African Journal of Engineering Research
Vol. 7(4), pp. 112-128, December 2019
ISSN: 2354-2144
Review

A review of engineering education at the University of Zimbabwe

Mathew T. Mamina[1]* and Rutendo Maganga[2]

[1]Department of Mining Engineering, University of Zimbabwe, Zimbabwe.
[2]Department of Metallurgical Engineering, University of Zimbabwe, Zimbabwe.

Accepted 11 December, 2019

ABSTRACT

Zimbabwe's industrialization thrust calls for skilled graduates particularly in the engineering disciplines. The government of Zimbabwe, in its endeavor to facilitate value addition and beneficiation across multiple sectors, has acknowledged the lack of technical skills as a drawback to industrialization on several occasions. As a means to address the skills gap, the 2017 Ministry of Higher and tertiary education transitioned from the education 3.0 model focused on teaching, research and community service to an education 5.0 model that incorporates two additional elements of innovation and industrialization. The major objective of the model is to industrialize and modernize Zimbabwe through science and technology with engineering education playing a critical role on the innovation and industrialization pillars. The status quo in Zimbabwe is that conventional instructional methods are being used to teach engineering related subjects whereas research has established that over the past three decades, engineering education has transitioned towards outcome oriented methods of instruction to improve graduate students' skills and meet industry demands. For instance, higher education in the United States, Europe, Asia, Australia, and South America has shifted from conventional instructional methods towards an outcome-oriented and student-focused Competency Based Learning (CBL). According to the 2018 minister of higher and tertiary education, the Zimbabwean education system has failed to foster practical application of acquired knowledge and industrial development, an issue addressed by CBL. In line with the objectives of education 5.0, this study reviews engineering education at the University of Zimbabwe and recommends necessary adjustments to address the growing need for competent engineers.

Keywords: Engineering education, education 5.0, interdisciplinary education, competency based learning, industrialization.

*Corresponding author. E-mail: mtmamina@gmail.com. Tel: +263786280449.

INTRODUCTION

Engineering education is critical for innovation and industrialization, the main drivers for economic growth in both developed and developing countries. According to the Zimbabwean Ministry of Higher and Tertiary Education, Science and Technology Development, the country's vision to become an upper middle-income economy by 2030 will highly depend on the development and utilization of engineering and technology skills. The Ministry, in its 2018 critical skills audit report, recommended four major action areas to increase engineering and technology skills; (1) increasing the number and quality of trained engineers and technologists, (2) creating linkages between the industry and tertiary institutions, (3) curricula reforms and (4) establishment of technology parks (Ministry of Higher and Tertiary Education, 2018).

In line with the development of quality engineering skills, several authors concur that 21st century engineering students lack the skills and competencies required in the current dynamic and competitive global economy. Conventional engineering education predominantly concentrates on technical competence whereas societal needs require that engineers be aware of social and environmental issues (Rampasso et al., 2018). The failure to fully comprehend sustainable development issues, address societal needs, engage in entrepreneurship and apply technical concepts in industry have emerged as the major themes that engineering education must address. Tejedor et al. (2017) and Rampasso et al. (2018) assert that traditional engineering education revolves around purely technical aspects and economicaly optimal solutions without an adequate reflection of the social and environmental aspects critical to society. Tejedor et al. (2017) further reports that according to Erin A. Cech, an engineer and sociologist, “students’ public welfare concerns decline significantly over the course of their EE” (Tejedor et al., 2017). Resolving problems related to climate change, natural resource governance, and inequality and poverty alleviation will require balanced and synthesized input from diverse disciplines (Styron, 2013). Collaboration of engineering education with social science and humanity disciplines can therefore create an engineering/society interface.

Gardner (2006) maintained that students need to go beyond mastery of course content and low level thinking if they are to fulfil real life skill requirements. Considering the rate at which the world is changing, practical knowledge application now spans across multiple interlinked disciplines (McTighe and Thomas, 2003) and this requires well-developed critical thinking, creativity, collaboration and communication skills among collegiate graduates (Styron, 2013). These skills were cited as the most important by over 400 United States employers (Conference Board, et al., 2006).

Chikuku et al. (2017) cited inadequate training infrastructure as the main reason for student incompetency and proposed industrial secondment for lecturers as a means for knowledge and technology transfer between industry and academic institutions. Through strong linkages and collaborative projects, lecturers will stay up to date on the prevailing industry technology skills needs while the inductry will influence the quality of graduates (Chikuku et al., 2017). This will subsequently improve industrial relevance of teaching outcomes, provide a good basis for engineering education curriculum review and creation of up to date case studies (Chikuku et al., 2017). Industrial secondment adresses Ciesla’s (2009) perspective that since educators teach abstract concepts in isolation from the real world, students perceive them as unimportant and easily forget them. Mazur (2013) argues that engineering education should reflect the real world where most of the parameters to solve a problem are unknown and collaboration is required to solve complex problems.

Collaboration can be achieved through interdisciplinary education, a concept introduced at the dawn of the 20th century to explore “clear and relevant links” across different disciplines (Styron, 2013) and enable students to gain the critical cognitive skills applicable in real life (Mathison and Freeman, 1997). Interdisciplinarity affords educational instructors a different perspective of how their disciplines affect and are perceived by other disciplines. Although interdisciplinary education has a sound theoretical background, instructor incompetency, inadequate support structures and poor execution can yield unexpected results (Styron, 2013). Proponents of the approach assert that it simulates the real world in a leaning environment while critics of the concept argue that it discourages specialization (Styron, 2013).

This study synthesizes the ideas that have been proposed to address shortfalls in engineering education. Synthesized ideas are then applied to review the status quo of engineering education at the University of Zimbabwe and recommendations are given in line with the Zimbabwean industrialization agenda and the recently crafted education 5.0 framework.

Zimbabwean engineering education: A macro perspective on quality

On a global scale, one of the critical indicators of quality in engineering education is innovation, which, according to Eurostat is reflected by the number of patent applications, research and development expenditure as a percentage of GDP and tertiary graduates in science and technology in a nation (Momete, 2015; Eurostat, 2018). These indicators were established through compilation of data from various sources and Figure 1 shows the number of patents registered per year by residents from Zimbabwe, Botswana, Mozambique and Zambia from 1980 to 2017 as reported by the World Bank in 2018.

Although no data was available for the 1996 to 2014 period, there is a drop from 55 patents in 1995 to 9 in 2015 and 8 in 2016. Contrary to this trend, the number of scientific and technical publications has been on the rise indicating the potential for innovation through implementation of ideas and the gap between knowledge acquisition and application. Figure 2 shows the number of scientific and technical journal articles published by Zimbabwean authors from 2003 to 2016. It can be noted that although there is a drop in patents from 2015 to 2016, the number of scientific and technical journal articles was on the rise.

In this study, credible sources of information on Zimbabwe’s expenditure on research and development, measured as a percentage of GDP were not found. Expenditure on higher and tertiary education in the national budgets were not clear on allocation of funds except for those targeted at improving infrastructure. However, the President of the Republic of Zimbabwe, Emmerson Mnangangwa, announced, in September 2018, that the government had commuted 1% of the country’s gross domestic product to research and development (Nyoni, 2018), a figure that is half the global average of approximately 2%.

In terms of tertiary graduates in science and technology, UNESCO (2018) quantified the percentage of graduates from science, technology, engineering and

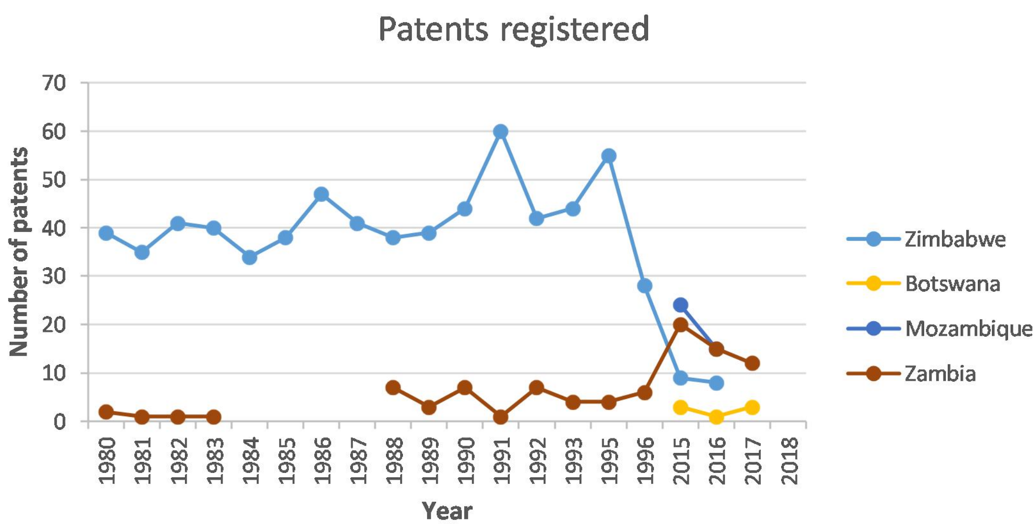

Figure 1. Patents registered in Zimbabwe in comparison with other neighboring countries (World Bank, 2018).

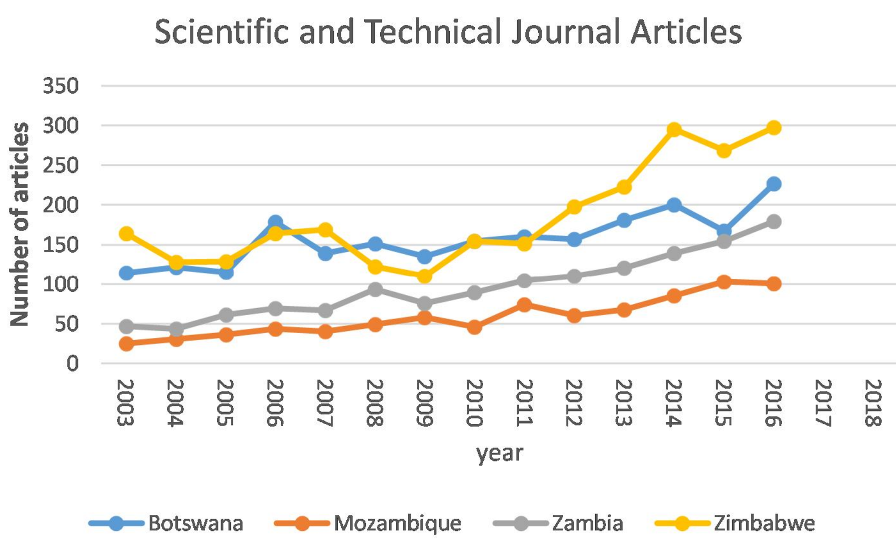

Figure 2. Scientific and technical journal articles (World Bank, 2018).

mathematics programmes in Zimbabwean tertiary institutions at 24.33% in 2012 and 30.22% in 2015. However, a critical skills audit done by the Zimbabwean ministry of higher and tertiary education, science and technology development revealed that, in terms of numbers relative to the OECD standard, there was a 93.57% skills deficit for the engineering and technology sector (Ministry of Higher and Tertiary Education, 2018). The study mainly focused on the number of Zimbabwean registered engineers against an OECD benchmark without any quantitative measure of skills quality. In addressing the skills quality gap, the following sections review different sources of literature on engineering education.

LITERATURE SURVEY: WHAT DRIVES INNOVATION?

Innovation is an important driver of technological advancement underpinned by the quality of human capital in a nation (Momete, 2015). According to Gantogtokh and Quinlan (2017), the interaction of boundaries between disciplinary groups creates a unique learning environment that fosters creativity. Akkerman and Bakker (2011) describe such boundaries as a “third space” where different perspectives are shared thereby stimulating co-learning, critical thinking, active knowledge construction, development of new ideas and innovation (Klaassen, 2018). Lam et al. (2014) identify sustainability, entrepreneurship, and big data as the major constituents of the space while Klaassen (2018) asserts that defining the problem and the extent of disciplinary synthesis are critical component in such a a third space.

In line with the proposition of disciplinary synthesis as a means to foster creativity and innovation, the Amsterdam Institute for Interdisciplinary Research classified the nature of collaboration into multidisciplinary, interdisciplinary and transdisciplinary. While multidisciplinary collaboration involves a disintergrated approach to problem solving with each discipline dealing with a single particular component, interdisciplinary and transdisciplinary collaboration involves an integrated approach to problem solving with disciplines collectively dealing with the problem as a whole. Transdisciplinary collaboration goes a step further to foster complex stakeholder engagement to come up with innovative solutions to problems (Klaassen, 2018). Industry – University collaboration is a perfect example of transdisciplinarity where the university research function gets to practically test developed ideas thereby nurturing innovation culture with students. The following section explores the concept of interdisciplinary education with embeded concepts of transdisciplinarity and how it can be implemented.

Interdisciplinary education

Klaassen (2018) asserts that University education is to a greater extent monodisciplinary although efforts to shift towards interdisciplinary education have been made over the past 20 years. Such efforts are evident on the websites of research institutes where collaboration stands out as a major goal (Klaassen, 2018) and the indication that one third of references in published scientific articles are from other disciplines (Ledford, 2015).

Within engineering, interdisciplinary education works on a principle of collaboration and need based innovation. While engineers are able to develop technical solutions, they may not be in the best position to assess the wide range of needs in business, healthcare, pharmaceuticals, governance etc., that require technical intervention. As an example, an interdisciplinary setting between health care and engineering students will result in technical interventions that address the needs for a functional healthcare system from a clinical perspective (Kim, 2019). In this way, engineering innovation will improve the quality of health care systems through addressing the predominant needs and challenges. Palmer (2001) supports the concept of interdisplinary education asserting that real life problems and solutions oftentimes do not occur within fragmented disciplines, a viewpoint Summers (2005) expresses saying,"*knowledge in the real world is not applied in bits and pieces but in an integrated fashion*".

The absence of interdisciplinary education poses a challenge for engineering students to become leaders in the emerging non-traditional high-tech sectors such as data analytics and health informatics. The challenge emanates from the incoherence that exists in teaching curriculum for different disciplines, which likely results in students having fragmented knowledge and skills (Kim, 2019). Moreover, specialized instruction, the status quo at the University of Zimbabwe, exclusively accommodates students registered in a single certain course creating a barrier for students who want to gain a comprehensive understanding of interrelations between different disciplines.

Models for interdisciplinary learning

Klaassen (2018) conducted a case study and established that the three factors critical to the design of a successful interdisciplinary model namely clear problem definition, level of interaction and problem guided constructive alignment. Two approaches that adress these three factors can be adopted for interdisciplinary model design. Firstly, the induction method proposed by Repko and Welch (2005), shown in Table 1, is adopted when both the elements of the discipline to be integrated are known and the outcome of the interaction is known.

Secondly, in the case where only the outcome of interaction is known while elements to be integrated and the nature of intergration are unknown, the design abduction approach proposed by Kees Dorst (2013) and shown in Table 2 is adopted.

Both the induction and design abduction methods achieve the same objective of clearly establishing interdisciplinary boundaries and goals of collaboration. However, the implementation of interdisciplinary education is based on the concept of group learning and can be accomplished in one of two ways: team based learning or inquiry based learning (Styron, 2013).

Team based learning

In team based learning, it is important that students and instructors work towards attaining a clear common goal with well defined roles and have enough funding as well as time for training and collaborative work (Styron, 2013). Kim (2019) proposes the establishment of an elective interdisciplinary course that facilitates team based learning between traditional (full time college registerd) or non-traditional (part time skilled workers) students from different backgrounds. The course would be taught under established guidelines relating to the interrelated disciplines by dual degreed individuals or through co-teaching arrangements. Students learn by doing in a simulated environment while patented innovations or low fidelity prototypes are the primary measurable outcomes of the course. A modified version of the model is shown

Table 1. The induction method, adapted and modified from Repko and Welch (2005).

1.	DEFINE: Warrant interdisciplinary education
2.	PRESENT: Give rationale for interdisciplinary education
3.	IDENTIFY: Identify relevant disciplines based on the nature of the problem
4.	CONDUCT: Literary review of the relevant disciplines
5.	DEVELOP: Ascertain which values/assumptions are being made in each field
6.	STUDY: Relate each field to the problem definition
7.	DIFFERENCE/SIMILARITIES: Recognise patterns that will allow innovation
8.	CREATE: Develop a Frame for interdisciplinary problems (learning)
9.	COMBINE: Integrate frames

Table 2. The design abduction approach (Dorst, 2013).

1.	ARCHEOLOGY (HISTORY): Historical investigation of problem
2.	PARADOX: Framing the problem definition
3.	CONTEXT: Identify research context
4.	FIELD EXPLORATION: Field review
5.	THEMES: Recognise themes
6.	FRAMES: Develop a Frame for interdisciplinary design problems (learning)
7.	FUTURES: Explore possible futures with integrated frame
8.	TRANSFORMATIONS: which transformations are realised in practice
9.	INTEGRATION: What can we learn from these changes and use in the future

in Figure 3.

Inquiry based learning

Inquiry based learning extends on traditional instruction methods and requires students to demonstrate an understanding of leant concepts, thinking and problem solving abilities through information acquisition, analysis and application of knowledge under the guidance of an instructor (Miami University, 2010). The instructor assumes a mentorship role instead of the traditional lectureship role (Luneburg, 2011) in traditional lecture based learning models. There are two types of inquiry based learning: "Problem-Based Learning (students are presented a problem with only one solution but many methods for determining that solution), and Project-Based Learning (students are presented a problem but there are many possible solutions)" (Styron, 2013).

The know be do model: The know-be-do model is a concept map for interdisciplinary education proposed by Drake and Burns (2004) that fits well into inquiry based learning. According to Styron (2013), "this model is predicated on three questions: What kind of people do we want students to be? What should students be able to do? (What assessments are needed?) What should students know? (What content knowledge is required?)". Figure 4 shows the concept model.

The model builds on knowledge acquisition to induce certain skill based habits and behaviral traits in students that complement practical real life application of skills. Traditional assessment techniques are intergrated into the model although the instructor assumes a coaching role and content mastery is replaced with an independent thinking framework that accepts different solutions to a single problem, similar in principle to project based learning (Drake and Burns, 2004). The approaches adopted in inquiry based learning are similar, in principle, to those applied in competency based learning, a concept explored in the next section.

Critical instructor traits for interdisciplinary learning

Orlando (2013) compiled a list of 9 traits of great teachers and these were adopted by Styron (2013) as the critical characteristics of instructors in interdisciplinary education. Instructors must:

1. Respect and value students' ideas and opinions such that students freely express themselves and learn to listen.
2. Develop a "supportive and collaborative" learning environment.
3. Be good listeners and available to assist students despite the existence of other commitments.
4. Set high perfomance standards for students.
5. Be enthusiastic about learning and willing to share information.

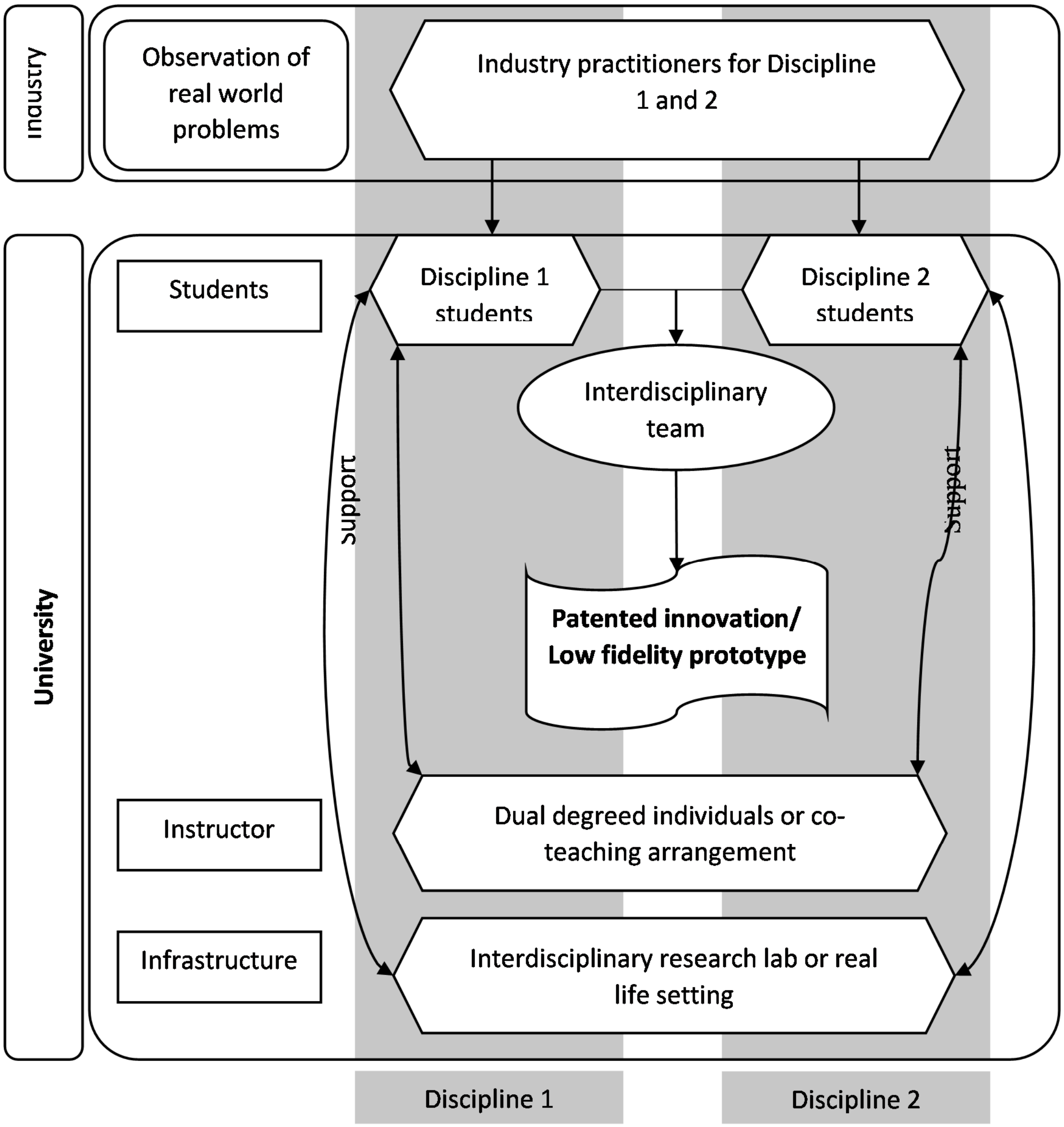

Figure 3. Team based learning (Kim, 2019).

6. Be skilled teamleaders and teambuilders who foster shared decision making.
7. Be flexible to change methods of instruction to ensure all students understand.
8. Collaborate with fellow instructors and learn from them.
9. Exhibit a high level of proffessionalism in all aspects of their work.

Competency based learning as a component of interdisciplinary education

The competency based learning (CBL) framework was introduced in the 1920's for teacher education and training and it found widespread use in the 1970's (Spady, 1977). According to the United States Department of Education (2016), CBL is "a structure that creates flexibility, allows students to progress as they demonstrate mastery of academic content, regardless of time, place, or pace of learning". Terms such as self-paced, student centered, student- or self-directed, individualized or personalized instruction, outcome based, performance-based, standard-based, and proficiency-based education have been used to describe CBL (Henri, et al., 2017; Roe, 2015). An imporatnt characteristic of competency based learning is that students are not allowed to progress to the next level of learning unless they demostrate a desired level of competency. Styron (2013) proposes that instructors should challenge students slightly above their level of

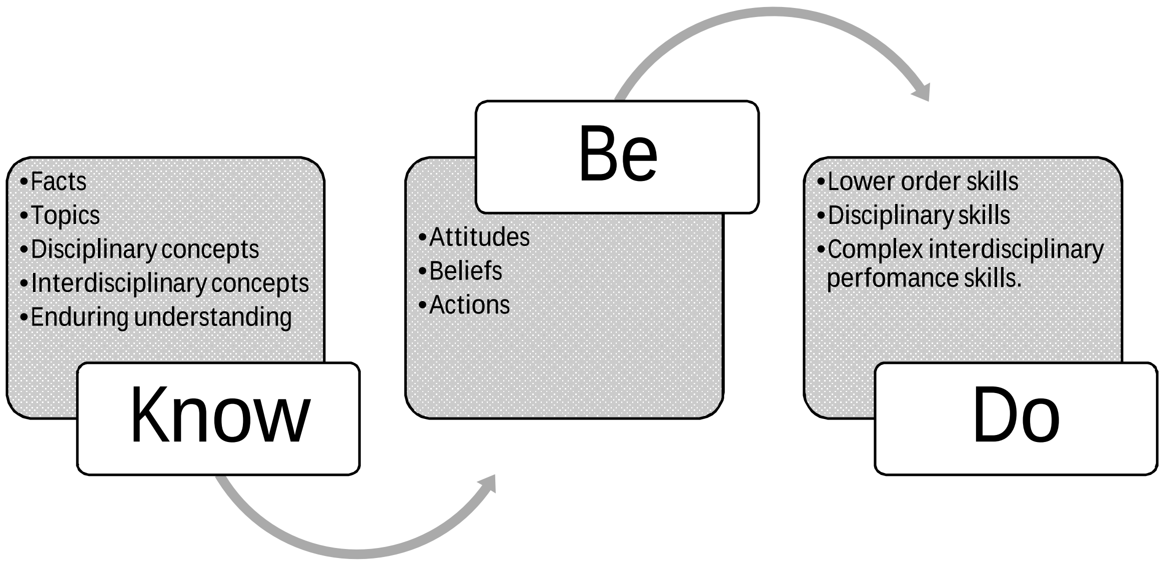

Figure 4. The Know, Be, Do model (Styron, 2013).

competence and present a new set of challenges when students reach a new competency level.

Over the past three decades, engineering education in the United States, Europe, Asia, Australia, and South America has shifted from conventional instructional methods that focus on content acquisition towards an outcome-oriented and student-focused Competency Based Learning (CBL) (Henri et al., 2017; Froyd et al., 2012). Unlike traditional instructional methods that impose learning time and pace limits, the CBL concept is outcome focused, analogous to mastery learning which requires students to attain a certain level of competency before proceding to the next level of learning. Measurable competencies linked to instructional material are explicitly communicated to the students at the beginning of each course and these can be in the form of real life practical application of taught components (Henri et al., 2017). CBL also promotes autonomy which is a critical factor for achievement (Henri et al., 2017; Fazey and Fazey, 2001) since students have a sense of control over their education and are therefore more motivated to perform better at information and knowledge integration (O'Reilly, 2014).

Brumm et al. (2006) propose that desired student skills must be broken down into interlinked discrete competencies and students are judged as competent based on their demonstration of behavioral patterns that reflect mastery of taught skills. The ability to apply learnt concepts in practical real life situations, is one of the predominant behavior assessed (Henri et al., 2017).

Accordind to Henri et al. (2017), CBL can be fully or partially implemented in certain courses and based on a 2014 infographic (Infographic: What Competency-Based Education Looks Like, 2014) is composed of three categories:

1. More conventional model that is structured like the traditional instructional model with elements of CBL.
2. Middle of the road which are mostly delivered online with "a higher level of mentoring and coaching".
3. Less conventional model with no formal courses and open entry or exit.

Implementation of competency based learning will require structural changes in the engineering curriculum and methods of instruction. The attitudes and skill level of lectures to assume a mentorship role will be critical to the success CBL. CBL can be implemented in conjunction with other educational models such as interdisciplinary learning described in the previous sections.

INTERDISCIPLINARY EDUCATION THEMES IN ENGINEERING

This section reviews the predominant themes for interdisciplinary education in engineering that have been discussed in literature. A survey guided by these themes was carried out to establish the status quo of engineering education at the University of Zimbabwe. A survey questionnaire based on the potential difficulties associated with implementing interdisciplinary education proposed by Rampasso et al. (2018) was crafted and used to analyze educators' perspectives. Additionally the top graduate engineering projects completed in the past five years and the existing engineering curriculum were reviewed to establish the degree of interdisciplinary education. This degree was established by assessing the integration of sustainable development and entrepreneurship with engineering education. Sustainable development covers a wide array of economic, social and environmental issues, while entrepreneurship is a way of translating technical know-how into economic development and growth. The Entrepreneurial Motivation indicator proposed by Yi and Duval-Couetil (2018) was used to evaluate the Entrepreneurial intention among students and the results from the model are discussed in the section on engineering – entrepreneurship. The next section discusses the engineering – sustainable development interdisciplinary interface.

Engineering – Sustainable development

The sustainability discourse around the world revolves around three dimensions, economic, social, and environmental (Rampasso et al., 2018) that, when expanded, include issues such as climate change, biodiversity loss, poverty, epidemics, security, and governance. However, engineering disciplines inadequately address sustainability issues due to a poor appreciation of social science and humanity issues (Tejedor et al., 2017). Although engineering education adequately covers the economic dimension and is giving more attention to the environmental dimension (Rampasso et al., 2018), it inadequately incorporates the social dimension (Edvardsson Bjornberg et al., 2015). In trying to address these pitfalls, several international declarations that include “Agenda 21 in Rio Declaration, the Ubuntu Declaration (2002), The Earth Charter and, specifically for the Engineering Education for Sustainable Development (EESD), and the Barcelona Declaration (2004)” have advocated for the inclusion of sustainability concepts in higher and tertiary education (Rampasso et al., 2018).

The inclusion of sustainability issues into engineering curriculum poses several challenges that involve complexity of the concept of sustainable development (Elms and Wilkinson, 1995), and a total of eleven difficulties were compiled from previous literature by Rampasso et al. (2018). The eleven difficulties were divided into to two groups: one associated with structure and planning and the other associated with instructional methods and the study concluded that the success of instructional methods was dependent on a sound structure and planning process (Rampasso et al., 2018).

In line with the classification of challenges done by Rampasso et al. (2018) several authours (Edvardsson Bjornberg et al., 2015; Svanstrom et al., 2012; Mulder et al., 2010; Hoolgard et al., 2016) highlighted the importance of instructional methods such as problem based learning, project based learning, and conceive-design-implement-operate (CDIO) frameworks in enhancing the intergration of sustainability concepts and engineering education. Mulder et al. (2010) further highlighted the need for a cultural change in engineering education and Mulder et al. (2012) cited the resistance of lecturers in as an obstacle to achieving better results from the inclusion of sustainability in engineering courses and reforming engineering curricula. Such resistance according to Rampasso et al. (2018) emanates from lecturers’ fear to lose autonomy in their disciplines and the prevailing perception that isolating disciplines allows professionals to dominate a certain area of knowledge. The lack of interest on sustainability issues within engineering students and maturity to comprehend the significance of sustainable development also poses challenges since ”during graduation, students are usually more interested in their grades than in the possible applications of concepts taught throughout their careers” (Rampasso et al., 2018).

In an endeavour to merge a sustainability component into engineering designs, Raoufi et al. (2017) developed an interactive web based learning tool to assist students in comprehending life cycle sustainability issues during product design. The tool allows students to investigate and visualise the response of economic, environmental and social perfomnce to changes in their product design (Raoufi et al., 2017). It facilitates “simultaneous analysis of economic and environmental impacts across materials and manufacturing supply chains by integrating product function modeling and unit manufacturing process modeling” (Raoufi et al., 2017).

University of Zimbabwe survey

The extent to which engineering education at the University of Zimbabwe incorporates sustainability concepts was established through three methods:

1. A review of the existing curriculum for all engineering disciplines.
2. A qualitative review of the top student projects presented at the annual engineering competition for the past 5 years.
3. A qualitative survey within the center of engineering educators to establish their perspectives.

The survey also quantified the potential impacts of the challenges established by Rampasso et al. (2018) and the methods that could be implemented to ensure success of interdisciplinary education.

Existing curriculum: The existing engineering curriculum was analyzed to establish the extent to which it addresses sustainable development and other issues. Themes outside conventional engineering, which emerged from the courses in the curriculum, were communication, research, information communication technology, management and leadership, modern technology, climate change, land and water resources. The total credits for courses falling into each of the themes expressed as a percentage of the total degree program credits were evaluated and are shown in Figure 5.

The curriculum review revealed that the curriculum on

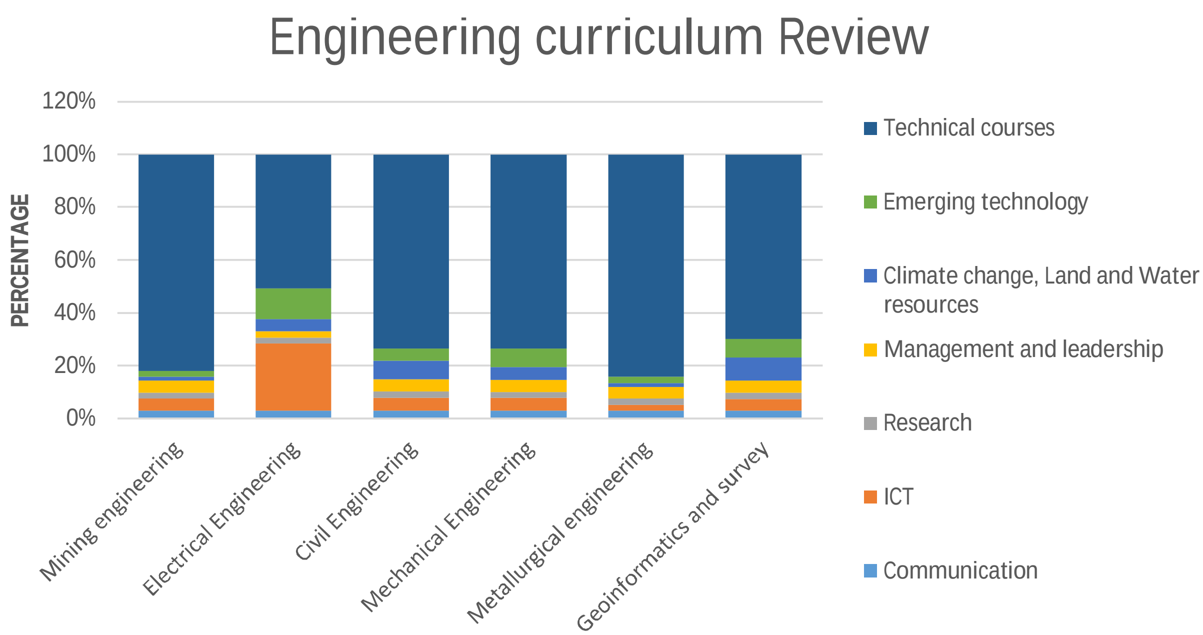

Figure 5. Engineering curriculum.

electrical engineering department is the only one that strikes a balance between the conventional technical courses, ICT and emerging technologies. The other disciplines have over 70% of their course credits falling into the conventional technical courses, with metallurgical engineering having the largest percentage of 84%. For electrical engineering, conventional technical courses constitute 51% of the total course credits while ICT and emerging technologies constitute 25 and 12% respectively. Courses that fall into themes related to sustainable development, management and leadership, and research constitute 12% of the total course credits. It is evident that although the electrical engineering curriculum is balanced, it does not adequately address sustainable development issues, particularly renewable energy, a finding which also emerged in the best final year electrical engineering projects presented over the past five years in the annual engineering competition.

Another interesting finding was that while there are a variety of environmental issues in the mining industry, only 2 percent of the course credits in the mining and metallurgical engineering courses address issues related to climate change, land use, and water resources. Purely technical courses, related to the operational aspects of mining constitute a major share of the course credits in the curriculum. A review of the best projects from mining engineering also revealed a similar pattern. The research function, which underpins all innovation, only constituted 5% of all course credits across all the departments. Overall, findings from the curriculum review suggest elimination of redundant and obsolete technical courses and introduction of more courses related to sustainable development, communication, research, ICT and emerging technology.

Engineering projects: The center for Engineering Education at the University of Zimbabwe holds an annual competition to identify outstanding projects among its final year students. Information for projects presented over the past five years was collected and analyzed to establish the sustainable development issues and themes outside conventional engineering, that each project addressed or had the potential to address. The themes that emerged from the presented projects were waste management, social issues, water treatment/water resources management, renewable energy, and land use. The percentage of projects from each discipline, which addressed each of these issues, was quantified and the results for each discipline are presented in the below sections.

Agricultural engineering: Agricultural engineering had the largest share of projects addressing sustainable development issues. Some of the specific issues that emerged from the projects included bio-waste management, utilization of solar energy in agricultural processes, and smallholder farmer technologies. Overall, 82% of the projects from the department addressed sustainable development issues and of those, 50% addressed waste management issues, while the rest addressed social and renewable energy issues, as shown in Figure 6.

The fact that agricultural engineering is a hybrid of conventional engineering disciplines and the agricultural sector partly explains why most projects from the department addressed sustainable development issues.

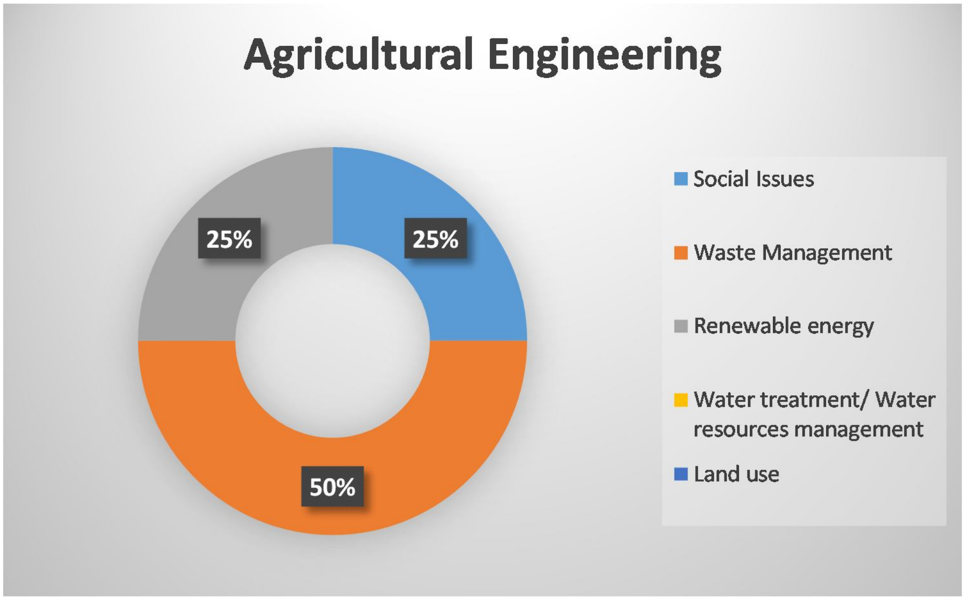

Figure 6. Breakdown of sustainable development issues addressed by agricultural engineering projects.

Civil engineering: Civil engineering had the second largest share of projects addressing sustainable development issues. Overall, 75% of the projects from the department addressed sustainable development issues and of those, 50% addressed waste management issues while the rest addressed social, renewable energy, water resources and land use issues as shown in Figure 7.

Similar to agriculture, 50% of the projects that addressed sustainable development issues were related to waste management and these included greywater treatment, utilization of biodegradable and non-biodegradable waste in construction and energy generation, and landfill design. The civil engineering curriculum and skill set of the educators, in the civil engineering department, partly explains the proportion of projects related to water resources management and construction. Courses that incorporate climate change, land use, and water resources issues constituted the second largest share of credits in the civil engineering curriculum.

Geoinformatics and survey: The geoinformatics and surveying department had the fourth largest share of projects addressing sustainable development issues. Predominant themes that emerged from the reviewed projects include real-time water quality and level monitoring and solar panel installation in one of the low-density suburbs in Harare. Overall, of the 50% of projects that addressed sustainable development issues, 67% of those were related to water treatment and water resources management, while 33% were related to renewable energy as Shown in Figure 8.

Electrical engineering: A surprising finding from the review of the top electrical engineering projects, presented in the past five years, was that none of them addressed issues were related to renewable energy. The projects, in line with the findings of the curriculum review, focused on addressing social issues through designing wearables and smart limps for the disabled. Additionally, it emerged that there were also ICT related system design for ecommerce and groundwater monitoring. Overall, 50% of the projects in electrical engineering addressed sustainable development issues and of those 67% addressed social issues and 33% addressed water resources management issues as shown in Figure 9.

Mechanical engineering: The mechanical engineering department had the third largest share of projects addressing sustainable development issues. 53% of the projects addressed social, waste management and renewable energy issues as shown in Figure 10. Some of the predominant solutions that emerged from the top projects include harvesting kinetic energy for reuse, solar energy, waste to energy conversion, and design of robotic limbs for the disabled. The large share of renewable energy projects can be linked to the skill set of educators in the department and that offer a postgraduate renewable energy course.

Metallurgical engineering: Paradoxically, while a vast array of sustainable development issues surround the mining industry, only 25% of the metallurgical engineering top projects addressed sustainable development issues as shown in Figure 11. This is a reflection of the curriculum and the focus on technical

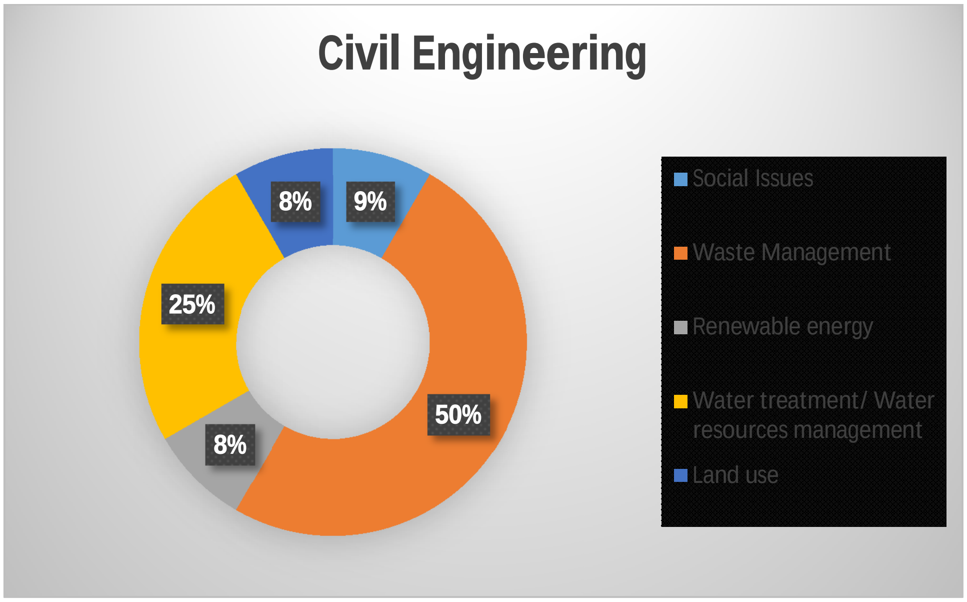

Figure 7. Breakdown of sustainable development issues addressed by civil engineering projects.

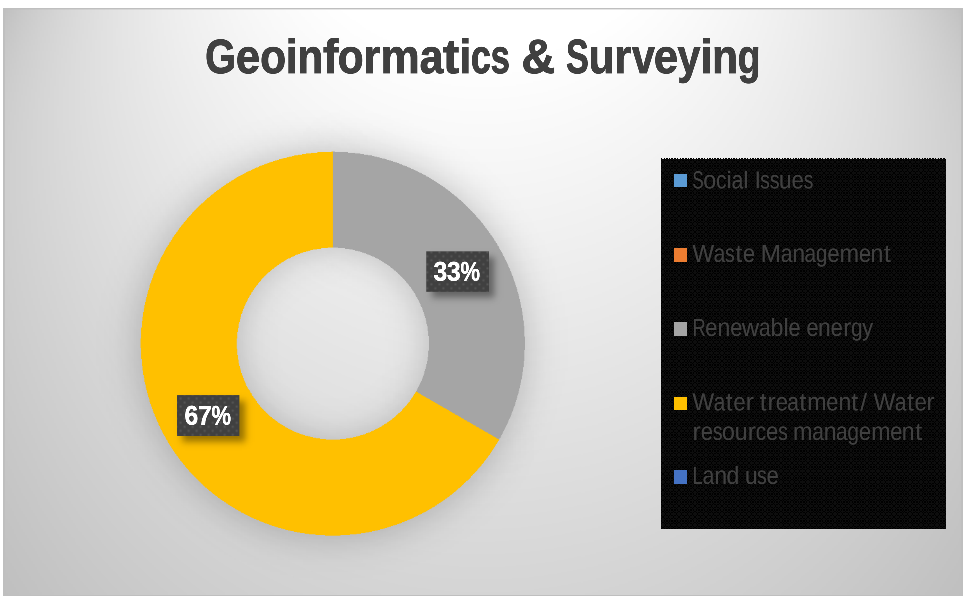

Figure 8. Breakdown of sustainable development issues addressed by geoinformatics and surveying projects.

operational aspects without adequate attention to socioeconomic issues related to mining. Of the 25% projects that addressed sustainable development issues, 33% focused on socio-economic issues while 67% focused on waste management through elimination of toxic substances and reduction of emissions in mineral beneficiation processes.

Mining engineering: The paradox mentioned earlier for the metallurgical department also emerged for the mining engineering department. Only 6% of the top projects from mining engineering addressed sustainable development issues and all of them addressed water resources management issues as shown in Figure 12. The bias of the mining engineering curriculum towards purely technical courses partly explains this finding.

Educators' perspectives: In order to further

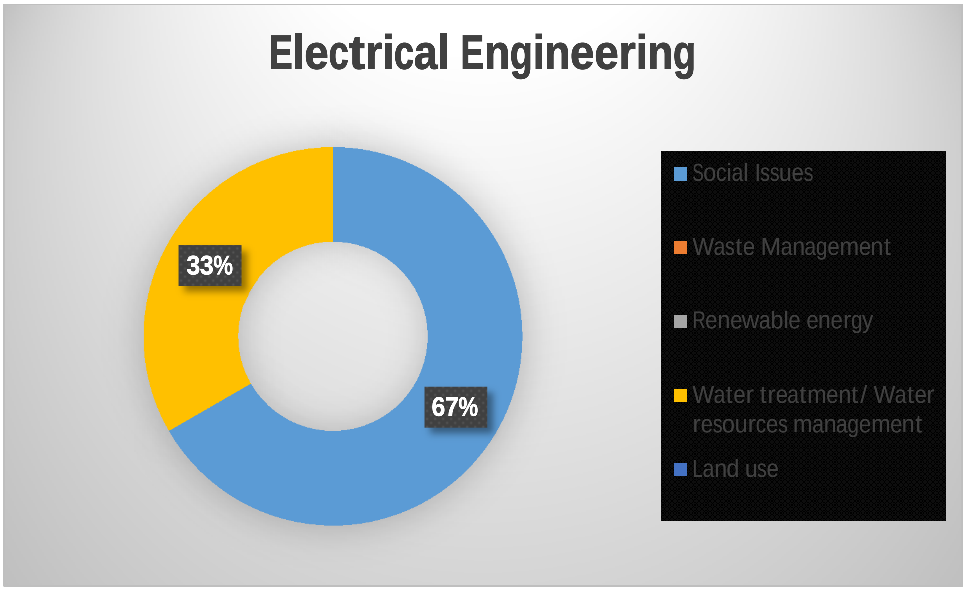

Figure 9. Breakdown of sustainable development issues addressed by electrical engineering projects.

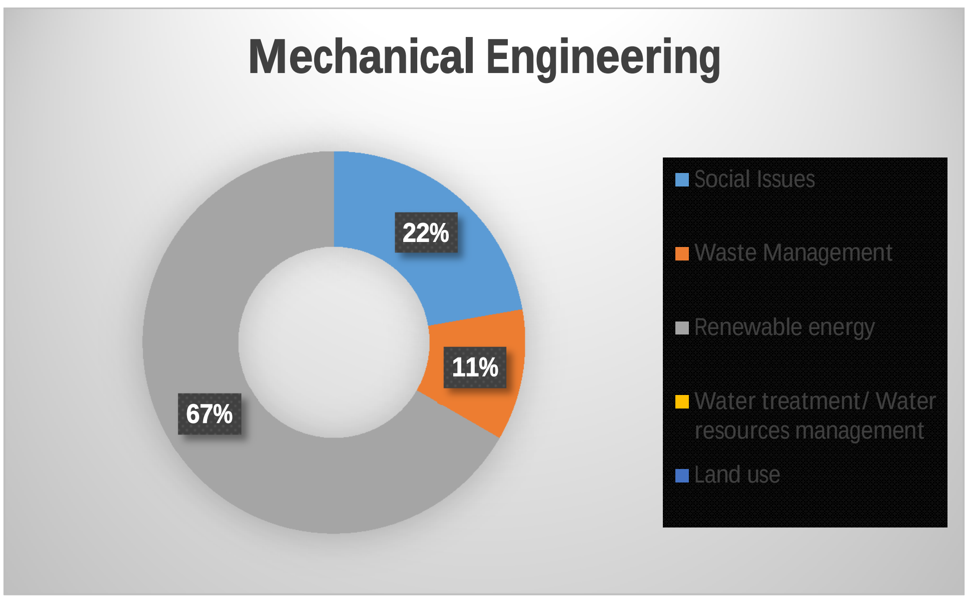

Figure 10. Breakdown of sustainable development issues addressed by mechanical engineering projects.

complement the findings of the curriculum and projects review, a qualitative survey was carried out among 20 educators in the center for engineering education at the University of Zimbabwe. The survey intended to establish if the engineering curriculum was entirely technical as revealed from the course credits analysis and if engineering graduates from the University understood the concept of sustainable development. An additional question was also included to establish the overall satisfaction of the educators with the graduate skill levels. The survey findings were as follows:

i. 77% of educators agreed that the engineering curriculum was purely technical.
ii. 46% of educators disagreed that engineering graduates fully understood the concept of sustainable development, 31% were uncertain and 23% agreed.
iii. 77% of educators were not satisfied with the skill level

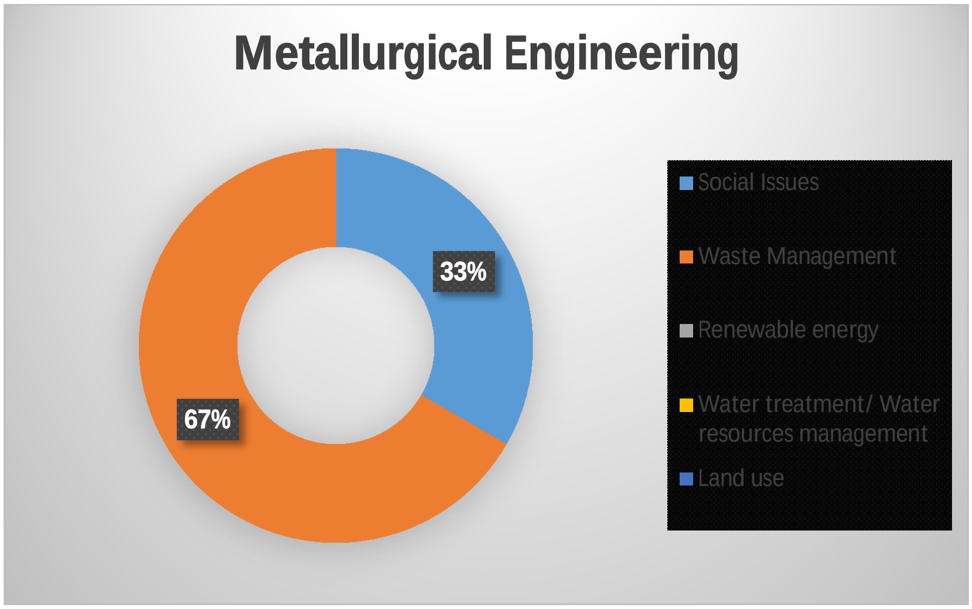

Figure 11. Breakdown of sustainable development issues addressed by metallurgical engineering projects.

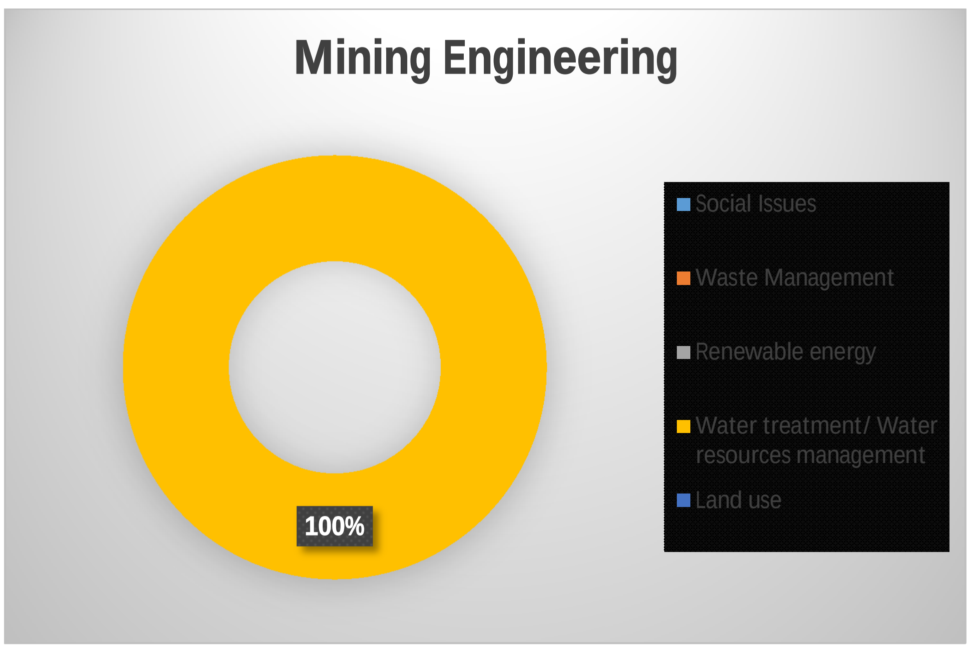

Figure 12. Breakdown of sustainable development issues addressed by mining engineering projects.

of graduates.

The findings of the survey were in harmony with the findings of the curriculum review and the projects review. This means that part of the problem lies in the curriculum and, as revealed by the literature survey, in the method of instruction and evaluation.

Engineering – entrepreneurship

Entrepreneurship and intrapreneurship allow engineering students to leverage on their technical skills in developing new products, solutions and creating wealth. The consensus within researchers in engineering education is that pure technical knowledge is insufficient for collegiate graduates to make a significant contribution to economic growth. Momete (2015) cited the top 10 qualities of an entreprenuerial engineer as the ability to solve complex problems, critical thinking, communication, creativity, logic, technical knowledge, economic knowledge, managerial knowledge, and reliability. She further suggests that economic knowledge among engineering graduates could be achieved through mandatory or elective courses in economics, management and communication.

In this light, a psychological indicator known as Entrepreneurial Motivation (EM) was established based on a framework crafted by Scheinberg and MacMillan (1988) to highlight what motivates people to pursue entrepreneurship. Yi and Duval-Couetil (2018) validated the application of the scale to engineering students and established a new Entrepreneurial Motivation (EM) framework which assessed Motivation for Creation and Solution (MCS), Motivation for Personal Interest (MPI) and Managerial Motivation (MM) as the critical factors underlying student motivation for entreprenuership. Table 3 shows the contributing student aspects to the three factors.

The relavance of the EM scale was determined by correlating it with entrepreneurial intention (EI), a measure of the expectation that a student will become an entreprenuer, and entrepreneurial self efficacy (ESE), a measure of the confidence that a student has to engage in entreprenuership. The latter scale consisted of two components: venturing self efficacy (VSE), the level of confidence in managing a business venture and technical self efficacy (TSE), the level of confidence in science and technology innovation.The study established that (1) students motivated by personal interest had a lower level of entrepreneurial intention (2) students motivated by creating innovative solutions (MCS) had a higher level of EI regardless of VCS and TCS (3)students motivated by the managerial factor require a high VSE to get a high level of EI (Yi and Duval-Couetil , 2018). The findings of this study suggests that in order to foster entreprenuership among engineering students, instructors should focus on the creation of market and societal based solutions as well as introducing concepts to foster VSE among students motivated by being leaders.

Entreprenuarial intent among engineering graduates at the University of Zimbabwe

The scale proposed by Yi and Duval-Couetil (2018) was adopted to establish the predomint motivating factor for students at the University of Zimbabwe to become entreprenuers. The sample size consisted of 40 students from the engineering faculty and similar to the findings of Yi and Duval-Couetil (2018), our survey revealed that students motivated by creating solutions had a higher entreprenuerial intent than those motivated by personal interest and being managers. Figures 13 and 14 illustrate students responses to the survey questions.

As shown in Figure 13, 50% of students in the survey were motivated by creating a solution and Figure 14 shows that 35% of the students had the intention to start a business within one year. The major inference that can be drawn from this survey is that adequate training of students in creating solutions, for practical situations, will significantly contribute to their entrepreneurial intent. Such a finding supports the idea of competence-based learning as a means of ensuring that students create solutions for well-defined problems individually under the guidance of a mentor or as an interdisciplinary team. Overall, the implementation of interdisciplinary education with components of competency based learning will not only address engineers understanding of sustainable development issues but will also allow them to create targeted solutions for social, economic and environmental problems that can be commercialized.

Likely challenges in implementing interdisciplinary education

To establish specific challenges that may hinder the implementation of interdisciplinary education at the University of Zimbabwe, the potential challenges outlined by Rampasso et al. (2018) were used as a basis for creating a survey questionairre. 20 educators from the center of engineering education were asked to rate the potential impact of likely challenges that may hinder the implementation of interdisciplinary education. The potential challenges were grouped into those related to the Educational System at UZ, lecturers and students.

The survey revealed that the educational system had the greatest potential impact of hindering interdisciplinary education with lack of resources and rigidity of institutional structures having been rated to have the greatest potential impact. Respondents rated the educational system to have a 53% impact on hindering relative to the other two dimensions of lecturers and students. The challenges related to lecturers were rated to have the second largest potential impact of 29% with lack of motivation and resistance to change having had the outstanding potential impact. Lastly, students were rated to have the least impact of 18% with the only significant potential challenge being that of students interest in grades than skill level and real life application fo taught concepts.

CONCLUSION

This study was undertaken to establish ways in which engineering education can be improved at the University of Zimbabwe in order to address the skills gap that exists

Table 3. Factors that contribute to entrepreneurial motivation.

Factor	Contributing aspects
Motivation for creation and solution (MCS)	Focus on a technology that interests me Satisfy a need in the market Solve a social problem Create something of my own
Motivation for personal interest	Have more free time Make more money Gain high social status
Managerial motivation	Be at the head of an organization Manage people Create jobs

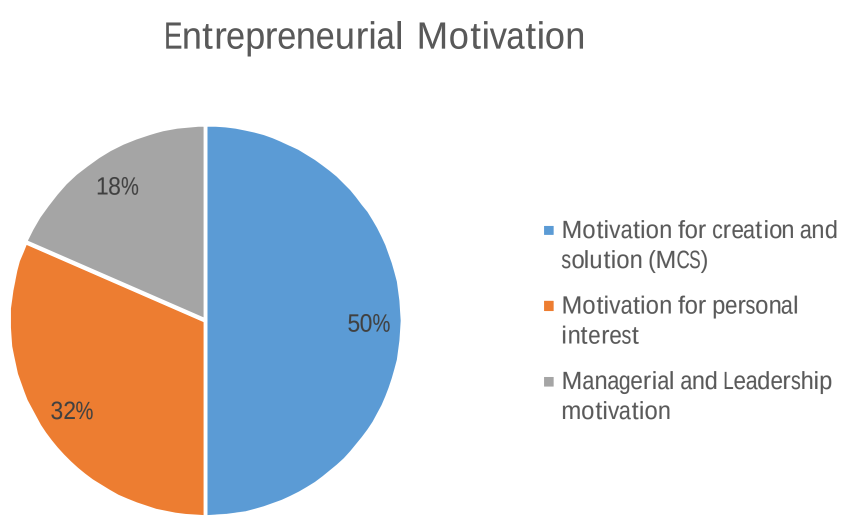

Figure 13. Results of the entrepreneurial motivation survey.

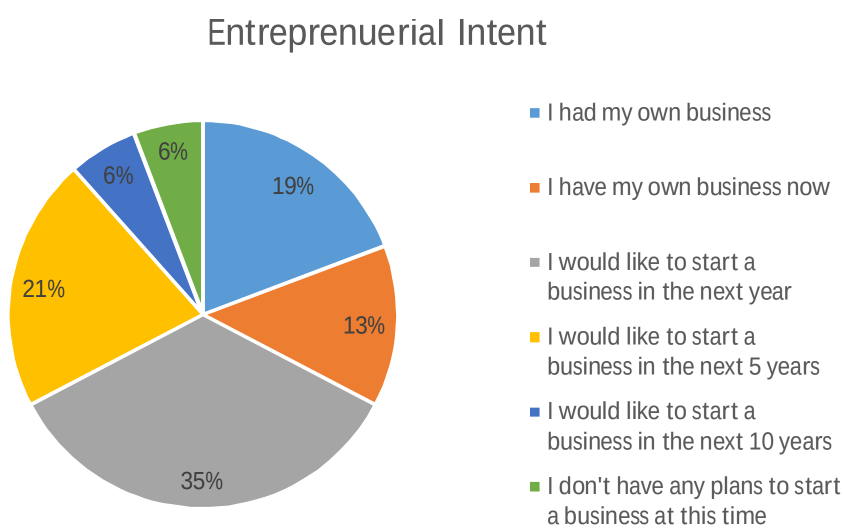

Figure 14. Results of the entrepreneurial intent survey.

in Zimbabwe and to meet the demands of the current global challenges. The study initially established the factors critical to improving the quality of engineering graduates from a macro perspective using indicators such as patents filed, investment in research and development, and the number of science and technology graduates. On a national level, macro indicators revealed that only 8 patents were filed in 2016 while about 298 scientific and technical journal articles were published. Two conclusions can be drawn from this; either (1) there exists a gap between knowledge acquisition and applications or (2) articles published were too abstract or impractical to implement or did not address significant societal, economic and environmental problems. In line with these two conclusions, the study went on to establish gaps in the system at University Faculty Level. Guided by findings in literature which assert that innovation can be enhanced through interdisciplinary education and competency based learning, where engineering students create solutions to address practical social, environmental and economic problems, the study went on to review the status quo of engineering education at UZ. Surveys carried out revealed that the engineering curriculum is biased towards conventional technical courses without adequate attention to current sustainable development issues although this is not an end in itself of engineering education. Additionally, curricula, which had a significant share of course sustainable development credits, such as civil engineering, also had a significant share of projects that addressed socio-economic and environmental issues. The entrepreneurial motivation scale revealed that the majority of engineering students are motivated by creation of solutions. This means that a focus on real world problem solving will play a significant role in improving the entrepreneurial intent of engineering students. Lastly a survey of the potential challenges that may hinder the success of interdisciplinary education revealed that the system posed the most significant challenges followed by lecturers and students. Based on these findings, the following recommendations are given:

1. The public and private sector invest in research and development to address the potential challenge of lack of resources in carrying out interdisciplinary projects.
2. The existing engineering curriculum must be reviewed to strike a balance between purely technical courses, sustainable development issues, emerging technologies, and entrepreneurship. This is especially critical in the mining and metallurgical engineering departments where above 80% of the courses are purely technical. An elective course that spans across mining engineering, environmental and social sciences should be introduced.
3. Introduce the concept of team-based learning supported by CBL where students and practitioners from different interlinked disciplines should provide a solution to address a real life problem. This will particularly make use of the recently constructed innovation hub and where additional resources are required, partnerships with the private sector can be sought to secure investment in research and development.

RECOMMENDATION

It is recommended that further research be carried out on a departmental level to identify interdisciplinary spaces that will enhance innovation.

REFERENCES

Akkerman SF, **Bakker** A (**2011**). Boundary crossing and boundary objects. Review of educational research, 81: 132-169.

Chikuku T, Chinguwa S, Mushiri T (**2017**). Industrial secondment as a tool to enrich engineeering education in Southern Africa. Procedia Manufacturing, 7: 15-21.

Ciesla K (**2009**). Building a Self-Supporting Web of Knowledge - What is Interdisciplinary Education? ESSAI, 7(16): 38-42.

Conference Board, Corporate Voices for Working Families, Partnership for 21st Century Skills & Society for Human Resource Management (**2006**). Are they really ready to work? [Online] Available at: http://www.p21.org/storage/documents/FINAL_REPORT-PDF09-20-06.PDF. [Accessed June 2019].

Dorst K (**2013**). Academic Design. Delft, Netherlands: Delft University of Technology.

Drake SM, **Burns** RC (**2004**). Meeting standards through integrated curriculum. Alexandria: Alexandria: VA: Association for Supervision and Curriculum.

Edvardsson Bjornberg K, Skogh K, Stromberg E (**2015**). Integrating social sustainability in engineering education at the KTH Royal Institute of Technology. Int J Sustain Higher Educ, 16: 639-649.

Eurostat (**2018**). Europe 2020 indicators - R&D and innovation. [Online] Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Europe_2020_indicators_-_R%26D_and_innovation#General_overview [Accessed 28 June 2019].

Gantogtokh O, **Quinlan** KM (**2017**). Challenges of designing interdisciplinary postgraduate curricula: Case studies of interdisciplinary master's programmes at a research-intensive UK University. Teach Higher Educ, 22(5): 569-586.

Gardner H. (**2006**). Five minds for the future. S.l.: Harvard Business School Press.

Henri M, Johnson MD, Nepal B (**2017**). A review of competency-based learning: Tools, assessments, and recommendations. J Eng Educ, 106(4): 607-638.

Hoolgard JE, Hadgraft R, Kolmos A, Guerra A (**2016**). Strategies for education for sustainable development e Danish and Australian perspectives. J Cleaner Prod, 112: 3479-3491.

Kim HN (**2019**). A conceptual framework for interdisciplinary education in engineering and nursing health informatics. Nurse Educ Today, 74: 91-93.

Klaassen RG (**2018**). Interdisciplinary education: a case study. Eur J Eng Educ, 43(6): 842-859.

Lam JCK, Walker RM, Hills P (**2014**). Interdisciplinarity in sustainability studies: A review. Sustain Dev, 22(3): 158-176.

Ledford H (**2015**). How to solve the world's biggest problems. Nature, 525: 308-311.

Luneburg FC (**2011**). Critical thinking and constructivism techniques for improving student achievement. Nat Forum Teach Educ J, 21(3): 1-9.

Mathison S, **Freeman** M (**1997**). The logic of interdisciplinary studies. Chicago: American Educational Research Association.

Mazur E (**2013**). Key Note Address at the 9th International CDIO Conference. Boston, MA, United States, MIT.

McTighe J, **Thomas** RS (**2003**). Backward design for forward action. Educ Leadership, 60(5): 52-55.

Miami University (**2010**). Partners in Learning. [Online] Available at: http://performancepyramid.muohio.ed [Accessed June 2019].

Ministry of Higher and Tertiary Education (**2018**). 2018 national critical skills audit report. Harare: Ministry of Higher and Tertiary Education, Science and Technology Development.

Momete DC (**2015**). Promoting Technological Entrepreneurship through Sustainable Engineering Education. Procedia Technol, 22: 1129-1134.

Mulder KF, Segalas J, Ferrer-Balsa D (**2012**). How to educate engineers for/in sustainable development. Int J Sustain Higher Educ, 13: 211-218.

Mulder KF, Segalas-Coral J, Ferrer-Balas D (**2010**). Educating engineers for/in sustainable development? What we knew, what we learned, and what we should learn. Thermal Sci, 14: 625-639.

Nyoni M (**2018**). Govt commits 1% of GDP to research. [Online] Available at: https://www.newsday.co.zw/2018/09/govt-commits-1-of-gdp-to-research/
[Accessed 25 July 2019].

Orlando M (**2013**). Nine characteristics of a great teacher. S.l.: Faculty Focus.

Palmer CL (**2001**). Work at the boundaries of science: Information and the interdisciplinary research process. S.l.: Dordrecht: Kluwer.

Rampasso IS, Anholon R, Silva D, RE Cooper Ordoñez, Quelhas OLG, WL Filho, LA Santa-Euláli (**2018**). An analysis of the difficulties associated to sustainability insertion in engineering education: Examples from HEIs in Brazil. J Cleaner Prod, 193: 363-371.

Raoufi K, Park K, Khan MTH, Haapala KR, Psenka CE, Jackson KL, Kremer GEO, KY Kim (**2017**). A cyberlearning platform for enhancing undergraduate engineering education in sustainable product design. J Cleaner Prod, 211: 730-741.

Repko A, **Welch** J (**2005**). Interdisciplinary Practice: A Student Guide to Research and Writing. Boston, MA: Pearson Learning Solutions.

Styron RA (**2013**). Interdisciplinary education: A reflection of the real world. Syst Cybernet Informat, 11(9): 47-52.

Summers M (**2005**). Education for sustainable development in initial teacher training: Issues for Interdisciplinary collaboration. Environ Educ Res, 11(5): 623-647.

Svanstrom M, Palme U, Wedel MK, Carlson O (**2012**). Embedding of ESD in engineering education. Int J Sustain Higher Educ, 13: 279-292.

Tejedor G, Segalas J, Rosas-Casals M (**2017**). Transdisciplinarity in higher education for sustainability: How discourses are approached in engineering education. J Cleaner Prod, 117: 29-37.

UNESCO (**2018**). Education: Distribution of graduates by field of study. [Online] Available at: http://data.uis.unesco.org/index.aspx?queryid=163# [Accessed 24 July 2019].

World Bank (**2018**). World Bank development indicators; Scientific and Technical Journal Articles. [Online] Available at: https://data.worldbank.org/indicator/IP.PAT.RESD?locations=ZW [Accessed 25 July 2019].

Yi S, **Duval-Couetil** N (**2018**). What drives engineering students to be entrepreneurs? Evidence of validity for an entrepreneurial motivation scale. J Eng Educ, 107(2): 291-317.

Citation: Mamina M (2019). A review of engineering education at the University of Zimbabwe. Afr J Eng Res, 7(4): 112-128.