in their understanding and employment of the scientific method. PBL was utilized. The students study astrogeology, biochemistry, advanced mathematics, and astronomy from industry experts, giving students in 5-8th grades a glimpse into the profession. Dahn shared: "We created a 'corporate collaborative' where students could get feedback on projects related to SpaceX: designing a better grid fin, finding creative ways to attract top talent, thinking through the first missions to Mars--- if students wanted to work seriously on 'Elon-level' questions, we did our best to help them connect with folks working on those problems at the company. The key was making it optional and supporting students who were most committed to doing the intensive work [5].” Dahn’s model trains students in PBL to become critical thinkers. These skills are desirable in engineering, but not normally found in elementary and middle school students.

Team Building and Communication Skills in Concert with PBL

While excellent math and science skills are necessary for a successful engineering education, there are other soft skills that are important to possess, such as communication and collaboration. Team building, problem solving, tenacity in the face of experimental or build failures are important skills that are not easily taught in a traditional school environment where emphasis is placed on meeting local, state, and national testing score metrics.

In that vein, Synthesis is an online venue that sprang from Ad Astra. Cofounded by Dahn and Chrisman Frank, Synthesis attracts students who are interested in problem solving, game simulations, and collaborative learning. Each week students meet within an international cohort of students ages six to fifteen to work through simulations that were built upon strategic game theory principles. Students are encouraged to team solve issues and achieve challenges within the construct of a video simulation under the hands-off presence of trained educational facilitators.

Frank was a lead designer of the philosophical and logical puzzle conundrums at Class DoJo. Students would work on these conundrums to strengthen critical thinking skills, then discuss them to practice team building and communication. He shared the key element of Synthesis’ educational model: “Engineering is just the process of solving problems together. Most people falsely equate engineering skill with mathematics skill. While mathematics is certainly helpful in engineering, the truth is that engineering problems involve far more uncertainty. In my observation, the way real engineers solve problems is through rigorous conjecture and criticism. That process of collaborative conjecture and criticism is what students do at Synthesis. They first have to figure out how the system (in our case, a complex game or simulation) works. Then they have to work with their peers to chart a course to manipulate the system. Synthesis is sort of a playground environment where students can practice rigorous conjecture and criticism in the form of games before moving on to solving real world problems [6].” The model is popular as the online subscription service has seen incredible growth and press in just it first eighteen months. Parents remark upon the resulting communication confidence and interest in problem solving resulting from the active learning environment.

Synthesis challenges elementary and middle school students with collaborative game play without explaining the rules: students uncover the rules of the simulations through conjecture, trial, and error. Course corrections in Synthesis cohorts allows a student to discover an error in approaching a problem and change their approach in an environment that rewards learning from mistakes. This creates a laboratory environment of communication where discourse does not criticize incorrect assumptions, but rather uses the team atmosphere to nudge the members in another, possible correct direction. The Synthesis model foresees its veteran students as potential interns in product design, simulation design, and computer security.

Early addressing of the learning gaps and needs of elementary and middle school students can only improve by an order of magnitude their comprehension of concepts to be studied later in high school. In relation to how these logical and analytical skills impact the students, Frank offered: "These skills compound over time, so the earlier you start learning them in a systematic way where the next step builds on the previous steps the better. By analogy, all the world's best soccer players started playing very early. There is no world class player who started playing in their 20s or even their teen years. We believe the same will be true for people who solve the kind of complex science and engineering problems to move the world forward. An early start confers a lifelong advantage. Unlike in sports, these advantages are not zero sum — an excellent student does not 'take away' a spot on the team that could have gone to someone else, but simply adds to the sum total of humanity's capacity for ingenuity [7]." It will be illuminating in the future to note what becomes of the graduates of disruptive PBL models.

Engineers as Mentors

The active learning models of online educational programming allows for a kinesthetic and collaborative learning environment. The ability to create a true PBL environment outside of a traditional school is not easy, but engineering organizations such as Young Engineers, Future Engineers, Invention Convention, and Rube Goldberg try to accomplish this with engineering road shows, challenges, and afterschool engineering classes. The opportunity for students seriously interested in engineering to find mentorship in these programs is a motivating factor for many families.

Working on engineering concepts allows enthusiastic students an opportunity to pursue engineering without a speed limit. Students get excited replicating engineering projects they see on You Tube channels from education entertainers like Mark Rober. Students are excited about the potential to create using CAD on a 3D printer. They can find easy online tools to start coding computer games and programs. The barrier to entry for engineer is lessening due to the outreach from many engineers seeking to grow the field.

Young Engineers [8] is a nationally franchised educational venture that hires engineers to teach elementary students practical physics in the framework of simple projects that can be taken home when finished. Inspiring students who may not otherwise be exposed to engineering and creating, Young Engineers guides students in understanding mechanical cause and effect relationships. Promoting the study of engineering in afterschool environments lends a "cool factor" to those involved in the program. There is also a pride of creation for each project built and taken home.

Future Engineers [9] creates quarterly challenges for elementary, middle, and high school students. Many of the challenges require students to use CAD software, produce 3D models, create a scientific experimentation plan. The organization provides mentoring and challenges have no fee to enter. Recently, they featured challenges for creating a lunar rover to capture regolith from the moon titled Lunabotics, and a challenge where the winning student team would be able to send science experiments aboard a Blue Origin rocket or a high-altitude balloon to the Karman Line. Challenges such as these bring the scientific method to life for students.

Similarly, the Invention Convention [10] is an international competition that teaches the engineering design process to students. Engineer mentors teach the students about the invention process and experimentation. Students are encouraged to create a unique idea, research the idea, and follow the steps in the process of inventing a product. A presentation board explaining their invention with a five-minute accompanying video allows the student to provide an elevator pitch to a group of local, national, and ultimately international STEM judges. The support from local engineering companies to support and guide interested students is paramount to its success.

Lastly, the Rube Goldberg [11] organization has multiple ways for students from elementary to high school to participate in an engineering design challenge. Based upon the cartoons of Rube Goldberg, students are tasked with producing a simulation of an activity made difficult by multiple imaginative steps. Challenges, such as opening a book or making lemonade, are marked by engineering principles and levels of complexity. In-person Rube Goldberg challenges have become a mainstay of the national Science Olympiad and are popular PBL activities in middle and high schools and seek out volunteer engineers to help mentor and coach competing teams. Mentoring the elementary and middle school age range is becoming a more common way engineers are volunteering and growing the field.

Motivation for Pursuing Extra Educational Opportunities

Although science and technology programs and camps are generally positioned at a high price point, many parents find it valuable as they offer a variety of hard and soft skills. For parents who want their children to get a head start on engineering and possibly graduate early, they are willing to finance this extracurricular preparation with a rough average of $1500-$2000 for a weeklong immersion STEM camp.

For-profit and not-for profit organizations have introduced online programs marketed to students interested in kinesthetic learning opportunities. Engineering needs to constantly attract new talent, and whether it is robotics, aerospace, or computer engineering, there are programs to support the interests of youth considering this field. Engineering camps and programs for elementary and middle school children provide a pathway for students to test out the work and research of engineers. This can provide an initial sifting of students who find engineering compelling, and those that decide to study other subjects. These supplemental PBL programs introduce physics, mechanics, drafting, robotics, and computer coding to elementary students.

Having witnessed firsthand the diversity these programs attract, there is an enthusiasm for engineering education for active learners that occurs outside the traditional constraints of a classroom setting. Whether that be a factor of the “extracurricular” nature of the engineering projects, or a pure connection to the creative process is impossible to determine. The offerings of these supplemental programs attempt to hold this wonder and excitement that young students experience, and nurture it unto college.

Engineering Outreach and Academically Accelerated Students

Competition for placement at higher education institutions prompts parents to invest in programming to learn engineering concepts. Pre-college summer programs and internships are highly competitive and can be expensive but help to fill gaps in learning for college bound students. PBL increases student independence. Xiangyun Du said in regard to his research on student perceptions of PBL: “The study also revealed that while a PBL setting highlights learner agent engagement, students, particularly those new to PBL, may still believe instructors are the major source of authorized knowledge, which may hinder their ability to take agentic actions. These results have pedagogical implications that both educators and students need to be aware of. Educators can support learner agency by increasing students' PBL knowledge, skills, and efficacy to help them navigate individual and collective self-directed learning” [12].

Some academically gifted students in traditional educational settings are not challenged to suit their abilities as gifted programs are erased from school budgets. Johns Hopkins University supports the Center for Talented Youth [13] and Northwestern University supports the Center for Talent Development [14]. Entrance into these programs for accelerated students, a successful candidate needs to score well on a proprietary test and/or a nationally recognized intelligence test. In return, the students enroll in accelerated science courses for ages 6-17. Advanced Placement classes are taught as well as classes in coding, computer science, engineering, physics, and space exploration. Small classes afford the student access to other students with similar interests and mentors. Courses offered by these two programs reflect the research nature of the University and allow students to study genomes, cybersecurity, aerospace engineering, and other more focused fields of engineering study.

Cost-Benefit Assessment of Early Exposure to PBL

In the future, it will be a compelling metric to assess what contributions to the field of engineering, mathematics, and science in general comes from the students educated at the elementary and secondary level with these supplemental PBL engineering activities. Will they choose engineering as a field of study because they have been actively engaged in engineering projects where they feel a sense of being a stakeholder in the outcome of small projects? Will these students be better prepared at an early age for undergraduate and graduate engineering degrees?

The exposure to experimentation beyond the commonplace introductory science-fair brand of projects is a variable that is not going to be available to everyone. The educational resources to provide specialized access to young students is not available in the majority of school budgets. It is increasingly becoming the realm of private groups to provide this fee-based learning.

Teaching engineering concepts outside of the traditional classroom curriculum which enables PBL can be acquired at a price point where many families view it as a solid investment in the future attractiveness of their students to prospective engineering programs. To this end, many families have chosen to seek out nontraditional and individualized education, such as private tutoring, homeschooling, immersive summer programs, and internships. The obvious divide of affordability and availability to some more expensive educational opportunities leaves out many students from gaining access, thereby losing out on exposure to engineering. Addressing inequities in elementary STEM education is a first important step in leveling the playing field for all students to excel in engineering.

Conclusion

In conclusion, the emerging industry of educational outreach programs designed to hone soft and hard STEM skills provides the best opportunities to prepare children for a studying engineering in higher education. Online and in-person organizations exist which enables true independent learner agency, but the key is to expose students to a variety of the branches of specialization under the tent of engineering.

The commitment on the part of engineering mentors and educational programmers to increasing the skill set required to complete an engineering degree is commendable. Introducing first principles at a young age may help strengthen the long-term commitment to the field. The key to the success of these outside organizations which mentor and teach students is the support from the public, private, and home school systems, as well as engineering firms and professional organizations. Growing the field of engineers can start in the elementary and middle school grades through fun and engaging projects that inspire the imagination, improve communication, and reinforce science and math skills.

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