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Re-engineering an Engineering Education Programme: Example of the University of Botswana

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BACKGROUND
Engineering practice continues to evolve in response to modern technological and scientific development. The accreditation systems of engineering education programmes has evolved in order to respond to the new trend and needs and also to provide mutual recognition of the different national engineering qualifications. The University of Botswana (UB) is currently the only tertiary institution in Botswana offering degree programmes in Engineering. To enhance its international recognition, UB is “re-engineering” its programmes to be aligned with the accreditation requirements.

PURPOSE
The principal purpose of the study is to establish that the process re-engineering model commonly employed in business environments can be used in an educational system. In particular the paper describes the process of re-engineering used for the transformation of the BEng (Mech) programme in order to align it with the accreditation requirements. It promotes re-engineering as the tool to analyse educational system.

DESIGN/METHOD
The study adopts a Business Process Re-engineering (BPR) in which engineering education is considered as a process. A modified McKinsey’s re-engineering model was chosen as a tool to re-engineer the educational system. The model involves five broad phases, namely, identification, review & analysis, re-design, test & implementation and continuous improvement. The paper concentrates on the first two phases. The existing curriculum is mapped according to the graduate attributes, competency profiles and the Engineering Council of South Africa (ECSA) Exit Level Outcomes.

RESULTS
The re-engineering process was used to identify the gaps between the existing programme and the accreditation requirements. Independent learning abilities and communication have been identified as clear gaps in Exit Level Outcomes between the existing programme and ECSA accreditation requirements. In terms of the graduate competency profile communication, team work and legal and regulatory issues are the most apparent deficiencies. In terms of graduate attributes the identified gaps are in life-long learning, team work and communication.

CONCLUSIONS
It was concluded that the major shortcoming in the existing programme was not necessarily its content but its mode of delivery. It is recommended that innovative flexible delivery methods should be used as teaching styles. The teaching and learning need to shift increasingly away from the lecture-laboratory approach to more active learning experiences that promote problem-solving skills, team building, creativity, design, innovation and life-long learning. As the study is not yet completed there is only anecdotal evidence that the re-engineering process could be used as a tool to re-engineer the educational system.

KEYWORDS
accreditation, re-engineering, mechanical engineering programme

Introduction

Engineering practice continues to evolve in response to modern technological and scientific development. The circumstances facing practicing engineers today are considerably different from those of the past. Moreover, the circumstances of the future will be even more different and challenging (Nguyen, 1998; Rugarcia et al., 2000). In this sense, the quality of future engineers critically depends on the quality of engineering education, which is itself dependent upon developments in engineering curricula (Nguyen, 1998).

Engineers in the past were mainly concerned with the technical aspects of engineering, commonly known as hard-engineering skills. However, as mentioned before, the world changed and the role of engineers has changed as well. In this context, the "engineer of the future" should be able to apply scientific analysis and holistic synthesis to develop sustainable solutions that integrate social, environmental, cultural, and economic aspects in complex and globalised systems (Amadei, 2004).

The accreditation system of engineering education programmes has evolved in response to the new globalisation trend and needs and also to provide mutual recognition of the different engineering licences across national borders. The accreditation systems are traditionally viewed as a measure of quality of the programme (Mardam-Bey, 2008).

Different international agreements to provide mutual recognition of the national accreditation systems have been developed several years ago. One of the first, and probably the most adopted, is the Washington Accord (WA), which was developed among the Engineering boards of some English speaking countries. Despite differences in their national accreditation systems, those countries have agreed that the resulting engineering graduate capabilities and knowledge are essentially equivalent.

Stimulated by the desire to enhance the quality of engineering education in Botswana and the need to provide international recognition to its graduates, the Faculty of Engineering and Technology (FET) at the University of Botswana (UB) is working to satisfy the requirements of the Engineering Council of South Africa (ECSA) for the accreditation of the Bachelor programme in Mechanical Engineering. ECSA is currently the only African Engineering board which has already signed the Washington Accord. To satisfy all the ECSA requirements the FET UB decides to critically re-think and review its educational process.

In this context, the paper aims to determine whether the business re-engineering process can be used in an educational system in order to identify the gaps between the current FET UB programme on offer and the ECSA and WA accreditation requirements and to provide some suggestions on how to bridge the gaps.

Washington Accord and ECSA Accreditation System

The Washington accord was signed in 1989 as an international accreditation agreement between bodies responsible for accrediting engineering degree programmes in some English speaking countries. The accord recognizes the equivalency of programmes accredited by those bodies and recommends that graduates of programmes accredited by any of the signatory bodies be recognized by the other bodies as having met the academic requirements for entry level engineering practice in member countries (International Engineering Alliance, 2011). The Washington accord’s programme requirements are designed on the Outcome Based Education (OBE). OBE involves a paradigm shift in curriculum design, mode of instructional delivery, assessment and reporting practices in education to reflect the achievement of high order learning rather than the accumulation of specific number of course credits. In particular, OBE specifies the "outcomes" that students should acquire and demonstrate upon successful graduation from an accredited programme (McBeath, 1992). It focuses on educational experiences, skills and competencies that could develop the expected graduate from a programme.

Graduates of engineering programmes are expected to possess a set of individually assessable outcomes that are indicative of the graduate's potential and competence to practise at the appropriate level. These are called graduate attributes and are designed to assist in the development of criteria and guidelines to be used for assessing readiness and suitability of a programme seeking accreditation status.

The Washington Accord is not prescriptive in terms of the curriculum structure but only provides guidelines related to the knowledge profile. In particular, WA accredited programmes would provide sufficient evidence of:

- Basic Science and Mathematics knowledge,
- Engineering and applied science knowledge including computing & IT,
- Complementary studies knowledge and
- Practice that summarises all the acquired knowledge.

Each WA member organisation has to translate and firm up these indicative requirements into more detailed explicit accreditation rules and guidelines which should be contextualised for the particular country and operating environments.

The Engineering Council of South Africa (ECSA) is the statutory body for the engineering profession in the Republic of South Africa. A programme is accredited when its graduates have satisfactorily met the educational requirements in all categories as stipulated by ECSA.

The accreditation process for South African engineering programmes was extensively revised in the late 1990s and in particular outcomes based criteria were introduced in 2000 to comply with the WA requirements. Pursuant to this review, ECSA adopted common accreditation criteria, policy and processes for all programmes applying for accreditation. ECSA requirements for the engineering programmes are not limited only to the curriculum structure but include also programme aims, objectives and outcomes, quality of teaching and learning, resources and sustainability of the programme.

Methodology Adopted to Re-Engineer the Educational System

Re-engineering activities can be considered at any level of an organizational process. Process re-engineering covers the examination, study, capture, and modification of the internal mechanisms or functionality of an existing process. It is affected in order to reconstitute it in a new form and with innovative functional and non-functional features, often to take advantage of emerging or desired organizational capabilities. However, the inherent purpose of the process that is being re-engineered should not be changed. In particular, Business Process Re-engineering (BPR) describes an organization considering different perspectives, such as the organizational structure, processes, staff and resources, and considering how they interact. Hammer (1993) aptly defined Re-engineering as “the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance such as cost, quality, service and speed.” Also Davenport (1993) stated that a “process is a structured, measured set of activities designed to produce a specified output for a particular customer or market.”

Therefore the BPR approach can be easily applied to an educational system. In that approach the university/faculty can be seen as the organization delivering a set of processes, which all together constitute the educational system. Some of the desired advantages of BPR are (Singh et. at, 2012):

- Speed - time to complete key processes
- Flexibility – adaptable processes and structures
- Quality – in terms of service delivery
- Productivity – effectiveness and efficiency of service delivery and
- Innovation – imaginative positive change to existing processes.

The re-engineering process chosen to evaluate and review the engineering educational system at FET is based on the re-engineering process cycle model adapted from the models developed by Hammer in 1990 and Zigiaris in 2000 (Hammer, 1990; Zigiaris, 2000) and later improved by McKinsey (Simon, 2008). The major components of a Business Process Re-engineering Life Cycle are presented in Figure 1.

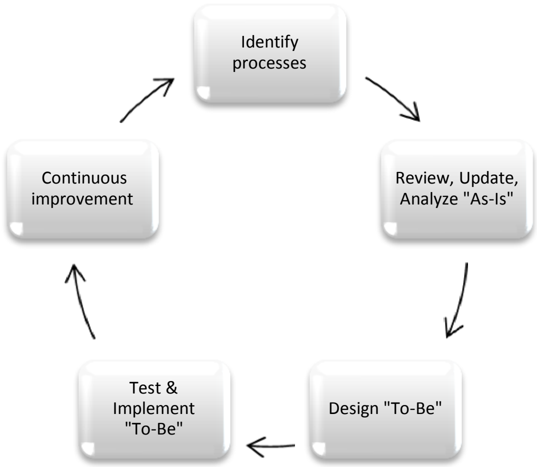

Figure 1: Re-engineering process cycle model (Zigiaris, 2000)

There are five major phases in the re-engineering model as described by Zigiaris (Zigiaris, 2000):

Identify processes. The starting point of the procedure is to identify the relevant system and sub-systems of the process under study. In this phase, it is necessary to establish a strong commitment at all levels of the University, Faculty and departments. In particular, all the academic staff should be aware of the aim of the process re-engineering. Moreover, in this phase it is important to identify ECSA requirements that BEng (Mech) programme at FET UB should fulfil.

Review, Update, Analyse "As Is". This phase aims to diagnose and identify problematic areas in the current processes by assessing their performance characteristics based on those factors and criteria identified in the ECSA and WA accreditation requirements. In particular, the existing educational process needs to be scrutinized, and the identified performance gaps diagnosed.

Design "To Be". In order to design the "To Be" it is important to identify the objectives, and in particular a detailed explanation of the requirements the education process wants to achieve.

Test and implementation of "To-Be" processes. The new process designed needs to be tested in order to verify the process logic, the usability, and the educational outcome that could be really reached. The test also includes the assessment of the resources allocation (students, academic staff, and facilities). The implementation consists of a road map for the new educational system implementation and rollout

Continuous improvement. This phase consists of periodically evaluating the performance of the educational processes. During this phase, it is possible to plan the time and the resources for the next re-engineering project.

This paper reports on the first 2 phases of the re-engineering procedure and the other phases will be reported after completion of the on-going exercise to develop quality and internationally recognised mechanical engineering programme at FET.

Re-Engineering the BEng (Mech) Programme

The first two phases in the re-engineering process followed in the programme review are described in this paper; i.e. 'Identify Processes' and 'Review, Update, Analyse "As Is"'.

It has been recognized in the identification process that there are a few relevant items which have to be aligned in order to satisfy ECSA requirements of accreditation. The following crucial elements of the educational processes have been identified.

Curriculum structural requirements – ECSA has defined the structure of the engineering curricula based on South African Qualifications Authority (SAQA) minimum credits by knowledge area (ECSA, 2004).

Exit Level Outcomes –ECSA has identified ten exit level outcomes which engineering students are to acquire during educational process (ECSA, 2004).

Resources – an institution desirous to offer an educational system which is capable to support the student in acquiring prescribed outcomes has to provide resources (academic staff and facilities - library, laboratories, computational etc).

Student – it is important to analyse the students' recruitment, instruction and assessment processes. It is the only way to establish whether the Exit Level Outcomes (ELOS) are reached.

In order to identify the differences or gaps between the current BEng (Mech) programme and ECSA accreditation requirements, the structures of the two programmes have been prepared, analysed and compared. The analysis included the assessment of the contribution of each course in the curriculum to the overall attributes and professional profile of the graduates. Gaps have been reported both quantitatively and qualitatively.

Curriculum structural requirements

The curriculum of the BEng (Mech) programme have been assessed and analysed by identifying the courses which contribute to a particular element of interest. The contribution has been considered in '0-1' mode (i.e. 'yes' or 'no') and a course could contribute to more than one element. The allocation was done by inspecting the course descriptions and interviewing lecturers in charge. The percentage values (used in Table 1 and Figure 2) have been based on the ratio between the number of courses contributing to an element and the total number of courses. For example for ECSA Requirements and current B.Eng programme, 10% and 8% of the courses contribute to Mathematical Sciences respectively (Table 1).

Two steps were taken in order to identify the gaps in the curriculum structure of the BEng (Mech) programme at FET UB. At first, it was scrutinized whether the four discipline areas required for accreditation (as prescribed by the Washington Accord) are covered by the BEng curriculum. Secondly, the ECSA curriculum structure requirements were considered using the percentage of credits required in each area (Table 1).

Although the WA does not prescribe any minimum level for each area, it is evident that the BEng. (Mech) curriculum is mostly technical and theoretical and not much consideration is devoted to practical and soft skill competencies that can be promoted in design & synthesis and discretionary courses (Table 1).

In terms of ECSA requirements, the structure of the FET UB programme seems to be well-aligned. The only major gap is in the Design and Synthesis area. There are however two discrepancies; the minor one in the Mathematical Sciences (the gap of 2%) and the major one in the Design and Synthesis area (3% difference). The development of skills in design and synthesis is essential to good engineering practice and technological innovation. Creativity skills are also normally introduced in that area. There is need to increase the elements of design and synthesis in the programme. It can be either by introducing a separate course in that area or by increasing the design and synthesis content in the existing courses. As the existing courses cover all areas of mechanical engineering it is recommended to increase design and synthesis component in the existing courses. Beyond synthesis, creativity and design, engineering students must acquire skills in innovation and entrepreneurship. Innovation involves much more than mastering emerging science and technology. It involves how to take this knowledge to the next stage of providing service to society (Duderstadt, 2008).

Table 1: Curricula programme structure

Area	ECSA Requirements	BEng. (Mech) Programme
Mathematical Sciences	10%	8%
Basic Sciences	10%	12%
Engineering Sciences	30%	34%
Design and Synthesis	12%	9%
Computing and IT	3%	5%
Complementary studies	10%	11%
Discretionary	25%	22%

The curriculum of the BEng (Mech) programme has also been mapped considering two elements; Graduate Attributes and Exit Level Outcomes. Those elements are based on the OBE and the comparison has been done with a similar (accredited) programme at one of the universities in South Africa (Figure 2). Figure 2 has been obtained by calculating the number of courses contributing to each element as a percentage of the total number of courses in the curriculum. It can be observed that the BEng (Mech) UB FET is skewed unlike the ECSA accredited programme. Based on the figure it is quite easy to identify deficiencies in the current programme.

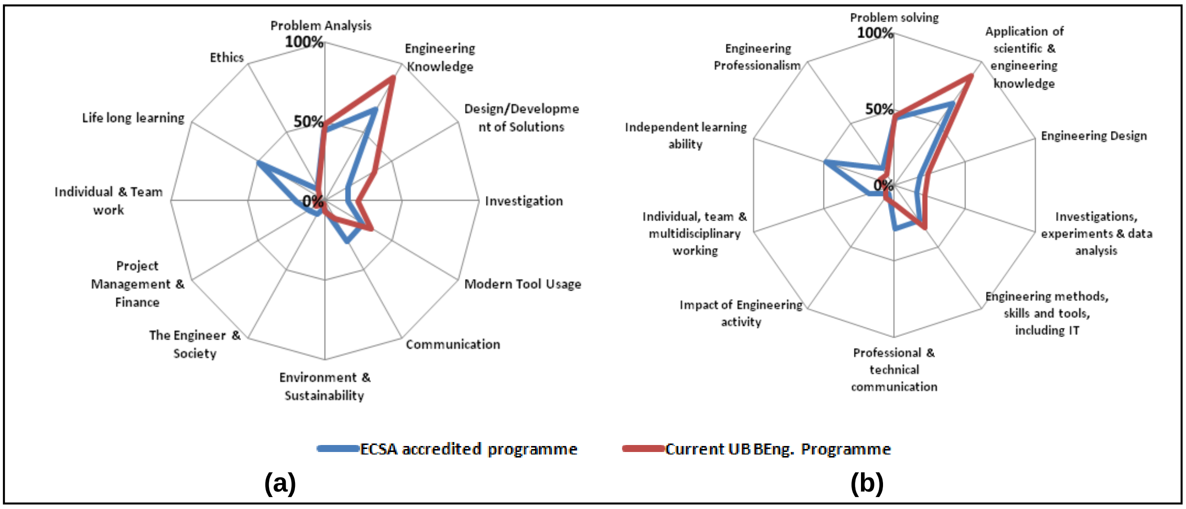

Figure 2: Graduate Attributes (a) and Exit Level Outcomes (b) of BEng (Mech) programme

Figure 2 indicates that the major emphasis of the programme is to provide technical knowledge and basic engineering skills. In terms of Exit Level Outcomes there are visible gaps between the programme and the ECSA requirements especially in independent learning abilities and communication. In terms of graduate attributes the identified gaps are in life-long learning, team work and communication.

It can be concluded that to reduce the identified deficiencies the current programme needs more provision in complementary studies with a global perspective and extracurricular activities to support students' initiatives and creativity.

The type of deficiencies also indicates that the major setback of the programme is not necessarily its content but its delivery. Most of the findings can be attributed to the traditional teaching style (confirmed during interview with teaching staff) which is not based on what the student can learn but on what the lecturer can deliver. The traditional approach adopted in the teaching activities is also confirmed by the fact that few courses try to develop or improve team and multidisciplinary working skills. Only two courses have a project based examination. Clearly, to eliminate this gap, the education style needs to shift increasingly away from the lecture-laboratory approach of the sciences to more active learning experiences that develop problem-solving skills, team building, creativity, design, and innovation.

There is also some lack of legal and regulatory issues, project management and finance in the FET UB programme. Those courses are of comparable importance in order to develop an educational process capable of "*producing*" global. They must provide the student an understanding of the global economy, engineers' need of the ability both to comprehend and work with other cultures, to work effectively in multinational teams, to communicate across nations and peoples, and, in particular in the developing countries, to understand the great challenges facing our world. However, only few courses provide the student competencies on the impact of engineering activities on the society and knowledge about engineering professionalism. In particular, the FET UB programme should provide more soft-global competencies, which are the key qualification for engineering graduates.

Programme Resources

Student - The admission requirements for BEng (Mech) programme at UB is the Botswana General Certificate of Education (BGCSE). Performance in this examination determines entry to the University of Botswana. All engineering students follow General Science programme in Year 1 and in order to be registered for engineering programmes they require a minimum grade of credit in mathematics and physics. This kind of approach is developed with the aim to have homogeneous knowledge classes and it is aligned with the ECSA requirements. However, it is still to be determined whether the level of knowledge of students admitted to engineering programmes is similar to those students in similar accredited programmes.

Academic staff - There is no noticeable deficiency in the qualification and experience of teaching staff i.e. they have profiles comparable to similar institutions in the region and internationally.

Facility Resources - The FET UB is a new faculty facing some problems in terms of laboratories and computing and support facilities. In particular, many difficulties are connected with the power supply. Frequent black-outs create problems in the management of the lectures and laboratories activities. Another issue is related to computing facilities, in particular to the internet connection, typical problem in Africa.

The FET UB library facility is well-resourced as current and state of the art materials and publications are readily available.

Redesign, Implementation and Continuous Improvement Phases: The OBE Approach

The OBE approach based on four principles shown in Table 2 can be used in order to transform the existing BEng (Mech) programme to eliminate the deficiencies and gaps previously identified. The ultimate goal is the accreditation of the programme by ECSA but the immediate goal is the improvement of the programme, its structure and delivery.

The four principles guide the transformation to the OBE approach and taken together they strengthen the conditions for both learner and teacher success (Spady, 1994). The systematic approach (Davis et al., 2007) for the implementation of the principles and some suggestions to enhance acceptability of the FET programmes in its transformation process are presented in Table 2.

The expected changes in the BEng (Mech) programme should be first related to a strong curriculum re-engineering and the adoption of innovative flexible delivery methods.

Moreover, as stressed in the OBE approach and in the ECSA requirements, it is absolutely necessary to introduce a variety of assessment and evaluation methods to analyse the Exit Level Outcomes reached by the students.

Table 2: Outcomes Based Principles – explanation & application

OBE Principles	Redesign Issues	How to implement
Clarity of focus	Focus on what learners will be able to do successfully	• Help learners develop competencies • Enable predetermined significant outcomes • Clarify short & long term learning intentions • Focus assessments on significant outcomes
Design down	Begin curriculum design with a clear definition of what learners are to achieve by the end of their formal education	• Develop systematic education curricula • Trace back from desired end results • Identity "learning building blocks" • Link planning, teaching & assessment decisions to significant learner outcomes
High expectations	Establish high, challenging performance standards	• Engage deeply with issues of learning • Push beyond where learners would normally have gone
Expanded opportunities	Do not learn the same thing in the same way in the same time	• Provide multiple learning opportunities matching learner's needs with teaching techniques

Although the re-engineering process at UB has not been completed yet, there are some benefits which have been observed. The main issue is related to critical analysis of the existing programme and its alignment with the accreditation requirements. The other benefits include identifying the gaps between the existing programme and the accreditation requirements in Exit Level Outcomes, competency profile and attributes of graduate.

Conclusions

The paper describes the process of re-engineering used for the transformation of the BEng (Mech) programme in order to align it with the accreditation requirements. The study adopts a Business Process Re-engineering (BPR) in which engineering education is considered as a process.

A modified McKinsey's re-engineering model was chosen as a tool to re-engineer the educational system. The model involves five broad phases, namely, identification of processes, diagnosis, redesign, implementation and monitoring, evaluation and improvement.

The current Mechanical Engineering curriculum is mapped according to the graduate attributes, competency profiles and the ECSA Exit Level Outcomes. In terms of Exit Level Outcomes independent learning abilities and communication have been identified as gaps between the existing programme and ECSA accreditation requirements. In terms of graduate attributes the identified gaps are in life-long learning, team work and communication.

From the identified deficiencies it can be concluded that the major shortcoming of the programme is not necessarily its content but its mode of delivery. It is recommended that innovative flexible delivery methods should be used as teaching styles. The teaching and learning need to shift increasingly away from the lecture-laboratory approach to more active learning experiences that promote problem-solving skills, team building, creativity, design, innovation and life-long learning. The programme must employ discovery-oriented learning environments that capitalize on the full power of modern communication schemes, information gathering, and visualization technologies.

As the re-engineering process is yet to be completed there is only anecdotal evidence that business procedure can be successfully used for engineering education process. However, apart from critical analysis of the existing programme the process has offered many new experiences to all involved in the transformation. For some staff members the exercise has triggered interest in engineering education as an important aspect of their academic duties and career.

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