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Sustainable Development Needs a Transformed Engineering Education

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Abstract— Engineering educators have an ethical responsibility to develop coming generations of critical and innovative thinkers to be the problem solvers for the grand engineering challenges facing humankind. Our engineering graduates must be the developers of innovative technologies, products and processes addressing sustainable development goals. In this paper, we propose a paradigmatic shift in conventional engineering education curricula, transforming out of conventional chalk-and-talk lectures only accompanied by limited assessment methods of problem sets and exams. This paper suggests engineering programs need to implement changes to update and upgrade curricular and programmatic approaches, ensuring the programmes will graduate transformative thinkers and creative problem solvers. In this paper, we propose several pedagogical approaches be integrated into engineering curricula to be relevant to sustainable development. First, Project based learning (PBL) pedagogies must be incorporated into each course. The PBL should be implemented through Service Learning (SL), requiring projects be community-based and socially beneficial. The PBL approach should utilize open ended design (OED) thinking in implementation and execution of projects, which must address needs and challenges faced by community members around the engineering institutions' communities. Most critically, awareness of ethics in engineering should be integrated into all courses. From the government's policy perspective, they should mandate that government funded and private engineering and technology educational institutions require students complete a community-based service project as part of graduation requirements. This completes the circle and integrates engineering education into sustainable development policy and practice. This paper will outline PBL, SL and ethics in engineering, while describing some of these projects that have served to demonstrate sustainable development through community-based student-driven projects.

Keywords— Engineering, Education, Pedagogy, Project Based Learning, Service Learning, Sustainable development, Open Ended Design, Ethics in Engineering, Policy

***JEET Category*—Practice**

I. INTRODUCTION

It is common for Engineering college Dean's to welcome the freshman class at which the Dean often tells the story of how when he (usually it is a
he) was a freshman and sat in those seats, the then Dean said to them, "Take a look to your left and to
your right, only one of the three of you will make it through our program in four years,". What the Dean
now wants to, and does, tell today's freshman is, "Take a look to your right and your left, and make sure that ALL three of you work together to graduate in four years." The shift in this introductory narrative should also be a signifier for a shift from the conventional pedagogical approach in engineering education of lectures (chalk and talk) and problem sets followed by exams or tests with all students competing against each other, to a pedagogical approach where students work collaboratively in groups to cooperatively solve real world problems applying the theories they learn in the chalk and talk components of the curricula to real problems faced by the communities that surround them. Engineering education must respond to this challenge through much needed transformations, integrating project-based learning (PBL) into as many courses as possible in their curricula, enabling service learning (SL) through community based and driven service projects, and integrating open ended design into faculty's pedagogical approach to teaching their students, while also incorporating discussions on engineering ethics into the course work in all courses in the curriculum.

The state of pedagogy and pedagogical approaches in engineering education appears, for the most part, to be stuck in old models that no longer address current needs (Sorby et al, 2021). There are exceptions, such as the Olin School of Engineering, but for the most part, engineering curricula (and faculty) emphasize theory over practice, rely on a lecture and problem set and exam approach, and are embedded in the pipeline model with sequences of courses in math and science that students must take resulting in many students being precluded, not just excluded, from getting an engineering degree, and the implications this has for equity. The need for transformative change in engineering curricula has been recognized and discussed before (Apte, 2021), including curriculum redesign to break calculus's bottleneck hold on student progress (and thus also addressing equity issues by allowing students with inadequate and insufficient preparation to still envision engineering as a career), course redesign to be

able to omit irrelevant material from "core" course syllabi with feeling neither that we have short changed students nor that we let student's get off easy!

It is important to remain relevant to today's youth, who are not content to merely address social justice and equity issues in their private lives but also in their work, that our engineering curricula and pedagogy must reflect this. Engineering education has to address the needs of our rapidly changing society, which is diverse, digital and global, preparing our students not only for career's that exist today, but to be able to prepare themselves for career's that are yet to be created, and indeed to be creators of those jobs as well. Engineering education and curricula must incorporate modern tools that enable students to work in groups to solve messy real-world problems that require the synthesis of concepts from multiple disciplines, and where students apply logical boundary conditions with rigorous assessment of outcomes. In fact, engineering education needs more integrative, hands-on problem solving, which would address issues described earlier as well.

To be relevant and provide students the ability and capability to address and sustainably solve problems faced by their communities, engineering programmes need to support faculty efforts to transform their courses to incorporate Project Based Learning and requiring open-ended design thinking in student work. These are approaches that will nurture and develop critical and creative thinking skills in students while enhancing their problem solving abilities (Tharakan, 2020).

In this paper, we propose that sustainable development thinking can be integrated into engineering education through Project Based Learning, Service Learning, and Ethics in Engineering. The transformations in engineering education necessary to develop the engineers of today and tomorrow who will be able to innovatively and creatively address the Sustainable Development Goals and Grand Challenges in Engineering that we are faced with. At the same time, government policy from ministries and departments of education must mandate state supported as well as private engineering and technology institutions require that students must work in groups and complete community-based community service projects as part of their engineering and technology curricula.

This paper proposes just that: service learning, implemented through PBL, incorporating community-based projects addressing community needs through ethical engineering design and open-ended design thinking, should be a requisite inclusion in engineering curricula, addressing sustainable development in developing and under-resourced communities. PBL and SL are discussed and developed as the vehicle for integration of sustainable development into the curricula and engineering program. This paper argues that sustainable development from the ground up in these diverse developing countries can be dramatically enhanced and expanded if curricular community-based service-learning experiences are made a regular and mandatory component of engineering, technology and social science program curricula in the country's universities and colleges.

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II. PROJECT BASED LEARNING

Project Based Learning (PBL) is a teaching method in which students learn by actively engaging in real-world and personally meaningful projects. PBL is a teaching method in which students gain knowledge and skills by working for an extended period to investigate and respond to an authentic, engaging, and complex question, problem, or challenge. Students work on a project over an extended period of time – from a week up to a semester or longer – that engages them in solving a real-world problem or answering a complex real question. Students then demonstrate their knowledge and skills by creating a public product for presentation to a real professional audience of their peers and faculty.

The benefits to students are broad and deep: they develop deep content knowledge while developing critical thinking skills. Having students work in groups enhances collaboration skills while the real-world community-based problem will ignite creativity and collaboration. Communication skills are developed with expectations of the students for written reports and oral presentations of their projects.

For PBL to be successful, these are some of the essential components, including a challenging problem/question that is based on a real-world context providing the authenticity needed. PBL programs and projects must be rigorous enough to require sustained inquiry and rigorous research. Students must have a voice and choice in the selection of the problems and projects, and all programs should be configured to provide students ample opportunity for reflection, critique and revision prior to presentation of a public product such as a report and presentation.

A. SERVICE LEARNING

The definition of Service Learning, or SL, is an academic and/or curricular activity that is both course based and credit-bearing, and that includes two major components: engagement of students in a self-selected, driven and planned, but professionally and academically supervised and mentored, service activity, *and* an opportunity and requirement to engage in scholarly reflection and writing on the service activity in an academic context (Bringle and Hatcher, 2007; Bringle et al, 2004). Service learning has been deemed of great value to a diverse set of stakeholders, delivering benefits of academic and experiential nature to students, faculty, community partners, and society in general. It has been shown over the past several decades that SL experiences promote independent and critical thinking skills and greatly improve educational outcomes (Eyler & Giles, 1999, 2001).

An earlier paper focused on SL (Tharakan, 2011) described the extension of Engineers Without Borders project activities into an academic service-learning experience that could be incorporated into regular engineering curricula. As demonstrated in that paper, engineering curricula had space for incorporation of service activities into academic curricula through the development of focused independent study courses, where the student service volunteer works closely with a faculty member to fashion and configure an academic

credit bearing course of study focused on the engineering and technology that the student's had engaged in as part of their service activity. A second paper (Tharakan, 2012) described this in the context of a renewable energy implementation project that students had engaged in as part of a broader research project (Tharakan et al, 2008).

These service activities were built around Engineers Without Borders-USA (EWB-USA, 2021) projects that the Howard University Student Chapter of Engineers Without Borders (EWB-HU, 2009) were engaged in. The focus of the EWB-HU projects were the development and implementation of rainwater harvesting systems and biosand water filtration systems in a rural community in Kenya that suffered from water quantity and quality issues. These service site visits of EWB teams to communities in need provided a model for academic and curricular based service-learning experiences that could be incorporated into standard engineering curricula. This was proposed as mechanism to expand the pool and provide all students in an engineering program with the benefit of these types of educational and practical experiences. Those studies also demonstrated that capacity building within the communities served was possible if the service-learning project was design and developed with appropriate mentoring that ensured that community education, outreach, engagement and empowerment was an integral part of the service project design and implantation plan.

B. SUSTAINABLE DEVELOPMENT

Sustainable Development as term came into existence several decades ago through the Brundtland Commission, which generally and broadly defined it as development that would not harm or reduce the capacity of future generations to sustain and thrive themselves. Sustainable development is characterized by moves towards environmentally benign resource extraction, the use of renewable energy sources, the minimization and eventual elimination of waste streams, a circular industrial economy and eventually a zero-waste system. Sustainable development has become a buzzword, often used without clear evidence that whatever is being proposed to be implemented in any under resourced community is actually "development" and whether it is actually "sustainable". For a development intervention to be sustainable, the capacity of the community to sustain it must be developed. Capacity building is grounded in the fundamental idea that in order for real sustainable development to take place, the capabilities of the community must be enhanced, increased and expanded, giving the community the capability, whether in terms of training, knowhow, or skillsets, to address their own developmental needs from the ground up. Education is critical to sustainable development, and engineering and technical education more so.

From a philosophical perspective, the emergence of the idea and notion of sustainable development occurred through a confluence of several factors including Paolo Freire's *Pedagogy of the Oppressed* which showed that education couldn't be handed down from the heights of master to student but had to be achieved through dialogue on an equal footing; Freire went further to validate and legitimize the knowledge and experience of the oppressed to give them voice in their own education. Hence for development to be sustainable, the process should reduce vulnerabilities and increase capacities of communities. Neutrality of the development cannot be assumed, nor is it a given (Eade, 2005). Renewed emphasis and focus were placed on sustainable development to be community engaged; development has to be participatory to be sustainable and has to build capacity in the communities themselves.

III. SERVICE LEARNING AND SUSTAINABLE DEVELOPMENT

Bringing service learning into the suite of tools available to address sustainable development efforts is a natural fit. Kapucu and Petrescu (2006) have demonstrated the success of service learning for CB exploring the history and characteristics of service learning at two universities, University of Central Florida and Eastern Michigan University and presents service learning as one way for the community and institutions of higher education to engage in CB. Although not a systematic scientific inquiry, the paper is a critical reflection on field experience and demonstrates the importance of service learning for the community's sustainable development. What is actually done through service learning is the promotion and sustenance of the common good through civic engagement, which in turn builds social capital. Their service-learning projects helped to foster development of a sense of caring about others, positively impact civic participation, and sustain social capital and hence everybody involved in the SL learns: most importantly, social capital is developed sustainably.

From the perspective of this paper's approach, we argue that engineering service projects that are community centered and focused on extension of engineering curricular content outside the laboratory and classroom to engage communities in addressing development problems, will foster sustainable development in the target community. A recent implementation site visit of the EWB-HU Student Chapter (EWB-HUSC) will serve to illustrate an example of sustainable development in a community where EWB-HUSC conducted an implementation visit as a follow-up to an earlier assessment visit to engage with the Choimim community in the Nandi Hills region of northwestern Kenya. The earlier assessment visit resulted in the community requesting EWB-HUSC intervention to help them address the dire water quantity and quality resource issue in the area. The implementation visit thus focused on addressing the community prioritized need for improved water quality and quantity. The EWB-HUSC team worked with the community, developing through education, training and technology transfer, a set of community engineers (CE's) who would be the node points for the initial implementation of the suggested technology solution of biosand filtration (BSF) systems. The EWB-HUSC team engaged with a local NGO in sourcing local materials for the implementation and raised the funding required for the purchase of components for six BSF systems.

The components were then transported locally and assembly and deployment of the BSF's was conducted with the engagement of the CE's. The development within the community of a set of "community engineer's" capable of maintaining and operating the implemented technology is enhances the sustainability of the biosand filtration technology in context of the Choimim community. These CE's are now engaged, along with the NGO in monitoring and evaluation of the BSF's functioning and are also capable of expanding and dispersing the BSF technology to other members of the community, dispersing the sustainable development.

IV. Engineering Education and Sustainable Development

Education policy has a tremendous impact on sustainable development, indeed on how societies address the challenges they face and how they come together to develop solutions that are beneficial to the community while not being harmful to the environment. Educational policy in Cuba, for instance, at their premier engineering and technology research and education institute, CUJAE, senior design projects in all engineering departments require community engagement and real-world problem solution through the execution of the senior design project. In a similar manner, the Indian government through the University Grants Commission (UGC) has put forth several initiatives where engineering institutions are urged to have their students engage in community service of some kind or other. This has been more finely tuned in the Unnat Bharat Abhiyan program they have launched, where rural development is the specific goal. What we have shown is an instance where the service-learning engagement of the EWB-HUSC team resulted in the sustainable development of the community of Choimim village, addressing their water quality and quantity resource issues. This has been demonstrated in other context as well, such as students in a graduate environmental engineering program addressing water resource issues to enhance literacy on water availability and access in women's self-help groups (SHG's) and community-based organizations (George et al, 2020).

This is a model, where the education of future technologists and engineers is integrated into the sustainable development policies, project and processes of any country, that should be considered in universities and colleges across the globe, more so in developing countries.

V. CONCLUSION

Service Learning has been discussed in the context of community development projects that are engaged in by student volunteer groups from the engineering and technology disciplines. It was previously demonstrated that service projects that had been extended into academic credit bearing independent study courses could positively impact quality of life issues in under served and rural communities. Here, we have argued for the transformation in engineering education moving away from the chalk-talk approach, to using PBL and SL in engineering curricula that has an impact on the sustainable development of a community, providing technology transfer and training that has been vetted through adequate and appropriate mentorship and professional guidance built into the engineering programs. What is suggested, and what reaffirms earlier indications, is that the SL pedagogy, appropriately implemented in engineering curricula across educational institutions and programs, using PBL, open ended design thinking and community-based problems as their target, and integrating engineering ethics into design thinking, could have tremendous potential to positively impact community sustainable development efforts from the ground up. Channeling the energy of our youth through appropriate academic guidance and mentoring should be an integral component of national sustainable development strategies and policies.

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