Proceedings of the 16th International Mechanical Engineering Congress & Exposition
IMECE2016
November 11-17, 2016, Phoenix Convention Center, Phoenix, AZ, USA

IMECE2016-68084

UNDERSTANDING THE IMPACT OF ENGINEERING THROUGH APPROPRIATE TECHNOLOGY DEVELOPMENT

Nickey Janse van Rensburg
University of Johannesburg
Faculty of Engineering and the Built Environment
Department of Mechanical Engineering Science
University of Johannesburg, PO Box 524, Auckland Park, 2006
Johannesburg, South Africa
nickeyjvr@uj.ac.za

Z Simpson
University of Johannesburg
Faculty of Engineering and the Built Environment
Engineering Education
University of Johannesburg, PO Box 524, Auckland Park, 2006
Johannesburg, South Africa
zsimpson@uj.ac.za

N Malan
University of Johannesburg
Faculty of Engineering and the Built Environment
Department of Anthropology and Development Studies
University of Johannesburg, PO Box 524, Auckland Park, 2006
Johannesburg, South Africa
nmalan@uj.ac.za

ABSTRACT

This research describes a pilot project which aimed to introduce CDIO-type (Conceive-Design-Implement-Operate), project-based learning through a community-based project in a third year Material Science module. The project formed part of an agriculture research initiative, and relied on interdisciplinary research collaboration between engineering, social sciences, management, entrepreneurship, and industrial arts. The initiative seeks to develop an agribusiness solution that will create an open-market, growth-oriented food economy. As part of the initiative, engineering students, participating in teams, worked alongside a community of urban farmers, most of whom are working poor, so as to develop appropriate, intermediate technology/ies that could support the farmers. This was informed by the need to have students demonstrate high level understanding of disciplinary content, but also to engage in human-centered design thinking and practice.

KEYWORDS

Engineering education; SOLO taxonomy; Project-based learning; Community engagement; Multidisciplinarity

INTRODUCTION

It is a global challenge to reduce our carbon footprint, and to lessen environmental impact more generally. At the same time, societal development needs to be addressed and a focus put on people's well-being. The growing pressure to lessen environmental impact is often at odds with the need for businesses to remain profitable and globally competitive. There is thus a significant need for investment and expenditure to improve energy efficiency, modernize infrastructure and create high quality living environments [1]. In a world defined by rapid change, the search for solutions to so-called 'wicked' problems [2] has become an urgent and complex challenge. The social change arena is growing rapidly, driven by an agenda for both sustainable economic development and stable democracies. The concept of 'social innovation' has been rapidly emerging since the late 1990's as an innovative approach to dealing with complex social needs [3]. With its emphasis on creative problem solving, in relation to human behavior and social innovation and through the use of technology, social entrepreneurship blurs the traditional lines between the public, private and non-profit sectors. Social entrepreneurship and innovation emphasizes hybrid models of for-profit and non-profit activity [4].

This paper argues that, within the higher education environment, participation in research and development programmes that support social innovation provides an authentic learning environment in which the impact of technology and engineering within society can better be framed. According to the Engineering Council of South Africa (ECSA), students are expected to demonstrate a critical awareness of the impact of engineering activity on the social, industrial and physical environment. This is similarly enshrined in the ABET student outcomes dictated for engineering degree programmes in the US. In both countries, and many others besides, students should also be able to demonstrate an ability to work effectively as an individual, in teams and in multidisciplinary environments.

This paper argues from the position that, if these student outcomes are taught in a decontextualized, artificial manner, we miss the opportunity to use social innovation and community engagement as a valuable tool for teaching competencies such as human-centered design thinking, project management, communication skills, teamwork, and business skills. Applying the principle of 'co-creation', we can build an environment where engineering graduates are challenged to create technology that serves society and brings about social change. By deploying the principles of human-centered design and collaborating with communities, we can create a multidisciplinary environment (including engineering, business and social sciences) to both teach and assess the ECSA/ABET student outcomes more effectively.

A key to innovation-driven economic development in Africa is the availability of a substantial quantity and quality of scientists and engineers that are adequately equipped to apply knowledge and technology so as to enhance the way society functions. The Research and Projects (R&P) Office in the Faculty of Engineering and the Built Environment at the University of Johannesburg encourages an interdisciplinary, project-based approach to research and the promotion of community-driven, social entrepreneurship and innovation through technology innovation, digital enablement and commercialisation. The R&P Office identifies social and commercial projects that connect community-driven, interdisciplinary research across faculties. This approach has proven to add significant value through enhancing research and teaching opportunities in collaboration with business and industry partners, and supporting local and national Government to achieve the goals identified in the National Development Plan. Exploiting the interdisciplinary research potential of social and commercial projects, the R&P office unlocks new opportunities for collaboration across faculties, with industry and business partners and civil society, and generates third stream income. The function of the R&P Office is illustrated in Fig. 1

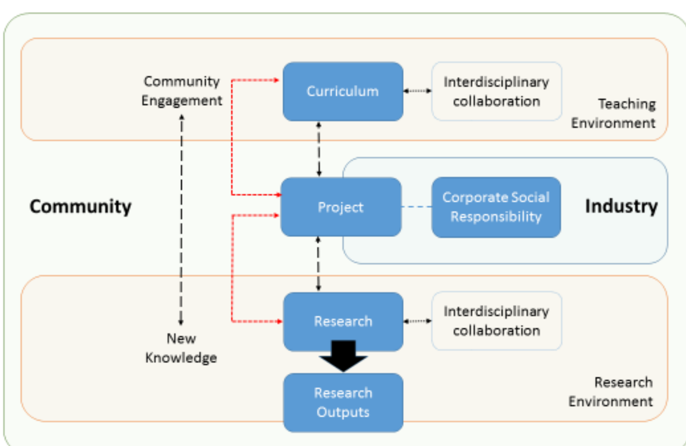

FIG. 1. PROJECT-BASED RESEARCH APPROACH

Community-based, interdisciplinary projects enable CDIO-type learning strategies to be deployed so as to teach students to conceive, design, implement, and operate (hence, CDIO) complex, value-adding engineering products, processes and systems in a modern, team-based environment [5], and in a real-life setting. However, social entrepreneurship and CDIO teaching methodologies do not sit comfortably within traditional academic institutions, even more so in environments where science, engineering and technology is the main research focus. The aim of this paper is to discuss one such community-based, interdisciplinary project, the Youth Agriculture Initiative, with a view to illustrating the important role that such projects can play in augmenting student learning and development.

CONTEXT AND ENVIRONMENT

We are teaching and learning in times of overwhelming change. Moreover, the ways we know, the ways we teach and what is expected of us as both educators and learners is changing. Engineering programmes need to not only teach the fundamentals of the discipline, but also need to develop personal and interpersonal traits [5], and the necessary skills to produce technologies, processes and systems that are aligned with the global sustainable development goals. There is an urgency in the need to eradicate poverty, lessen inequality and achieve sustainable development. The development of solutions requires extensive collaboration and participatory and co-creation methods for design [6]. Furthermore, empathy, awareness and a human-centered approach are required so as to reframe the problem and to develop innovative solutions. Design thinking and entrepreneurial skill are also important in such a climate of change, being as it is littered with complex, interconnected, seemingly insurmountable problems, framed by incomplete and contradictory knowledge and beliefs.

As a progressive model with roots in design education, design thinking has found its way into business schools as a way of driving innovative decision-making and organisational change. Unlocking the resources and potentials of Universities in addressing social challenges is not a novel concept. The salient benefits of integrating community-driven research activities into the curriculum are known [7, 8]. Organised voluntary associations (such as Engineers Without Borders) are seeing more students volunteering their time and skills to extracurricular activities that promote social change. The educational benefits of cooperative learning, working in multidisciplinary teams, and implementing project-based learning [9] have long been established, yet this is not the norm in higher education. The opportunity to drive social change and develop change agents through the tertiary education system is not often realised, particularly not in South African universities. The reasons for the seemingly slow uptake of social innovation within academia could include perceived academic risk on the part of students, an overloaded curriculum, additional burden on financial and human resources, a performance management system that promotes institutional ranking and individual performance, difficulty in assessing learning outcomes, and resistance to change. As Universities continue to navigate by the stars of world rankings, primarily derived from easy-to-measure criteria, they conform to a very specific set of standards not necessarily designed to promote innovation, social change and quality education [10].

Promoting social innovation through technology demands a comprehensive view of technology as embedded in socio-technical systems. Developing technology in such a context demands that engineers hold skills derived from the social sciences and economics. These skills can be taught in formal settings or in applied and practical service learning contexts. Exposing engineers to social science skills and then applying these through service-learning activities enables engineers to tacitly and implicitly understand society better and cultivate a sense of how their designs will impact society. The benefits of such real-world exposure are numerous and include the potential to see problems afresh and thus develop novel and creative solutions. The literature is clear on the fact that social and technical skills are equally important components of the repertoire that graduates need in order to be considered industry-ready [5].

There has been a marked shift in the acceptance of the pedagogical usefulness of service-learning and community engagement within engineering as evidence increasingly points to how these experiences prepare students for careers in the private, public and non-profit sectors. There is also growing evidence that community engagement can be a powerful tool in the efforts to eliminate underrepresentation within the engineering profession [11, 8, 12]. Engineers are expected to function in a highly competitive environment, which demands that projects are developed in increasingly efficient and cost-effective ways, across various disciplines. The literature reveals that engineering students "must learn how to merge the physical, life, and information sciences at the nano-, micro-, meso-, and macro- scales; embrace professional ethics and social responsibility, be creative and innovative, and write and communicate well. Our students should be prepared to live and work as global citizens, [and] understand how engineers contribute to society" [5]. These lofty goals are embodied in the outcomes that ECSA, ABET and other accrediting bodies define for engineering graduates across the globe.

DESIGN THINKING AND CO-CREATION

Design thinking has emerged as a progressive method for creative problem solving and for effecting social change. It relies on an iterative, collaborative, human-centered approach in which the designer redefines and reframes the problem with end beneficiaries involved and in mind. Design thinking is characterised by five iterative stages: empathy, definition, ideation, prototyping and testing.

The first stage involves developing empathy through ethnographic research. This stage aims to engage with stakeholders and beneficiaries through open-ended conversation and applies ethnographic methods of immersion to observe end-users. Explicit and implicit needs, as well as underlying meanings and insights, are identified and then used to reframe the problem. During the definition stage, the system is mapped out and choices made regarding which solution spaces to focus on. This implies that solutions are designed so as to address a specific subset of needs as opposed to attempting to address all needs. During the ideation, prototyping and testing phases, brainstorming and flaring techniques are applied and prototypes are developed so as to test and evaluate solutions. As mentioned, this is an iterative process and it relies on extensive collaboration, stakeholder engagement and co-creation of solutions.

In recent years, a method of organisational change known as co-creation has spread rapidly within the business sector. In a co-creative effort, multiple stakeholders come together to develop new practices that would traditionally have emerged only from a bureaucratic, top-down process. Change, moreover, occurs not just at the level of an organisation, but also across an entire value chain. Applying the same principles, it is proposed that co-creation and multi-stakeholder participation can be used to develop an integrated curriculum design approach, the purpose of which would be to change the way we train graduates by emphasising creative problem solving.

Such a curriculum has to acknowledge the need for enhanced positive social impact through technology design. This is an uncertain outcome, but the likelihood of such outcomes can be enhanced by exposing students to events where they come into contact with marginalized groups in society who could potentially benefit the most from appropriate technology. Students also need to understand that these efforts to engineer positive outcomes have roots in development paradigms such as sustainable development [13]. Furthermore, the curriculum can be layered with critical and novel perspectives on technology and design, particularly the longstanding tradition of 'appropriate technology development' [14]. Scenario-building and 'what if' thought experiments can also be used to optimize the impacts of technology and design on society. Lastly, the curriculum and service-learning context can be enriched by instances of Socratic Dialogue where an interlocutor tries to expose assumptions and unsaid inferences in decision making in design [15]. Fisher calls these interlocutors 'embedded humanists' whose role it is to alert technologists to alternatives: the use of such embedded humanists has been proven to lead to significant, novel design. In all these efforts, maximizing participation in the design process on the part of researchers and beneficiaries is the bedrock upon which socially innovative design is founded.

THE PROJECT-BASED DESIGN TASK

Inappropriate or improper decisions in the design process can be disastrous from both an economic and a safety perspective. Included herein are decisions regarding material selection, which was a particular focus of the pilot project focused on in this paper. In the project, students were tasked with identifying appropriate intermediate technologies that can support local urban farmers. This project formed part of an interdisciplinary community engagement project undertaken in partnership with local government as well as not-for-profit and non-governmental organisations.

During this assignment, students worked in randomised groups and the software application CATME was used to coordinate peer reviews and surveys. Students were organized into teams of 20, each with 4 divisions. Students were expected to demonstrate an understanding of the procedures involved in the design process as emergent from a design thinking standpoint, and also to use appropriate manufacturing and material selection strategies. The objective of the assignment was to introduce students to the procedures and protocols normally employed in the material selection process while developing design concepts that could support an urban farming community through appropriate technology development. Guidelines on design were made available to the students and two workshops were conducted aimed at introducing and framing the design task. The first of these design thinking workshops introduced students to strategies used to develop empathy, define the design problem, develop ideas and conceptualise solutions, and to develop and test prototypes with the end-user involved. A guest lecture was also presented by a colleague from the Humanities faculty regarding appropriate and intermediate technology design.

To create opportunities for the students to apply these newly-introduced skills, they were introduced to farmers participating in a community engagement initiative with the University. Students interviewed these urban farmers in an attempt to better understand the environment for which, and the people for whom, they were developing solutions. Students were also given the opportunity to pitch their design ideas to graphic design students from the Faculty of Arts, Design and Architecture who assisted in developing the visual design of their design concepts.

Krippendorff [16] defines human centered design as an approach to design and research that takes seriously the proposition that behavior and understanding are interlinked, that the use of artefacts is inseparable from how users conceive them and engage with them in their world. He further adds that "humans do not respond to the physical qualities of things but to what they mean to them." This implies that design activities should aim to identify the meaning which a product, system or service should offer to the people intended to use the artifact. Such a view suggests that design activity should concentrate first and foremost on questions of motivation, discourse and learning before proceeding to identify the means of implementation [16].

As discussed above, design thinking relies on an iterative, collaborative, human-centered design approach during which the designer redefines and reframes the problem with end beneficiaries involved and in mind. The iterative stages of design thinking include empathy, definition, ideation, prototyping and testing. To evaluate students' perspective on design thinking and human centered design, students were asked to schematically illustrate the design process. This paper serves to describe the project-based intervention, and the pedagogical and social bases for this project, rather than to evaluate the project. As such, only limited reference is made herein to evaluative data collected, and this is done only so as to provide an indication of the potential benefit that can be derived from such project-based interventions.

A survey was completed during one of the class lectures where students worked in smaller divisions within their teams. The students were allowed to discuss the question pertaining to the design process and constructed a schematic illustration that represented their group view, with 3 to 5 members in each of the groups. Artifacts created were handed in after each question to avoid students going back and editing or adding as the survey continued. In an attempt to test the human *centredness* of their understanding of design, artifacts produced were evaluated based on whether or not their representation of the design process included human centered design thinking elements. Four categories of design processes were identified and typical examples are shown below (Figs. 2 and 3).

The majority (12 of the 16 of the groups surveyed) presented what would be termed a traditional, linear design process. A sample of what the student-groups produced in response to this question is illustrated in Fig. 2. These groups illustrated the design process typically starting with the problem identification phase or by defining the problem statement. Their representations of this phase included no mentions of the end-user needs as a parameter which could inform the problem identification phase.

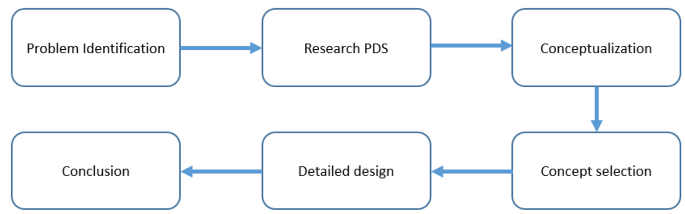

FIG. 2. LINEAR ENGINEERING DESIGN PROCESS MAKING NO REFERENCE TO INVOLVING THE END-USER.

Of the 12 examples mentioned above, it was noted that approximately half of the groups did include some reference on efforts to understand the problem, brainstorming ideas or to conduct background research, but did not explicitly mention the end-user in the design process. This was largely represented as part of the beginning of the design process, and was usually counted as part of the problem identification phase mentioned above. Two of the groups indicated that defining the product design specifications was the first phase of the process. The remaining students, representing a quarter of the students surveyed included some elements of developing empathy, framing the problem with the end-user in mind and involving the end user in a iterative the design process as illustrated in Fig. 3.

The second part of the survey asked students to define human centered design and reflect on the importance of a human centered design approach in engineering design. Students also had to comment on how their perspective changed relating to human centered design as a result of the intervention. The students managed to accurately define human centered design and highlighted the importance of the approach as it relates to identifying customer needs, to understand the environment where the technology will be implemented and the impact the technology could have on people's lives. The students also referred to the importance of co-creating solutions through an iterative process, involving the end-user. All the students participating in the discussion, bar one, reported being unaware of the concept of human centered design prior to the intervention.

Design, particularly engineering design, is often made synonymous with 'high'-technology. However, examples are becoming numerous of instances in which the most 'appropriate' designs are in fact 'low'-technology (one such example is the gravity light: see http://gravitylight.org/); such designs are much more appropriate than high-tech designs in solving many of the problems of today. Technology needs to emancipate people from their dependence on large, costly socio-technical systems that are often highly inefficient. Technology should also be repairable in local context, perhaps even manufacturable within decentralized systems, and amenable to modification by users. Such is the promise of 'appropriate' technology, which could release considerable resources for the rest of human endeavor.

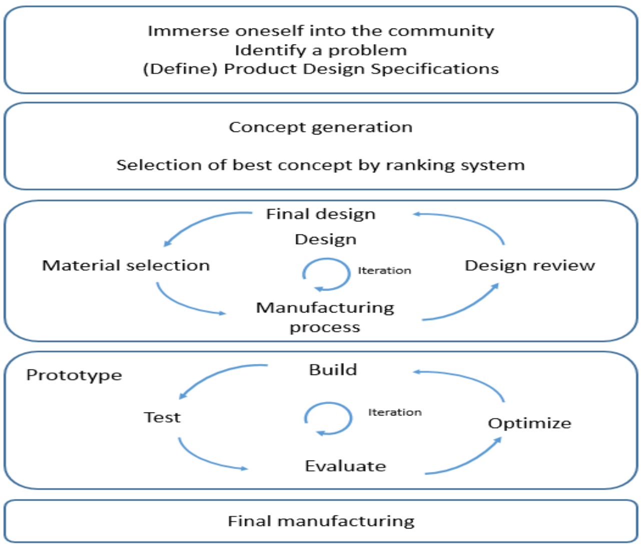

FIG. 3. ITERATIVE ENGINEERING DESIGN PROCESS MAKING REFERENCE TO INVOLVING THE END-USER.

TEAM WORK

The students reported on typical group dynamics and challenges associated with working in teams. Students were asked to reflect on the challenges they faced as a team and report on strategies they implemented to overcome the biggest perceived challenges. This exercise was completed in 4 teams of 20 members, and recorded for each group following a group discussion. A list of the challenges identified by the groups are merged below:

- Effectively communicating (one team specifically mentioned language barriers in a multilingual society
- Decision making
- Group efficiency, participation and focus
- Division of labor and varying levels of commitment.
- Scheduling meetings outside of scheduled group work sessions on timetable.
- Delegating tasks and managing design process
- Time management and missing internal deadlines set by group
- Varying skills level

All teams reported that communication was one of the biggest barriers to overcome and that although working in a team gives the individual more resources to work with, it complicates the task execution. Strategies implemented included subdividing into smaller groups, organized around tasks that needed to be completed and relying on mobile messaging applications to communicate.

CONSTRUCTING A NEW CURRICULUM

From a pedagogical perspective, another way of examining a project-based teaching and learning intervention such as that described above is by examining the extent to which it enables students to engage in high-level understanding (that is, application, evaluation and theorization) of disciplinary content. To this end, it is helpful to consider Biggs' (2003) Structure of the Observed Learning Outcome (SOLO) taxonomy. This taxonomy gauges student learning in terms of the complexity of understanding that they demonstrate. Assessment often requires of students only that they display *uni-* and *multistructural* understanding of disciplinary content: this means students are required only to undertake tasks such as list, define, compare, contrast and so on. However, engagement in human-centered design practices, such as those required of this project, requires that students operate at a *relational* and *extended abstract* level of understanding of disciplinary content: this requires of students that they evaluate, criticize, hypothesize and, importantly, reflect on what they have learnt. The SOLO taxonomy, as a framework for understanding student understanding is represented in Fig. 4. High-level understanding of disciplinary content is necessary if students are to fully appreciate the impact of technology on the environment and society, and link their learning to the achievement of sustainable development goals. In Table 1, two of the relevant ECSA/ABET outcomes are described with reference to their associated assessment criteria. In Table 1, we provide discussion of how this pilot project develops these outcomes and how it moves students towards high level understanding of the content of, in this case, material science.

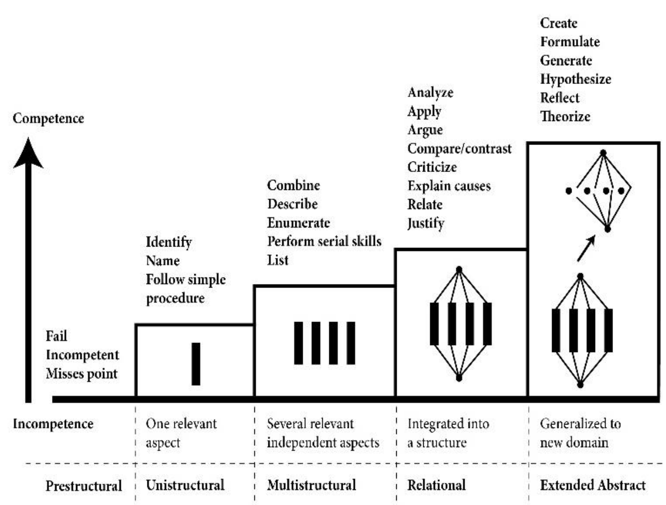

FIG. 4. SOLO TAXONOMY AS A FRAMEWORK FOR UNDERSTANDING

TABLE 1. ACCREDITATION STANDARDS FOR UNDERGRADUATE ENGINEERING PROGRAMS

ABET (h)	The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
ECSA ELO 7	Sustainability and impact of engineering activity.
Description: An awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment.	
Associated Assessment Criteria*: The candidate identifies and deals with an appropriate combination of issues in: 1. The impact of technology on society; 2. Occupational and public health and safety; 3. Impacts on the physical environment; 4. The personal, social, cultural values and requirements of those affected by engineering activity.	
Range Statement: The combination of social, workplace (industrial) and physical environmental factors must be appropriate to the discipline or other designation of the qualification. Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: health, safety and environmental protection; risk assessment and management and the impacts of engineering activity: economic, social, cultural, environmental and sustainability.	
How is high-level understanding realized, as per the SOLO Taxonomy? Students are required to *reflect* on the challenges facing urban farmers and *hypothesize* how technologies might be developed to address these challenges. In order to complete the project, students must *formulate* various solutions to the problems and *evaluate* these solutions. In the final year capstone courses, students must ultimately *select* one solution and *create* a working design.	
ABET (d)	An ability to function on multidisciplinary teams
ECSA ELO 8	Individual, team and multidisciplinary working
Description: Work effectively as an individual, in teams and in multidisciplinary environments.	
Associated Assessment Criteria: The candidate demonstrates effective individual work by performing the following: 1. Identifies and focuses on objectives; 2. Works strategically; 3. Executes tasks effectively; 4. Delivers completed work on time. The candidate demonstrates effective team work by the following: 1. Makes individual contribution to team activity; 2. Performs critical functions; 3. Enhances work of fellow team members; 4. Benefits from support of team members; 5. Communicates effectively with team members; 6. Delivers completed work on time. The candidate demonstrates multidisciplinary work by the following: 1. Acquires a working knowledge of co-workers' discipline; 2. Uses a systems approach; 3. Communicates across disciplinary boundaries.	
Range Statement: Multidisciplinary tasks require co-operation across at least one disciplinary boundary. Co-operating disciplines may be engineering disciplines with different fundamental bases other than that of the program or may be outside engineering.	
How is high-level understanding realized, as per the SOLO Taxonomy? Student teams *incorporate* information from multiple other disciplines, including industrial design and the humanities. They *evaluate* each other's work. They *analyze* the project given and break it down into its constituent parts so as to ensure equal division of labor. Ultimately, through the use of CATME and other means, they are required to *reflect* on their experience of working in a team and with people from disciplines outside of their own.	

Ultimately, the pedagogical benefit of a project-based approach to human-centered design is that it allows students to predict the impacts of their designs on society by being exposed to the life-worlds of those who will labor under and use the technology they develop. Teaching for maximum social impact requires a multi-pronged strategy. Exchanges between engineering and social science practitioners is one of these prongs. This may include study of the history of industrialization, social studies of science and critical theories of technology, all of which have many lessons to offer to emerging engineers as they lead to an understanding of the development - and the place - of engineering in the contested process of progress. These insights can be further enhanced by creating opportunities for students from diverse disciplinary backgrounds to interact with each other. This can take place in the classroom, but may find equally useful expression in the creation of student clubs and societies that focus on solving problems in which disciplinary knowledge intersects. Food security is such an issue, as it simultaneously links water, energy and soil considerations. Furthermore, engagement between engineers and the general public can be facilitated so as to enhance engineering understandings of how their designs are taken up, that is, of how consumers interact with, by way of some examples, energy systems (such as hot water systems), transportation systems (such as the choice between road and rail transport) or water systems. Such insight regarding user take-up has the potential to reinvigorate engineers' designs promoting enhanced creativity and usefulness.

CONCLUSION

This paper has sought to describe a project-based, human-centered design intervention in the third year of a degree programme in Mechanical Engineering at the University of Johannesburg, South Africa. In doing so, it has presented four inter-related arguments:

1) The problems facing the world today require of engineers that they are able to participate, and even lead, social action, change and innovation. This in turn requires of higher education institutions to build design thinking and, in particular, human-centered design, into the curriculum.

2) This paper has presented a description of a project-based intervention that aimed to incorporate such design thinking into the curriculum. This intervention saw students develop appropriate, intermediate technologies for urban farmers as part of an interdisciplinary, agricultural development initiative with poor farmers in Johannesburg.

3) Preliminary data reported on herein indicates that although students' understandings of human-centered design is fairly well developed, they do not necessarily link human centered design to the engineering design process. Students' appreciation of teamwork highlights the typical challenges experienced as a result of group dynamics with the importance of effective communication emphasized by the students. Project-based learning such as this, therefore, also enhances our teaching and assessment of the relevant ECSA/ABET-required student outcomes.

4) Ultimately, project-based interventions such as this have the potential not only to develop students design practice by making it more end-user oriented, but also has the potential to deepen students' understandings of the content of their chosen discipline.

Project-based interventions such as this need to be made throughout engineering degree programs, including in the final-year capstone modules, so as to ensure that graduates of these programs are able to tailor their design thinking to the needs of end-users.

REFERENCES

[1] M. Airaksinen and M. Kokkala, "VTT Research Highlights 12 Smart Cities," VVT Technical Research Centre of Finland Ltd, Espoo, Finland, 2015.

[2] H. W. Rittel and M. M. Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences,* vol. 4, pp. 155-169, 1973.

[3] F. Moulaert, D. MacCallum, A. Mehmood and A. Hamdouch, The International Handbook of Social Innovation, Cheltenham: Edward Elgar, 2013.

[4] C. Fowler, "NGDOS as a moment in history: Beyond aid to social entrepreneurship or civic innovation?," *Third World Quarterly,* vol. 21, no. 4, pp. 637-654, 2000.

[5] E. Crawley, J. Malmqvist, S. Ostlund and D. Brodeur, Rethinking Engineering Education: The CDIO, New York: Springer, 2007.

[6] E. Manzini, Design, when everybody designs: An introduction to design for social innovation, Cambridge, Massachusetts: The MIT Press, 2015.

[7] C. R. Anderson and S. M. McLachlan, "Transformative research as Knoeledge mobilization: Transmedia, bridges, and layers," *Action Research (Article in Press),* pp. 1-23, 2015.

[8] A. Cummings, J. Huff, W. Oakes and C. Zoltowski, "An Assessment Approach to Project-Based Service Learning," in *Proceedings of the 2013 ASEE Annual Conference*, Atlanta, GA, 2013.

[9] R. Felder and R. Brent, "Cooperative Learning," in *Active Learning: Models from the Analytical Sciences*, P. Mabrouk, Ed., Washington, ACS Symposium Series 970, American Chemical Society, 2007, p. 34–53.

[10] R. Craig and A. Williams, *Educause Review,* no. September/October, pp. 10-18, 2015.

[11] J. Huff, C. Zoltowski, W. Oakes and R. Adams, "Making Sense of Design: A Thematic Analysis of Alumni Perspectives," in *Proceedings of the ASEE Annual Conference*, Atlanta, GA, 2013.

[12] . H. M. Matusovich, W. Oakes and B. Carla, "Why Women Choose Service-Learning: Seeking and Finding Engineering-Related Experiences," *International Journal of Engineering Education*, vol. 29, no. 2, pp. 388-402, 2013.

[13] W. c. o. E. a. Developmen, "Our Common Future," 1987. [Online]. Available: http://conspect.nl/pdf/Our_Common_Future-Brundtland_Report_1987.pdf. [Accessed 1 April 2013].

[14] I. Smillie, Mastering the Machine, Rugby: Practical Action Publishing, 2012.

[15] E. Fisher, "Ethnographic Invention: Probing the Capacity of Laboratory Decisions," *Nano Ethics*, vol. 1, pp. 155-165, 2007.

[16] K. Krippendorff, The Semantic Turn: A New Foundation for Design, London : CRC Press Taylor & Francis , 2006.

[17] J. Giacomin, "What is Human Centred Design?," in *P&D Design 2012, 10th Conference on Design Research and Development*, São Luís, Maranhão, Brazil, 2012.