Engineering Brightness: Using STEM to Brighten Hearts and Minds

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***Abstract* -**
The Millennial Generation requires their efforts to have meaning today which is often juxtaposed against industrial education and the attached silos. Engineering Brightness uses philanthropy and engineering to provide motivation and a foundation for the Millennial Generation to learn in all subject areas. Engineering Brightness students design and build lights for some of the 1.5 billion people who do not have access to clean reliable light. One of the many ramifications of little clean light is the inability to study after sunset. Many students have to choose between sitting in the dark or burning brush, garbage or kerosene which have health, environmental and safety concerns. STEM, specifically electrical engineering, is used to solve this real problem for real people. Primary, middle and high school students from Colorado, Canada and the UK, collaborate in the process to produce different prototypes of lights. Students interact with community members and local businesses to learn how to assemble circuits, the functioning of electrical components, sewing, 3D printing, world issues, health, language arts and philanthropy. The project motivates students in a novel way. If a student does mediocre work, it is much more devastating than a poor mark because someone else's life is negatively impacted. The work supersedes a grade and survives the trash can at the end of the semester. Students are proud to be leaving a legacy, participating even after they moved on to another school. Engineering Brightness, Philanthropic Engineering's (http://p-e.io) flagship project, aims to deliberately engineer brightness literally and figuratively including in:

- **the room of studying students all over the world who otherwise do not have access to clean light.**
- **the minds of students who bring many skills and aptitudes to bear in the design and production of lights.**
- **the hearts of students who use their learning to impact the lives of others.**

Index Terms - 3D printing, k-12 engineering education, philanthropic engineering, school reform.

INTRODUCTION

Engineering Brightness is designed to solve two critical problems in education. The first issue is that the Millennial Generation is not motivated the same as previous generations. They are largely disconnected from their educational system because subjects are presented in isolated silos with artificial situations. This generation finds the traditional model of education lacking meaning because they want their work to be real and to matter today.

The second major issue for Engineering Brightness is the approximately 1.5 billion people who do not have access to clean reliable light [1]. This lack of light has a dramatic negative impact on the education of students worldwide and we know that education is the single best way to alter the living conditions of both individuals and whole communities.

How might we address both the lack of connection between the Millennial Generation and their education system and the pervasive lack of clean light? Engineering Brightness, the flagship project of Philanthropic Engineering (http://p-e.io), leverages students' desires to do work that matters and allow them to design, 3D print and assemble lights for those who cannot study after sunset. While students practice philanthropy, they simultaneously learn geography, economics, humanities, literacy, and numeracy. The students who are behaving as engineers are changed as well as the students who are partners in the process and receiving the lights.

Engineering Brightness has many goals. We hope to provide a learning environment that will engage the Millennial Generation to use their learning from all subject areas to solve real problems for real people. Engineering Brightness hopes to provide clean lights to those who cannot study after sunset. We also hope to add to the mounting pressure for educational systems to change how students learn.

This paper will describe the journey of Engineering Brightness to brighten the world literally and figuratively in an effort to recruit other partners to the cause and to serve as an example for how STEM can be integrated into the school systems.

BACKGROUND

The creators of Engineering Brightness were searching for real problems for their students to solve. Unfortunately the lack of clean light sources is a serious problem. Fortunately, it is a problem that students from a variety of academic levels and geographies can work to solve. Producing lights seems to be the perfect topic for students to use their learning to help others.

One of The United Nations Millennium Development Goal is to; "Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling" [2]. Reading is a key to learning and light is a prerequisite for reading. Many students have to make a choice at night to either sit in the dark to the detriment of their studies or burn something like brush, candles or kerosene, all of which have serious environmental, safety and health concerns. A clean and reliable source of light after dark will expand their opportunity to learn. Access to clean light after sunset is serious enough that UNESCO had a whole program dedicated to "Study after Sunset" during their International Year of Light and Light Technologies [3]. Their projects seem to focus on large scale infrastructure solutions whereas Engineering Brightness is a grassroots solution to an unfortunate and real problem facing real students and impacting whole communities.

Fortunately, the lack of clean sources of light is a problem that students from all age groups can address. Light, electricity and circuits are topics that appear in official curricula from primary through high schools all around the world. Educators are therefore able to match their prescribed curriculum to the real problem of a lack of clean lights and its innovative solutions. These topics are flexible enough to provide an entry point to participation for any student, making it attractive for whole classroom projects. Students are able to collaborate with other students across age groups and geographies. Sometimes they are acting as mentors and other times they are in the role of mentees. The ubiquity of electricity and circuits as a topic in the educational systems allows for a broad range of age groups, academic abilities and geographies to interact for a single purpose.

The single purpose of producing lights for those who do not have is the crucial motivating factor for the Millennial Generation. They are less motivated by the delayed satisfaction of the promise of a corporate ladder, a white picket fence and the American Dream and are more concerned that their efforts are making a real difference today [4]. The idea that one needs to study so that one can graduate so that one can get a good job does not seem to have the impact that it once had [5]. Engineering Brightness uses philanthropy as the motivation for learning in all of their subject areas.

Preston Middle School in Colorado have been exploring philanthropy to learn all subject areas for a while. Tracey Winey's and John Howe's students at Preston Middle School in Colorado spent one semester learning with an orphanage in Uganda and Haiti. None of the orphanages had reliable access to electricity. Preston students learned from Ugandan and Haitian students about each country's cultures, especially how crippling life was when there is no light after dark. Preston students designed a battery powered flashlight to be hand-delivered to Haiti. The group learned that they were able to provide some light for the village, but soon the batteries started dying and some of the flashlights did not work when they arrived. The community was grateful to have the light for a short amount of time, but were soon back to the original problem.

The Preston students who participated were changed. They realized their work mattered, but understood that their first attempt was not a long term, viable solution. Throughout the experience, Preston students did not receive a grade, nor were they given homework; however, they were invested in the work. Seeds of entrepreneurism, philanthropy, cultural understanding, and self-worth had been planted and were beginning to grow. This initial experience provided the impetus for something bigger and Engineering Brightness was born.

Solving the problem of a lack of clean light requires more than just STEM. During the design phase of Engineering Brightness, the educators purposefully embedded opportunities for students to strengthen their varied talents and practice their weaknesses from the arts, humanities and entrepreneurship. The arts and humanities cannot just be additional isolated silos that are beside the project. It is not enough that they also learn how to write, or do graphic arts or consider geographies and cultures. All subject areas must be intertwined and indistinguishable from each other. It is important that all understand the interplay of the subject areas to solve real problems worth solving, yet not everyone is an expert in all areas. Learning how to collaborate will be crucial to learning STEM and arriving at a successful product.

There is a problem of a lack of light for the education of much of the world. Light and electricity is a ubiquitous topic in education around the world. STEM, the Arts, Humanities and Entrepreneurship are all required to solve the philanthropic problem. The Millennial Generation is looking to invest their efforts to a cause that matters. Building Engineering Brightness can begin.

DISCUSSION

Engineering Brightness grew organically with multiple partnerships. This paper will focus on the work of each partnership one at a time, even though in reality, they were happening simultaneously and chaotically.

RIVERVIEW HIGH AND PRESTON MIDDLE SCHOOL

Students from Preston Middle School in Colorado and Riverview High School in New Brunswick, Canada, discussed several global problems and used two very different background experiences to agree on one common goal: create a global collaboration to provide a rechargeable light source to areas that do not have reliable, safe access to electricity.

Each school adopted different places in the world. Ian Fogarty's twelfth grade physics students at Riverview High adopted a pair of sisters who lived in the Dominican Republic. These sisters wanted to be doctors when they grew up. The major roadblock to pursuing this dream was that when the sun went down, they had no reliable access to electricity for light, which means they could not consistently study after dark. It was very difficult to become a doctor if studying after dark was not possible.

Preston Middle School adopted the CHAT House orphanage in Uganda. Although they have electricity at the school, there is a lack of clean light in the dormitory, on the grounds and in the general community. Both schools focused on different geographies with a common goal of providing clean sources of light.

Just as both schools had links to real-life clean light problems, both had complementary areas of strengths and weakness. Riverview had the advanced physics as part of their curriculum, while Preston had expertise in 3D printing and a history of global collaboration.

Preston's previous experience with global collaborations pointed to the need to enlist the expertise of the students living in Uganda and the Dominican. The project needed student consultants to critique the lantern prototypes, collect data, and field test how the lanterns work in their area. The field testers can distribute the lights to the sections of town that would benefit most.

Preston and Riverview began the hard work of designing lights together. Together the learned Ohm's Law, series and parallel circuits using a PHET™ virtual simulator. Students spoke to each other using SKYPE™ while they manipulated the PHET™ simulator that was displayed on a SMARTBoard™. Bridgit™ is a piece of software that allowed students on different ends of the continent to take turns using the simulator in real time to build a circuit, providing a unique opportunity for collaborative learning. Students safely manipulated and ignited simulated batteries. They brainstormed, listened to each other's ideas, failed, tried, tried again, and ultimately were able to create a working circuit.

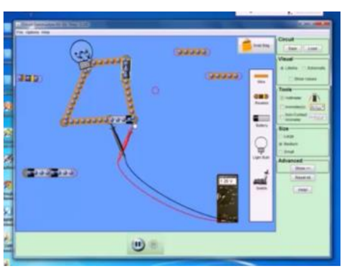

FIGURE I
PHET Circuit simulator controlled at distance using Bridgit™

For many students, this was their first successful international collaboration. All students learned new information, and were motivated to apply their knowledge. Students in both countries committed to work independently to design lights, then share their work every few weeks.

Initial Design Ideas

The educators adopted the idea of "Fail often in order to succeed sooner!" [6] as the students began their designs. Students were not accustomed to trying and failing. Getting a question wrong was systematically discouraged in school. In this project, students made multiple iterations of their own designs. As teachers, we saw a student move from version V1.0 to V1.1 to V1.3. As time went by, we also saw students learning from the work of other students moving to V2.0 and V3.0. They learned from their failures and their successes.

A few weeks after our SKYPE™ communications and trial and error, both Preston and Riverview students had preliminary designs for a solar rechargeable light that worked on the short term.

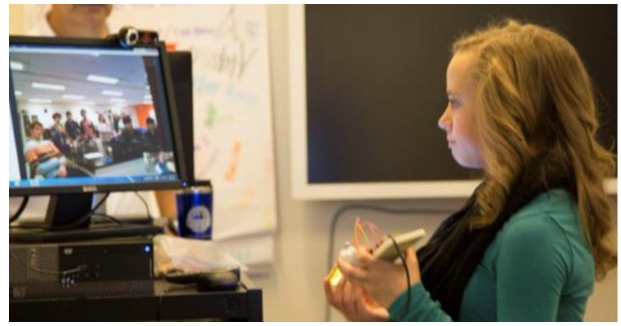

FIGURE II
Preston Skyping with Riverview to discuss breadboard circuit

Despite the wonderful learning that happened with failing often, before the lights left the building to our field partners, there was a certain safety standard required. In a typical high school project, it might be satisfactory to have the project work long enough for the teacher to assign a grade and then it would go in the garbage. In this case, it was not good enough to be 90% right, it had to work and it had to be safe. There was no part value. We did not want to burn down the few possessions that the recipients might have. This was wonderfully frustrating to students.

The design was sent to two universities for a safety check. Both university faculties suggested that we NOT produce these designs because of the risk of overcharging and resulting fire. Riverview and Preston students decided to follow separate but parallel paths.

The Colorado Lantern

The Colorado group pivoted and changed directions from a solar light to match their clients' needs and to get some safe success sooner. The result was the first useable light from Engineering Brightness called the Colorado Lantern. It was designed for an orphanage or school that had power during the day but where students had a lack of power at night. Students would plug their lights in during the day and then take them back to their residence or homes at night where there was no power.

The Preston group was using community resources including INTEL and SPARKFUN to set up stations to produce multiple Colorado Lanterns in a couple of days. They produced nineteen Colorado Lanterns, included hand chargers and sent them to their partners in six countries including Uganda.

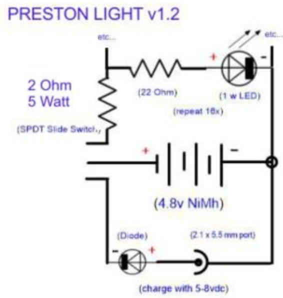

FIGURE III
PRESTON CIRCUIT DIAGRAM WITH TEN TO TWELVE LEDS

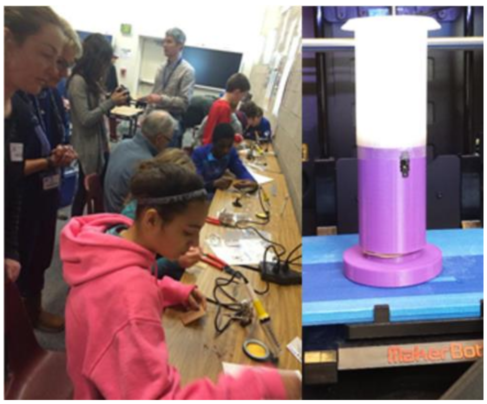

FIGURE IV
PRESTON STATIONS FOR MASS PRODUCTION OF COLORADO LANTERNS 3D PRINTED ON A MAKERBOT REPLICATOR 2

FIGURE V
NINETEEN LANTERNS READY TO SHIP FROM PRESTON TO CHAT HOUSE IN UGANDA

The Ugandan students gave some valuable feedback to Preston about their lanterns. The chargers did not have a good success rate, with 50% of them breaking and only getting a couple minutes of light from fifteen minutes of hand cranking. The hand cranks were certainly good enough for students to use the lights to travel to the outside bathroom at night, but not enough for a focused study session. Riverview suggested that the resistance to the LEDs should be increased significantly to increase the longevity of the charge. This was later confirmed by an electrical engineer at Ludlum Industries.

FIGURE VI
CHAT HOUSE FIELD RESEARCHERS FROM UGANDA WITH COLORADO LANTERNS

RIVERVIEW DESKTOP LIGHTS

While Preston was being very productive and shipping lights all over the world, and getting feedback from their field testers to inform future iterations, Riverview was still prototyping.

After receiving the feedback from Universities that the original circuit was unsafe, the Riverview group decided to address the safety concerns and continue on the solar rechargeable track. A local company, MASITEK, released a couple of their electrical engineers to help design a safe circuit with a temperature shut off at the battery and an overcharge safety. The circuit design was significantly more complicated with many more soldering joints to make, each joint increased the potential to fail, with a significant increase in the cost.

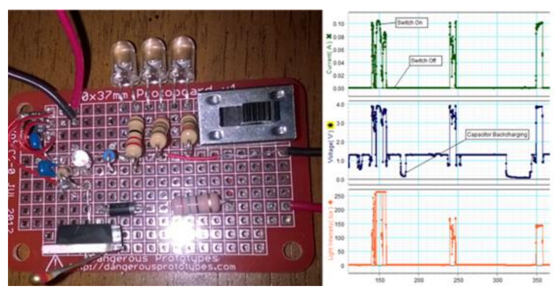

FIGURE VII
MASITEK SOLARCHARGING NIMH CIRCUIT WITH OVERCHARGING AND BATTERY TEMPERATURE SAFETY
AND MEASURING THE CURRENT, VOLTAGE AND LIGHT INTENSITY

We had a working circuit designed for a village in the Dominican who had rotating blackouts. The battery capacity was large enough for multiple nights of study in the case of unexpected extended power interruptions. Finally, there were some tangible steps forward.

A 3D printed case was needed to hold and protect the electronics. Riverview made two: the Podium light and the Clam light that would contain the MASITEK circuit. The

Podium light had a base containing the batteries to give it some stability, a tall neck and a rotating head with 6 bright LEDs and a solar panel on the top. The hinge connecting the neck to the head turned out to be fragile and directing the light became problematic. Students learned from the success and failures of others in the next iteration. The Clam light, brought the LED's closer to the page, had better stability, with vents to reduce heating and had fixed LEDs to better direct the light.

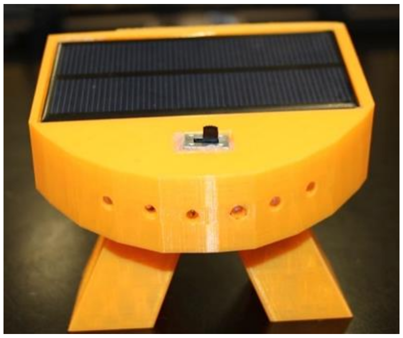

FIGURE VIII
RIVERVIEW CLAM LIGHT

CREATING CIRCUIT BOARDS

NBCC, the local community college was kind enough to create some PCB circuits for the solar lights. However, they would eventually run out. One student decided the Riverview should etch their own boards with ferric chloride. They used markers to free hand mask a blank PCB which they ordered from China and purchased themselves. This worked fine for the relatively simple LED panel that was found in the Colorado Lantern, but would not be useful for the complex solar circuit. They 3D printed a stencil from the complex solar circuit *.fzz file that could guide the markers.

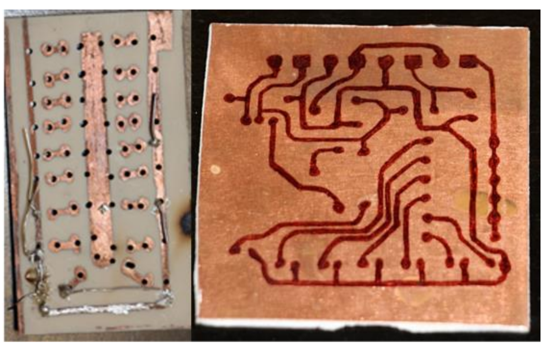

FIGURE IX
RIVERVIEW HAND ETCHING OF THE COLORADO LED PANEL MASKING WITH A MARKER AND ETCHING WITH AQUEOUS FERRIC CHLORIDE AND THE SOLAR RECHARGEABLE CIRCUIT FROM 3D PRINTED STENCIL AND MARKER

This same student wondered if they could be more environmentally friendly by 3D printing a circuit with conductive filament surrounded by insulating ABS. The plan was to heat the electrical components until they would melt through the plastic and make contact with the conductive filament. Had this worked, we would be able to produce our own circuit boards that did not require soldering or ferric chloride to etch. This plan failed because the conductive filament was not very conductive after all.

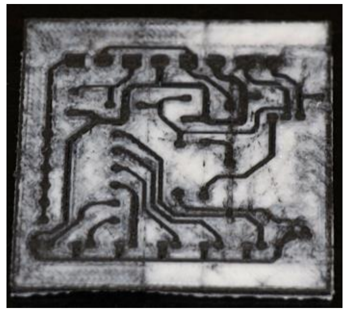

FIGURE X
3D PRINTED SOLAR RECHARGEABLE CIRCUIT WITH CONDUCTIVE FILAMENT IN BLACK AND WHITE ABS

PHEASEY PARK ELEMENTARY AND RIVERVIEW

Part of the mission of Engineering Brightness is to make as many global connections and have as many students making lanterns as possible. The first new school to join Engineering Brightness was Pheasey Farm Park Elementary School in the United Kingdom (UK). Gareth Hancox, David Whyley and their year four students collaborated with Fogarty's Riverview class to design and produce different lights for the Dominican partners. A partnership between Riverview and Pheasey Park came to life.

The elementary and high school students used SKYPE™ for voice and SMART AMP™ as a virtual collaborative workspace. The primary and high school students discussed the social ramifications of a lack of clean light. They discussed the pros and cons of different light sources ranging from brush fire to candles to battery-powered lights. Riverview students demonstrated how to make a circuit. The Pheasey students drew their own circuits on the digital SMART AMP™ workspace in real time.

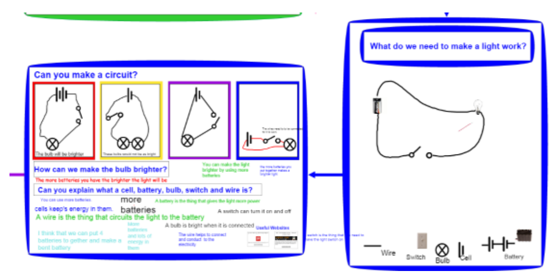

FIGURE XI
SMART AMP™ WORK SPACE SHOWING PHEASEY CIRCUITS AFTER LESSON FROM RIVERVIEW

After teaching circuits, the Riverview students tasked the young ones to design a new case for the lights with some broad specifications. The Riverview students were hoping to get some ideas for the next iteration of the clam or the podium lights. The Pheasey students spent their lunches and after schools in small teams designing and coloring some new designs on paper. A week later, the Pheasey students pitched their ideas to the Riverview students with some interesting results that really showcased the power of collaboration.

The high school students listened to the pitches and recorded the pros and cons of each design. Then in real time, both schools co-created a single new design that incorporated many of the pros of each individual pitch. The final blueprint envisioned that the light would operate a bit like a wrist watch that would point towards the page and would follow the reader as they moved down the page.

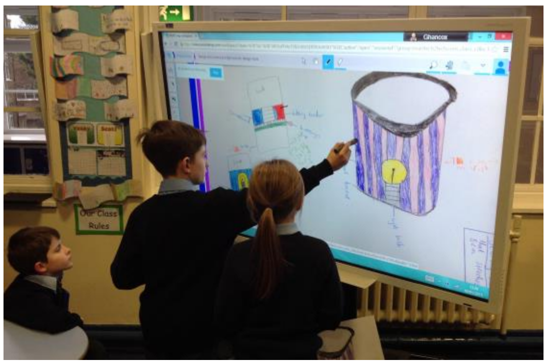

FIGURE XII
PHEASEY STUDENTS PITCHING THEIR WEARABLE LIGHT TO RIVERVIEW

A handful of Riverview Grade 10 students were tasked to bring the wearable wrist light to life. They built a team of people who knew the story of why they were building lights, people who could sew and people who could solder. Together they built a sewn wrist light that uses button cells encased in some cordura and elastic.

FIGURE XIII
WRIST LIGHT V 1.0 AND V 1.3 SHOWING CONDUCTIVE THREAD, ELASTIC BANDS AND CIRCUIT BOARDS

It was a good first prototype with two major flaws. Each light would need to be custom made to fit the many different wrist sizes and the batteries would need to be replaced continuously.

The Dominican field testers liked the wrist lights because it gave a concentrated light directly where they were reading and writing; however, they commented on how the lights did not fit everyone's wrist. Riverview had an epiphany to improve on the design. They could use snap bracelets as the foundation to achieve a one-size-fits-all design. However, the circuitry did not fare well with the constantly moving wrist band. The Preston students suggested that a 3D printed box could contain the electronics and still use the snap bracelet as the foundation.

FIGURE XIV
WRIST LIGHT V 2.0 USING THE SNAP BRACELET AS A FOUNDATION

The current endeavour by the Riverview students is building on the 3D printed watch suggestion using rechargeable lithium button cells connected to a phone charger. They are in the middle of designing the more complicated circuit. They have already made contact with an electrical engineer at NAVCan to help them with the safety aspects of using lithium batteries.

FIGURE XV
RIVERVIEW STUDENTS SOLDERING CIRCUITS

PARTNERSHIPS IN THE FIELD

An important principle of the project was the idea that we needed field testers and partners in the design process. The partnership with the field testers was more than to simply get valuable feedback on the designs. We also wanted a subtle but critical paradigm shift in the attitudes of our students. We wanted to change the relationship from privileged donors and impoverished recipients to all participants being partners in the design process. It was important to learn from the arrogance of our history and we did not want to assume that privileged cultures know what struggling cultures require.

The cultural exchange provided as much learning as the production of the lights and helped incorporate the arts and humanities in a meaningful way. For example, the

Dominican students gave Riverview some valuable feedback recorded on video in Spanish. None of the Riverview students knew any Spanish being mostly English and French. We sent the video to Preston, where there is a large Hispanic population.

At Preston Middle, there was a girl who knew very little English and was very excluded from school because of the language barrier. Mrs Winey knew a little Spanish, but was not adept enough to keep up with the pace of the video. This was a beautiful opportunity to bring diversity to bear. The Spanish only student transcribed the video conversation. Together the student and the teacher translated the text, each making significant gains in each other's languages. They were able to return the translated document to Riverview for the next iterations. The Riverview students realized the value of being multilingual in a flattening world. The Spanish speaking student was able to turn a previous disadvantage into a spectacular asset where she became an invaluable contributor to the project. She was all of a sudden, needed and powerful. It was an inspiring moment for all.

The translated document informed us of the pros and cons of the Colorado Lantern, the Podium, and the first sewn wrist lights (v1.3). The Colorado Lanterns were not bright enough, perhaps because of the thickness of the 3D printed diffuser. The wrist light worked well, but the batteries needed constant changing and there is a need for a variable wrist size. The podium light seemed to work well, but it kept falling over because it was top-heavy.

FIGURE XVI
DOMINICAN FIELD TESTER EVALUATING THE PODIUM LIGHT, WRIST LIGHT V1.3 AND COLORADO LANTERN

Having field partners did three things. Firstly, it enlisted voices in the process that had traditionally gone unheard. Secondly it helped create a worldwide community. Thirdly, it provided valuable feedback for the next iterations in the design cycle.

RESULTS

CAN PHILANTHROPY AND ENGINEERING CHANGE EDUCATION?

Jurisdictions around the world are struggling with school reform. Students seem to be disconnected with their learning and the traditional content seems to be ill-designed for today's society. We believe that school can leverage the depth of knowledge and skill of students with their desire to change the world as motivation to learn the academic content, the technical and soft skills that the Millennial Generation will need.

Motivating the Millennial Generation is different than previous generations. More students than ever wonder out loud why they need to study this topic or that topic, including circuits. Too often we witness a response to that question similar to, "It is April, and April is circuit month. The April test that was inherited from the previous teacher had circuits on it. The curriculum document says that circuits should be done in April. Since it is April, we are doing circuits." This argument is not a compelling motivator to the Millennial Generation who seems to be motivated by purpose rather than following a document. Moving forward, how will educators better motivate the Millennial and future generations? Philanthropy may very well answer that question.

Riverview High School in Canada, Preston Middle School in Colorado, and Pheasey Park Elementary in the UK provided a different motivator for learning. At the high school level, we still did all the same worksheets, labs, demonstrations and notes but in the context of learning something essential to building the lights and helping improve someone's life. Previously, if a student did not perform, it was only their individual grade that was impacted. Now if a student underperforms someone else's life is negatively impacted. Our females were particularly open to philanthropy as motivation for learning STEM.

CLOSING THE GENDER GAP IN ENGINEERING

Engineering is still victim to a gender gap. Canadian engineers have set a goal of 30% of engineers being female by 2030 [7]. Engineering has not been very successful in attracting many females despite significant effort. As with any real issue, there are multiple influences in a complex dynamic relationship.

One path of thought believes that one of the many contributors to the persistent gender gap is the perception that engineering is a cold-hearted way to make a better mouse trap. Engineering Brightness seems to be changing this perception to a warm hearted way to make someone's life better. As a result, greater than 60% of the participants at Riverview High School are female. The boys in the class seem to be done the project when the class is over. However, the girls seem to be involved even after the class is finished because, "we are invested". This success at closing the gender gap at high school is particularly encouraging for the goal of 30% by 2030.

STEM, STEAM AND ESHTEAM?

Students too often have little interactions between the silos of classes. This leads to the unfortunate notion that one only does math in math class and one does not need to worry about literacy in science. Engineering Brightness makes meaningful bridges between those silos and makes it obvious to students why they are studying many different subjects. One student who is very adept with the hands on electrical engineering side of the project struggles with English, not because he lacks talent, but rather because he sees it as unnecessary and a distraction. Over his Christmas break, early in the morning on Dec 23rd, he biked in the snow to school to join three other students as they prepared a poster proposal for ISEC'16. He spent four hours writing and editing with language expert students. He was then able to share the latest step forward in the electrical design with his peers.

The large problems that our world so desperately needs to solve will require a multifaceted approach, not relying solely on STEM. Science and engineering can easily solve many of today's serious problems ranging from world hunger to climate change to lighting the world. Reasonable solutions also have to satisfy economic, cultural, legal and logistical tests in order to take effect. The science and engineering aspects of this project are obvious. However the world issues, writing, communicating, listening, history, culture and entrepreneurship are also vital.

The STEM movement started to realize that the arts are also needed for the balanced education of students and STEAM was born. We believe that Entrepreneurship and Humanities are also required, leading to ESHTEAM, pronounced deliberately similar to "esteem". Engineering uses the knowledge of science and math to solve a problem and make the world a better place, while the philanthropy plays to the heart. The languages and arts provide the tools to make compelling arguments while the humanities aid with the social and historical contexts. Engineering brings all of the subject areas together, and requires many skills while philanthropy changes the motivation for learning.

If we do not give students a chance to work with all aspects of serious problems now, how will they possibly be expected to solve them when they have power?

CONCLUSIONS

Engineering Brightness is a project that brings all of the silos of education together to solve a meaningful problem. Thus far, approximately 35 lights have been sent to six countries who do not have access to clean light.

Philanthropy is the motivation while engineering is the foundation. Making lights is a natural way to make electrical engineering accessible to all age groups, in all geographies in all cultures and languages.

We invite schools all over the globe to join us to produce lights, adopt this style of learning, and form meaningful partnerships in making the world a brighter place.

CORPORATE CONTRIBUTORS

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NBCC Moncton, http://www.nbcc.ca/, Moncton, NB, Canada.
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