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Students' Perspective on the Effectiveness of Design-Based Curriculum during an International Design Project

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Alex Gamble is a third year engineering student at the University of Prince Edward Island (UPEI). Coming from the small rural community of Alaska, PE, Alex will be transferring to the University of New Brunswick to study mechanical engineering after his completion of the UPEI Engineering Diploma in May 2015. During his second year at UPEI, Alex was part of the four-person design team responsible for developing a better charcoal production system for rural Kenyan farmers. Through their client, Mikinduri Children of Hope Foundation, this team worked diligently to develop a more cost and energy efficient, user-friendly, and greater yield producing charcoal briquette press. This charcoal briquette press design project won the Best Design Team award at the 2014 Engineers PEI Design Expo.

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Spencer Montgomery grew up in Kensington, PEI and graduated high school from Brewster Academy in Wolfeboro, NH in May, 2011. Spencer completed the Engineering Diploma program at the University of Prince Edward Island in April, 2014. While attending UPEI, his second year design group was able to work with the Mikinduri Children of Hope to design a charcoal press that would assist farmers in Kenya. Their final product and expo presentation was awarded the 2014 Engineers PEI Design Team Award. Spencer is currently in his third year of Civil Engineering at the University of New Brunswick in Fredericton, NB where he is a member of the UNB Baseball team.

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Abstract

Design projects are part of many engineering degree programs. During a design project, student engagement and learning are affected by many factors. Writing from the student perspective, the authors formed a model of the structure of what they believe contributes to an effective engineering education. This aided the success of their recent project designing a charcoal press for the Mikinduri Children of Hope Foundation. The design process allows students to apply the mathematic and scientific theory that they learn in other courses. The open ended nature of design projects teach students to think like engineers.

The authors summarized their experiences and key insights from the project. It was concluded that students are motived by their engineering mentor's engagement in their learning and drive to seek improvement. The authors were also enthused by the desire to make a difference, making their learning experience more meaningful. Design projects that address problems posed by real clients, especially those that involve third-world problems, provide that opportunity. Through an evaluation of the design curriculum the authors made recommendations to strengthen student engagement in engineering education.

1 Introduction and Background

Context based education methods, where students are presented with application before science, are proven to be significantly more effective than traditional approaches that teach science first, then apply it to real life.[1,2] The curriculum of many engineering programs within North America has been adapting to this approach within the past few years.

This improves retention rate in engineering programs because it develops anticipation for the engineering profession and pride in the projects that students work on [3]. Moreover, there are also programs where engineering students are exposed to international projects. This allows students to gain experience and learn about different cultures. As the global economy, engineering, and business demographics shift to be more distributed towards the rest of the world rather than being centralized in the west, engineers are now faced with the challenge of solving technical problems within a 'flattened world' and such immersions become vital .[4]

Engineering educators are now faced with the challenge of preparing students to be competitive for a diverse and globalized future. National Academy of Engineering (NAE), in their 'Vision of Engineering in the New Century', discusses the challenges of the global economy and the predicted implication of migration, age demographics, and other effects of globalization in the future of engineering education. Problems increase in complexity, resources are scarcer, and the audience is bigger and conversely more unpredictable. Engineers need increased expertise on systems thinking, customer-focus, working with public policy, communication and teamwork skills more than ever. NAE predicts that engineering will be increasingly applied in ways that significantly, even uniquely, synergize technical and societal knowledge. [5, 6]

Design-based curriculum sets the stage for all of these predicted shifts, such that the emphasis on the balance between skills-based and knowledge-based learning is increasingly incorporated within different programs.[7] The holistic approach of project-oriented and design-based courses leads to students engaging early with the mindset of life-long learning, and shift to ‘process of knowing, rather than possession of knowledge.[8] This promotes flexibility, open-mindedness and adaptability, conversely honing more creative and socially aware engineers.

The authors, four engineering students, present their experience of the design process for an international client. The project was completed as part of a design-based curriculum that incorporated linking students to community-based projects. This project was a partnership with a non-profit organization, Mikinduri Children of Hope Foundation (MCOH) that works in rural Kenyan communities. The problem presented by the client was the currently inefficient process of charcoal production in that region. Due to scarcity of firewood, villagers convert agricultural waste into charcoal briquettes. The current process of compressing the charcoal mixture uses a small steel cup and plunger. The process is highly tedious, has poor ergonomic nature, and is extremely inefficient due to its highly manual operation. It also does not produce enough yield for the amount of work that is required. The MCOH desired to improve the process to minimize the manual operation, and to also provide potential income for the villagers. All feedback from the end user was received electronically as the authors did not travel to Kenya initially.

The authors continued developing the project beyond the course, and the design is now in the implementation stage for use in practical applications. One of the major factors of the projects' success is the experience the authors received before, during, and after the design course. Presented in the next sections are the curriculum structure and content, the design process that was followed, and the evaluation of the curriculum structure. The final section offers a model discussing the authors’ perspective and recommendations for an effective engineering curriculum, to achieve desired student engagement and optimal quality of engineering education.

2 Curriculum Design

The engineering program offered at University of Prince Edward Island (UPEI), where the authors took their first and second years of engineering, consists of four design courses allowing students to work in small multidisciplinary teams to solve real-world problems proposed by real clients. Students progressed through the stages of design, from ideating unique conceptual ideas to gradually building and refining a fully functioning prototype. Professional skills such as critical thinking, decision-making, communication, computer aided design, ethics, and teamwork, are practiced continuously during these courses. Figure 1 enumerates the key aspects of the curriculum, their explanations, and their student outcome reference on the Accreditation Board of Engineering Technology (ABET) Criterion 3. [9]

ABET ref.	Curriculum Key Aspect	Example activities
E, C, H, J	Client-based and Real-life problems	•Students solve problems for clients from industry or non-profit organizations •Regular client meetings provide opportunities for students to receive feedback on ideas •Professors provide students with feedback on submitted work that can help improve the design. •Students participate in every aspect of the design including research, ideation, detailed design, analysis, fabrication, testing, and documentation.
A, B, K	Integrated Theoretical & Experimental Learning in a Problem-Solving Context	•The first two years of the design program combines math and science with engineering specific courses. •Each design project requires analysis to verify the device at each stage of the project. •Students were exposed to using engineering tools like CAD, Matlab, etc.
F, I	Professionalism	•Second year design courses dedicated all lecture time for group meetings, requiring students to remain focused. •Second year students are expected to manage deadlines for their projects and are not required to submit weekly deliverables. • Students are expected to represent the university when they interact with their client. •Students are required to maintain a log book recording the design process, as well as their thoughts and reflections. •At the end of the semester students a required to submit a portfolio of their
D	Team Work	•The design teams are formed from students with varying interests and discipline choices. This combination of ideas contributes to the strength of the projects. •Teams are self-directed
G, K	Communication	•Deliverables were intended to provide students with opportunities to develop their oral and written communication skills. •Technical reports following each stage of the project. •Engineering Drawings of the prototype. •Presentations to the client and fellow students three times during the semester. •Exhibiting at the UPEI engineering expo.

Figure 1: Key aspects of the design-based curriculum at UPEI

3 Student Experience

The students were exposed to real life engineering experience during the second year engineering courses, which allowed them to apply the acquired knowledge of the design process in a community-based project. This allowed the authors to acquire a perspective shift from their focus on tools and theory, into integrating the sustainable and abstract skills required for the profession. Figure 2 highlights the key learning outcomes.

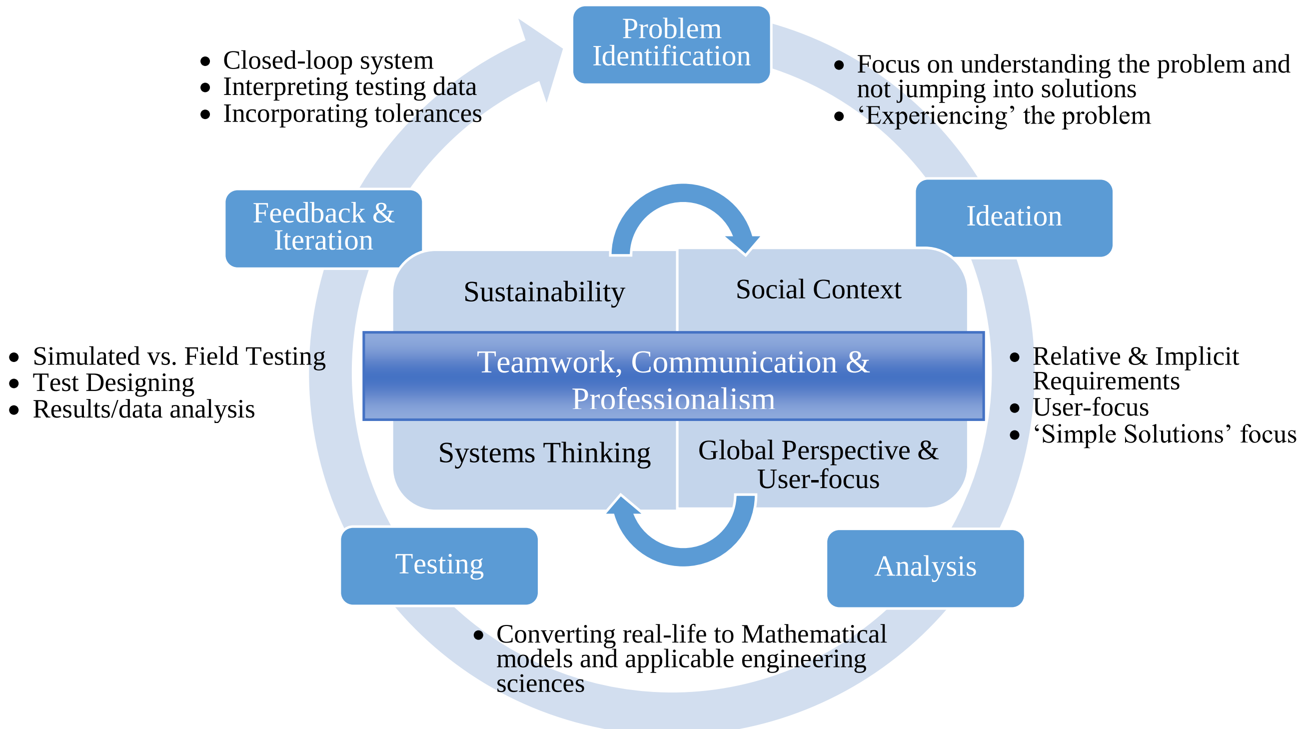

Figure 2: Visual representation of the student experience within the design-based curriculum at UPEI

3.1 Engineering Design Process

For the second year design courses, the team was formed and tasked with developing a charcoal press to improve the efficiency of making charcoal briquettes in Kenya. Two weeks were spent researching the problem, but this only provided superficial knowledge about Kenya and the properties of charcoal.

The first client meeting, with the representative of the Mikinduri Children of Hope Foundation, provided valuable information from someone with firsthand experience of the problem. Speaking with the client made the problem seem real and worthwhile. Having the client take time out of his day provided reassurance that the project we were working on was valuable and that the solution would address a real problem.

Figure 3: Carbonizing Wood

The charcoal-making process was replicated locally, to give the team a better understanding of the current process and to produce the charcoal that would be required to test the prototype. Charcoal is produced by heating organic material until only the carbon structure remains. This process is known as carbonization and in Kenya it is done in a 55 gallon drum (Figure 3). The current process for making charcoal is labor intensive and time consuming. One observation was the length of time it takes to just pack the organic material into the barrel, this is something the authors would not have appreciated otherwise.

Figure 4: Screw Press

The new press concept, developed over the Christmas break, used a grid layout (also called the cookie cutter) to allow a larger batch of charcoal to be pressed into individual briquettes.

Afterwards, the design was developed into a device that applied the force required to compress the charcoal paste with a screw (Figure 4). The screw press consisted of a box with a lid. The grid was placed upright at one end of the box with the horizontally oriented screw and pressing plate at the other. Turning the handle on the box applied a force and pressed all of the charcoal toward the grid. Because the Mikinduri Children of Hope Foundation was sending a team to Kenya in February, it was decided that an initial prototype would be sent. It was during this prototyping process that many of the screw press' weakness began to show. Finding a screw with a large enough thread to compress the charcoal in a timely manner proved to be very difficult. The force application, while consistent, became really difficult as the charcoal became denser. The device was still sent to Kenya despite these flaws.

A video of the inaugural use of the press in the rural community was filmed and emailed to the team for review. Constant communication with the MCOH team was kept during the trip through video calling, which allowed for an immediate iteration of the design. The videos that were sent made the problems with the screw press immediately obvious. The screw press was designed to be used on top of a table; however, in Kenya, the press was used on the ground. This made turning the handle strenuous for the user. This also showed the ergonomic issues that are associated with repeatedly turning the handle, especially with the increased resistance as the charcoal compresses. Since the villagers were also not familiar with the mechanism, they verbally said they appreciate the design but they did not understand how it was really better than their current process. It was observed that the test participants were quite fond of the grid layout and larger batch size. When asked what size of charcoal briquettes they would like the press to produce, the participants responded saying they wanted longer, narrower briquettes as opposed to the smaller, flatter ones typically used in North America. From these observations, it was determined that a new method of force application and a standard recipe for the charcoal paste would be required.

Figure 5: Levered Press

The levered charcoal press (Figure 5) was developed to solve the force application problem. The long lever arm with the fulcrum directly over the vertical plunger allowed for high force to be delivered in less time and with less complexity. The grid, along with the charcoal briquettes, could be removed from the bottom of the press similar to a drawer. The grid was made taller to accommodate the long narrow briquettes desired by the test participants. A wooden prototype of the press was constructed. A design addition resulting from this prototype were the two vertical rails on the side of the press to prevent the plunger from tipping forward and jamming inside the press. A full sized metal prototype press was constructed at a local welding shop. Producing a full drawing package and building the press ourselves was an excellent learning experience and it greatly improved the design. An example of this was that the grid was initially going to be formed out of individual small metal rectangles; however, it was realized that by grinding thin channels into longer metal pieces, they instead could be slotted together.

The UPEI Engineering Design Exposition provided an opportunity for engineering students to show their projects to the public and further develop their communication skills. It also allowed the authors to network with members of other organizations who might be interested in implementing the press. The project received the Design Team award for 2014 from the Association of Professional Engineers of PEI.

At the end of the semester, the final design document and drawing package were prepared for evaluation and delivery to the client. Individual log books were submitted to the professors. A simpler version of the report that would be suitable for use in Kenya was also prepared; however, it was not completed until after the course had ended. In February of 2015, the design was brought and implemented in Kenya, and was used by the actual intended clients for final testing, which proved its success. The Kenyan farmers were pleased with the press and were grateful for the potential aid it can provide them. Their feedback and minor design changes from the trip are now being incorporated in the design, and the drawing package is now being finalized.

While other students in the class completed their designs and closed their projects at the end of the course, the authors felt compelled to continue through the summer because of the potential of the project to make a difference in people’s lives. They also believed that the project was a valuable experience that produced a useful output, and it will be unfortunate to just leave it behind.

3.2 Perspective Shift

One of the most important lessons taken from the project is the perspective shift that resulted from experiencing the design process and the international project.

3.2.1 Global Perspective and User-focus

The project was unique such that the distant clients were made close by the use of technology and connections through community groups. This experience instilled the value of having a global perspective, which was rooted from understanding the importance of a user-focus and the importance of the social context, as shown in Figure 6.

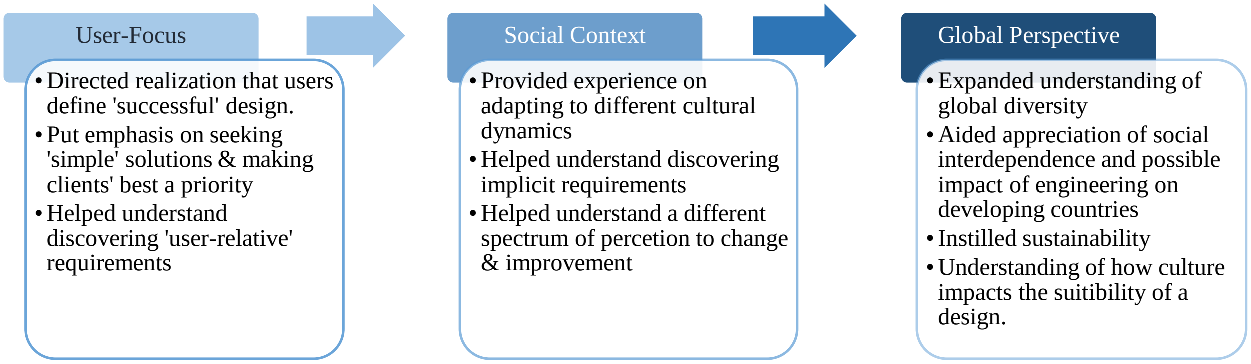

Figure 6: Significance of each level of global perspective to the authors

During the ideation phase of design, it was easy to develop ideas on how to press charcoal because of the convenience of living in North America. There is an abundance of supplies, and creativity is almost unnecessary. The screw press appeared to be ideal due to its compact and portable nature, while still providing the necessary force. It was also easy to manufacture, requiring only the bench screw attached to a plunger and the box.

However, what was an effective design in North America did not function as well for the intended users. Any requirement is relative, and has to be interpreted in terms of the end user. “Simple” meant “convenient to build” in the perspective of the designers before the user input. Yet, it really meant “intuitive and convenient for repeated use” by the users. While analysis and testing proved the design theoretically successful, what mattered was if it served the end users. Every requirement and the success of the design must be defined and determined by the users and their needs.

Embracing a perspective shift by analyzing the issues through the users’ eyes will enhance any design. The rules of theory and classroom education only go so far in developing problem solving skills. The social aspect of engineering design became prevalent throughout the process. The clients are in small communities or rural towns consisting of farmers that have stronger sense of community and a more intact culture. Furthermore, most of the potential users are women. In design, this meant there should be a less than average force required to operate the device. These were requirements only implicit within the context of the problem, and requires understanding the culture to be considered. These problem identification skills are only developed with experience in real-life situations.

Change is difficult for most people, and for smaller rural communities it is even harder to convince villagers that a completely new design is better than their current process. This was another lapse of the Screw Press, since the farmers were not familiar using work benches or cranks, the mechanism did not appeal to them. While there are circumstances where complete change is possible, during this project it was necessary to develop a design that would look and feel familiar to the users. This was one of the reasons why the lever design was used. Changing the culture is not the intent, so the solution had to align with the culture. One of the team members travelled to Kenya in February of 2015 to work with the community to test the design and complete the next iteration based on their feedback. The importance of user-focus in a successful design was proved by their keen interest to the ‘machine’ as they call it, and the design’s acceptability within the community

3.2.2 Engineering Design Cycle and Systems Thinking

This project involved many iterations and is still not complete. These iterations resulted in a shift from perceiving the design process as an open loop or one-way process, to a closed-loop, open ended cycle. Change is constant and applications vary in requirements, therefore the design needs to be flexible and alterable.

The design was brought to Rwanda in November 2014, but not built because of the cost of material in the country. While it is feasible in Kenya, metal fabrication is not ideal in these countries, at least this is the current assessment. Therefore, a wood or concrete box may be more cost effective. Another alternative considered is analyzing the long term benefits of creating a metal design, and if the benefits still outweigh the costs, it can be done elsewhere, though not as quickly as in Kenya.

The project is a useful experience of real-life engineering solutions, where no single formula solves the problem. Not every question has a single answer. And not one, or two, but many cycles through the engineering design process is required to develop an optimal solution.

It also presents the concept of Systems Thinking, which is an important principle in engineering. Engineers need to think in terms of the big picture as well, when developing solutions. To design is not to consider the requirements one at a time. It took keeping all the requirements as concurrent constraints, balancing and weighing where the focus needed to be placed. Within these complexities, genuine creativity is formed.

The design process and the project were useful in understanding systems thinking on a micro-level in terms of the device itself and its components, and on a macro-level, with the design within the intended use and the context it involves.

4 Recommendation and Conclusion

4.1 Model & Recommendations

This section discusses a model that illustrates fundamental components of effective engineering education, from a student perspective. The authors deem that having competent engineering knowledge is equally important as practicing an ethically sound, sustainable, and socially aware profession. This is supported by the principle-focused ABET, as well as the Canadian Engineering Accreditation Board (CEAB)[10] criteria. Therefore, the model in Figure 7, developed by the student authors, presents these two components as the desired balanced outcome, and utmost indicator of the success of engineering education. These two outcomes are balanced by implementing an effective design based curriculum. This is built on a properly balanced framework, consisting of the Mentor Engagement and Methods, Engineering Theory, and Understanding of Engineering Impact at all Levels.

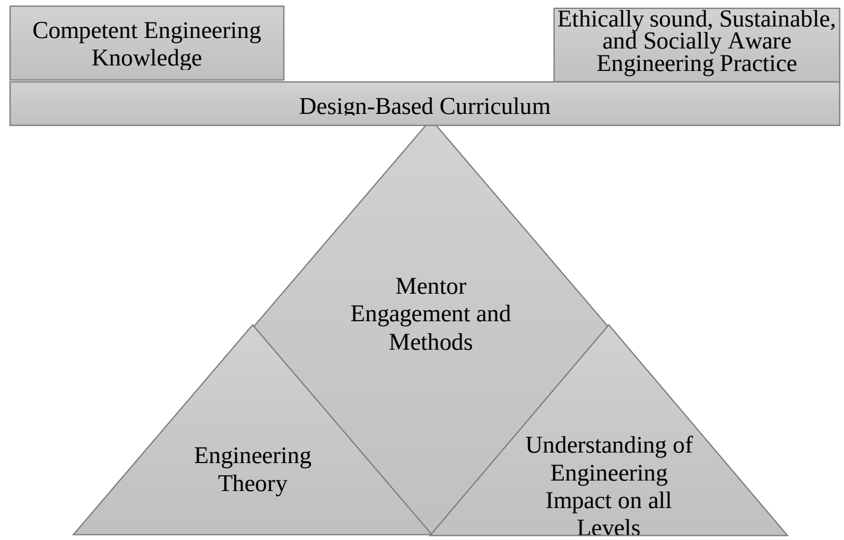

Figure 7: Suggested model of effective engineering education in authors' perspective

The first fundamental is solid engineering theory. Without the proper foundation in the right knowledge and skills, an education opts to fail. This theory includes both essential engineering sciences that instill necessary background knowledge to practice, and disciplines and skills that instill methods and thinking required within the profession. Without teaching students how to 'think' in terms of engineering, all the mathematics and sciences combined do not make up engineering. However, without them, there are no tools to utilize. A carefully and strategically designed curriculum includes courses that offer sound and correct theory, and teaches and empowers students how to think like engineers.

Traditional engineering education focuses on theory, yet, engineering is not a stand-alone profession. It is part of a system that provides different contexts and social realities. The authors then believe this is another foundational aspect to effective engineering education. Students have to be provided with sufficient exposure to these links to the bigger picture, in order to take the most out of the information they learn, and also motivate them to appreciate the profession.

The social aspect of engineering design is usually difficult to grasp within theoretical engineering concepts. Social science electives are required courses in many university engineering programs, but it can be difficult to realize their importance until opportunities like these are taken. This understanding shifts the perspective of students into a systems thinking, which they do not learn theoretically. This enables them to be effective problem solvers, which takes into account global, economic, environmental, and societal factors, which cannot be learned without a contextual setting and experience.

As a link between the two fundamentals and the curriculum, mentors represent a significant piece because of their major influence on the students' learning. The methods used by the mentor and their engagement determines the balance of the curriculum, and also handles a substantial rudder to how it is to be implemented. This suggests that mentors play a significant role in the success of engineering education. Without an effective mentor, even the most perfect curriculum can falter. This requires a credible professor, with considerable experience as an engineer, knowledgeable of theory and appreciating the impact of engineering at all levels. Also, ample concern for the students' learning, and the willingness and ability to mentor and coach.

With an increasing population in engineering, it is rather difficult for a professor to be engaged and involved with every student. However, students are motivated by professors' feedback. Teaching Assistants are usually present, but the level of respect that students pay to professors and the experience they draw from has a different level of motivation.

The bar upheld by the mentor in the model (Figure 7), represents curriculum design, which includes the course structure and content. This bar carries the two outcomes to students and links the goals to the framework. A strong curriculum that integrates all the previous factors well, is required for any successful engineering education.

On a student's perspective, an effective design-based curriculum involves a strong integration of engineering theory and provision of context, as they are discussed in this model. It is difficult to learn abstract concepts, especially within the first few years of study, when the rationale is unclear. The authors propose that the curriculums should further involve focus on developing appreciation and rehearsal of the engineering practice. Students often hear, "This is important because when you work someday…" from professors, but the thought is usually distant and unappealing. Providing opportunities for students to appreciate these themselves, especially in community-based and project-based courses, are rather more effective. While these are aimed at cooperative education through work terms, being able to practice in a classroom environment without the fear of being dismissed or creating distress at work is a good experience. This takes away the focus on the tools, and being mechanically correct in using the formulas, but shifts the perspective to focus on the underlying principles and discipline of problem-solving.

Having multiple design courses also strengthens this concept. As students get feedback, mentoring and coaching from their professors, they become more comfortable and empowered to practice the skills they learn. This may require multiple design courses, or projects, throughout the program. At this time, many programs only include a single design project. This also sets up the students for success in the later years of study and creates a foundational motivation to be a responsible and well-rounded professional.

4.2 Evaluation

Having an actual client and working on real-life problems was an effective immersion into real-life engineering practise. The nature of the problem immersed the authors into third-world country situational realities, providing a foundation to understanding ethics and engineers' responsibility with public & environmental good. Working on problems provided by clients provided students with the opportunity to make a difference in the world. This motivated many students to try harder knowing that if they were successful, their product would be implemented and could change people's lives.

The project also depicts a "step back" to place into perspective how each engineering science course fits within a bigger picture of the engineering process, and how they all interact as a system comprising a design or engineering solution. It also solidifies the abstract concept of the engineering design process, which students learn about but may not necessarily grasp.

Working within the project provided an appreciation for difficult concepts and course work required within engineering. Understanding the principles and the whys and wherefores of the concepts lead to motivation for the profound understanding of the tools, techniques and formulas engineers deal with every day.

As engineering students, it was unusual not to have instructions for how to complete course work. Although there was a steep learning curve, this problem-based learning approach provided an insightful glance into the actual profession, before the senior year engineering projects normally take place. Exposure to the design process in the first year of the program was also a primary reason for the project's success because students had opportunities to learn from their own experiences before this project was undertaken.

The curriculum instills the principle of life-long learning, as the same design process is used during every term, but with increasing complexity and higher expectations, which motivates personal development and continuous self-improvement. This also incorporates mainly through the substantial involvement that the professors invest into mentoring students. The importance of feedback was highlighted, for example, on having to do at least three progressive technical reports to the final report, and requiring multiple revisions for the final report. Professors would print these reports and literally write comments on them for students to reflect on. The students found this to be meaningful and motivational. Valuable feedback was always provided throughout the course through constructive criticism and responding with thought-provoking questions, communicating expectations, and facilitating class meetings.

And finally, this principle places emphasis on the importance of team work and communication principles, which are commonly neglected skills, but are essential for long term success. This is because students can picture how these skills will be useful in the future and how improving them could benefit their personal and professional development.

The authors observed from the experience that while the curriculum is effective in training future engineers and setting them up for success, it is also discouraging to some who do not work well this way. The course structure was found to be problematic and cumbersome for some students. This is expected, since the time commitment is certainly greater than many first and second year engineering courses.

Although the following items were covered in short tutorials, students found that more emphasis and time could have been spent on topics such as: engineering ethics/morals, experience with CAD, build/test plan construction, and building/testing quality assurance roles. Students also felt as though more projects could have been devoted to solving third world problems, as the Kenya charcoal project was the only one to address this. Time spent ideating unique ideas was another curriculum factor students would have liked to have seen increased.

5 Conclusion

The project was intended to teach students to design a device or solution, but it has, most importantly, instilled a greater appreciation of the engineering practice and the value of every aspect of engineering education the students are given. The real-life experience taught authors to think like, and how to be engineers, as opposed to merely teaching them what engineers do and how to do it. The innovative incorporation of a community-based project from a distant third-world rural community introduced the students to a new global perspective. This also enthused the authors to fully engage and persistently seek solutions, because they see the potential to make a difference and impact people's lives. And finally, the engagement of the mentors and their genuine concern for student learning, together with their valuable feedback, fuels motivation and drives students to seek self-improvement. Some recommendations to improve the course are making more resources available to students in terms of facilities and skills training, and increasing the number of community-based and third world projects.

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