Study of Critical Success Factors in Engineering Education Curriculum Development Using Six-Sigma Methodology

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Abstract

Highly skilful and competent human capital especially engineers are critically needed to accelerate and contribute efficiently towards the development of technology in view of spearheading much of Malaysia's transformation agendas. Hence, Institutions of Higher Learning (IHL) are required to play a pivotal role to produce graduates, who are equipped with sound engineering based knowledge, technical competencies along with related desired attributes to support the nation's transformation roadmap. As employability of graduates forms as one of the important Key Result Areas (KRA) of all IHL, interesting active learners teaching methodologies such as Outcome Based Education (OBE), Problem Based Learning (PBL), Project Base Learning, Case Based Learning (CBL) and TRIZ has been infused in the curriculum to ensure that connectivity prevails between classroom instructions and the curriculum contents besides producing industry ready graduates. However, rapid technological development at work front has created an impact towards employment of graduates, which calls for an immediate redefining of current technical attributes to cultivate elements of creativity or "out of box" thinking approach to spark ideas of highly innovative that are of commercial value to generate revenue for the sustainability of businesses. Hence, this study is to determine the critical success factors required in engineering education curriculum to produce engineering graduates of global minded workforce where adaptability to new conditions and creativity for innovations are much sought after by industries.

Keywords: Outcome Based education, Problem Based learning, Continuous Quality Improvement;

1. Introduction

As Malaysia moves towards becoming a developed nation by the year 2020, it needs to create a better educated and a more highly skilled population to spearhead much of Malaysia's transformation agendas. However, the era of globalization has played a crucial role in influencing the current trends in the engineering education sector. Hence, Institutions of Higher Learning (IHL) are required to play a pivotal role to produce graduates, who are equipped with sound engineering based knowledge, technical competencies along with related desired attributes to support the nation's transformation roadmap.

Universities are usually classified as non-profit organizations that perform the primary role of imparting knowledge to undergraduate students and are deemed to be the focal point to generate knowledge in abundance and to conceive new innovative ideas that will lead to technological breakthroughs.

Hence, in order to assist Malaysia in many of its transformation agenda targeted by year 2020, engineering graduates produced by universities and other engineering providers are expected to well prepared with elements such as strong analytical skills, practical ingenuity, creativity, good communication skills and business goal oriented, leadership and professionalism as well as thirst for discovery of new knowledge [1].

Engineering education is often perceived as a process of imparting valuable engineering concept and vast theoretical knowledge coupled with matching practical skills in view of producing engineering graduates who are able to play a dynamic role in assisting to shape the future technological society of a nation. However, engineers

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venturing into the workforce in this era of rapid change in global and technical environment face an uphill battle of discharging their role effectively and most importantly demonstrating high sense of innovativeness at work front.

As engineering educators strive to master the many teaching and learning pedagogical approaches to stimulate, teach and motivate students and to tap into as much knowledge as possible, it is inevitable that at some point educators will realize that they efforts are in vain as the gap will still persistently exist between students' performance and the industry's expectations in terms of hiring graduates of innovative talent as well as adaptability towards technological changes [2].

The traditional lecture-homework-test approach adopted by many engineering educators is ineffective in producing graduates of high critical thinking caliber as these modes fail to create an empowering learning environment impact to stimulate students learning process. Furthermore, teaching or lecturing process needs a new paradigm shift as it does not enhance problem solving skills nor stimulate critical thinking attributes of students to face challenges as professionals [3].

Concern that the engineering undergraduate education curriculum and course instruction cannot adequately prepare graduates to exhibit innovativeness at a satisfactory level to meet the expectation and demand of industrial partners, engineering educators are going back to discussion room to explore modes to reinvent the engineering curriculum.

It is critically important that a mechanism is establish to gauge the engineering education system such that gaps between the need for well trained innovative graduates and the ability of engineering providers to produce such graduates are narrowed. Hence, this study attempts to identify the critical success factors that are essential in the engineering education curriculum in producing graduates of highly innovative talent for the workforce.

2. Research objectives

The primary aim of an education system is to assist students, as much as possible, in grasping the theoretical knowledge and stimulating their intellectual capabilities. Hence, the process of teaching and learning focuses on the satisfactory planning of elements such as contents, strategies, assessment and other parameters, with the view of ascertaining the extent and feasibility of the learning curve and the amount of learning achieved by the student. It is an extremely delicate process, and the desirable learning outcomes from the teaching and learning process must be measured in an appropriate manner so that learners are well equipped for the workforce. However, there are many factors that will affect students' academic performance, ranging from students academic ability, the environment, teaching methodologies and teaching aids used, students' attitude and lecturers' involvement in teaching [4].
Thus, sensing a critical need for a highly competent human capital that is equipped with both technical and scientific skills, the liberalization of education in Malaysia is instituted to ensure that the nation's economic growth transformation blueprint can be transformed into reality. The liberation of education policy also enables good practices to be adopted in view of minimizing defects in terms of attributes gained by graduates.
However, technology-driven organizations normally develop mechanisms that allow them to efficiently harness engineers of the "innovator" profile to sustain and promote business growth. It is expected that graduates armed with knowledge from academic institution are capable to discover new ideas as part of technological breakthrough which could be optimized for business sustainability. This then beget the questions below:

1. Is engineering education curriculum sufficiently producing graduates of innovative talents to the workforce?

2. Does the developed engineering curriculum need to accommodate further relevant elements in order to harness innovation to meet industry demands?

3. Critical Success Factors

Vast reviews are widely available pertaining to the importance of identifying key elements that forms the core nucleus that drive the business growth of organization forward into an upscale trend.

Critical success factors could be viewed as an important tool that could be used to explore and identify key factors that faculties or entities should focus on to be successful. In this way, faculties would be more focus in injecting efforts on strengthening their capabilities to meet the critical success factors [5].

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4. Factors Affecting Graduates' Success

Gaining knowledge upon completion of an engineering education should not be restricted purely towards securing employment but to strive to harness ones full potential to contribute effectively and innovatively towards successful implementation of employer's tactical and strategic directions.

A number of variables influencing the success of producing innovative graduates for the workforce were identified following an extensive literature review session. Some of the elements are discussed below.

4.1 Washington Accord

The impact of globalization has changed the landscape of engineering undergraduate education to adopt standard framework outlined by Washington Accord which is viewed as an important milestone of success to produce graduates of global mentality.

Washington Accord is a multinational agreement and mutual recognition of the equivalency between each of the engineering degree programmes accredited by the responsible bodies in each of the signatory countries. The agreement also recognises that engineering graduates from these programmes have met the academic standards for entry into the practice of engineering in any signatory country. It is basically a quality assurance process adopting the world best practices [6].

One of its guideline outlines that connectivity should prevails between classroom instructions and the curriculum contents so that students are well equipped with desirable attributes to join the workforce. This is because industry representatives have stressed that engineering education should prepare students for real-world problem situations. They expect students to be equipped holistically and to have acquired competency in functioning as a team and able to display interaction and interdisciplinary skills [7].

Relevancy of engineering education to the demand of industry is seen as least priority as universities tend to develop undergraduate programmes based on their own requirements and policies that do not necessarily blend with the industry's requirements. This mismatch between the industry's expectations and the education provided by universities has resulted in graduates being ill-prepared for work in the real-world, bearing degree that does not include the most current technologies [8].

Teaching to impart knowledge to budding engineering students should not be restricted purely towards content coverage and available knowledge but rather to adopt engineering instruction that enable to narrow the gap between theory and practice. Hence, another distinct drive of Washington Accord is to instigate engineering educators to steer away from the conventional lecture base learning approach but instead to adopt new pedagogical approach that could develop a holistic graduate with desirable traits for the workforce [9].

In view of meeting these expectations, Washington Accord ensures that programmes that are accredited should demonstrate that its graduates are equipped with 13 professional abilities such as sufficient knowledge in sciences and mathematics, design capabilities, work in multi disciplinary teams, broader problem solving skills, adopt lifelong learning approach, work ethically and communicate effectively. Nurturing these desirable skills to the graduate via an innovative curriculum structure forms as a best practice pathway to provide young graduates the opportunity for better employment and room for development as they are prepared to adapt to the impact of rapid globalization, to blend and contribute towards the advancement in technological breakthroughs as well as to intensify the pace of the nation's growth and development [6].

4.2 Outcome Based Education (OBE)

Innovative teaching pedagogy in the form of Outcome Based Education (OBE) is considered as another factor that enables learners to acquire knowledge in an effort of stimulating their intellectual capabilities.

OBE is a model of teaching that is of result oriented which seeks the learners to demonstrate upon learning.

The paradigm shift towards OBE culture in the engineering sector forms as a mandatory requirement for an accredited engineering degree program. OBE approach is considered superior than the prescriptive mode as it has the capability of exploring the cognitive level of learners in view of flagging demonstrable measurable attributes [10].

The OBE culture is basically a performance base criterion which requires a system to be developed that demonstrates the graduates achievement in terms of knowledge, competencies and other desirable skills, thus producing graduates with attributes more relevant to industry stakeholders [6].

The competency level of present-day graduates, using already known facts of science, is inadequate for solving industrial problems. Students assume that the majority of problems encountered are well defined in terms of inputs, processing modules and outputs. However in the event a complex problem surfaces in the real world environment, they are unable to rise to the expectation of the industry in solving such problems and thus performs poorly at the workplace [7]. Utilization of appropriate tools for honing innovation and steering interest in the area are normally not stressed in engineering undergraduate programmes [11].

The fact that OBE is a needs-driven approach which focuses on the development of contents such as knowledge, skills and attitude expected from graduates, is the key feature that champions this approach. In addition, assessment is on continuous basis and is of criterion referenced type so that it aims to assess learners in a holistic manner. Hence, OBE forms as an antidote to some deficiencies of engineering education curriculum as it enhances core competencies of the learner in terms of improved perception towards acquiring knowledge and skills gained, develops creative and critical thinking capabilities, instil sense of responsibility and global outlook towards technology development and leadership traits [12].

4.3 Problem Based Learning (PBL)

Engineering education providers are pressured to ensure that graduates are well equipped with the necessary transferable and creative thinking skills that enable graduates to be successful in gaining employment. In view of this, providers have taken initiatives to adopt educational strategies such as Problem Based Learning (PBL) which forms as another key successful factor for this study.

PBL is generally executed by giving learners a problem to ponder over prior to teaching the topics required to solve the problem. This encourages learners to explore the problem via a series of discussions to generate hypotheses-based solution solely on the merits of whatever knowledge they have. Eventually, mentored by the instructor, they are engaged and are asked to highlight the possible solutions to the problem. The teacher's task is to blend-in, and not to dictate or attempt to control the procedural thinking of the students. After the session, students would engage in self-directed learning by searching information from reliable sources to reinforce their analysis of the given problem. Hence, the primary aim of this approach is to support the learner in becoming more effective thinkers in a particular domain in view that learning has been synthesized and organized within the context of the problem [13].

PBL is viewed an attractive pedagogical approach which assists students in developing self-directed learning skills that challenges the cognitive side of learners. The approach uses knowledge contents to foster creative thinking and problem solving skills; thus encouraging students to be more aware of the way they think and learn. PBL approach encompasses elements of problem solving, inquiry, project-based teaching, case-based instruction and anchored instruction. Geared towards student centered learning and the concept of ownership of learning, this strategy has created positive attribute changes in learners, such as the observable increase in student motivation, deepened understanding of context, the increase in the level of interaction and communication skills and the cultivated interest in sourcing information to supplement contents [14].

This approach forms as the main remedial driver to tackle students with passive attitude, low motivational drive and communication skills as the challenges at industrial work front requires dynamic, innovative and talented graduates to spearhead many areas.

4.4 Theory of Inventive Problem Solving (TRIZ)

TRIZ is a powerful methodology which consist set of tools for inventive problem solving and innovative thinking which is considered as another key factor in this study. The core principle of TRIZ is that it offers to analyze a problem, build its model and apply a relevant pattern of solution to identify appropriate solution.

Recently, innovation has been a primary concern of industry players; especially its application in developing strategies that targets business growth to outperform competitors and build sustainable survivability. This has resulted in industry players being selective in employing engineers. An element of extra edge is always sought after from graduates as they are expected to produce ideas to develop highly innovative products to meet customers' demands and to reinforce customers' market confidence [15].

The task of educators is often to equip the next generation of engineers with the skills for the challenges in the ever-challenging competitive environment. However, a majority of engineers face many different technical issues when it comes to inventing, improving, designing, modification and repairing works and inclusively the evolution of the next generation system. The element of innovative capability is often seen as a lacking skill amongst engineers who are required to source new and essential ideas in invention and design. In view of this, TRIZ is an epitome of a design tool that enables students to overcome contradictions in system design [16].

Engineering education should support and hone the ability of its student to define real world problems accurately before trying to actually solve problems. Lack of innovative engineering talents to take on the leading role in producing new products may affect job employment as this talent is critically sought after by industry partners. Innovation by means of technology transfer triggers conception of new ideas and products; but this too is expected to be entrepreneur-driven in order to attract firms to invest in the idea [17].

Thus, creative thinking is an important element that needs to be addressed by engineering education providers as innovative capabilities amongst graduates are much sought after by the majority of successful organizations.

4.5 Project Based Learning

Another critical success factor to be considered is Project Based Learning, a self-directed and multi-disciplinary orientated pedagogy of mentoring budding engineering learners. Project Based Learning is a hands-on mixed-mode approach and it is usually infused into mini project-based modules in the engineering curriculum. Implementation of this mode involves mainly application of knowledge. It is highly dependent on knowledge previously gained and it stresses on the learning process rather than the teaching. The scope of project development spans a large area, covering design and building, system integration, testing and debugging. It also stretches to the extent of system analysis in view of producing products of high reliability. Hence, the tutor plays an active role in rendering guidance of the appropriate level as this approach requires product-oriented supervision [18].

The project based learning pedagogy introduces the other set of skills that are frequently expected by employers such as project management (involving time, resources and budget), and critical thinking as shown by their ability to tackle issues during their course of study. It encourages learners to be vocal in sharing ideas, and thereby be inspired to put their ideas into motion; a cooperative behaviour forms the key essence of this learning approach [19]. This is an approach that provides opportunity for students to work together in a cooperative manner to tackle issues with confidence. This effectively stimulates their creativity, and ultimately works towards the goal of producing a product that is their own version of reality; and these are some of the key attributes sought after by employers.

4.6 Case Based Learning (CBL)

Another critical success factor that is an important element of this research is Case Based Learning (CBL). This is a small-group approach whereby the group would be given some pre-assigned topics to study prior to commencement of the learning session. This enables the learners to carry out some initial ground work and to be engaged in a discussion session.

This approach drives students to explore their understanding and reasoning capabilities and expects learners to be content experts of that particular session as discussions will have enriched their knowledge. It encourages positive attitudes in students, as can be evident in their capability of articulating with confidence during interactions with their mentor. Involvement of the facilitator is not limited to guidance only but to also include the provision of feedback pertaining to students' performance [20].

4.7 Internship

Internship or industrial training forms as another important factor that is considered for this study. Internship module is a program offering supervised practical experience for undergraduate students in the field of engineering. It is offered for a pre-determined period of time at an off campus location for academic credits.

Industrial attachment provides the opportunity and the environment for students to have first-hand experience of the activities and functions which relate directly to application of knowledge outside of their classrooms, and this shapes the students' higher education experience. With this element infused into the engineering curriculum, graduates with a degree and the experience gained through internship will increase their career options by tenfold [21]. Thus reinforcing on the idea that there is a critical requirement for hands-on skills and real-life experiences in order to stay afloat in the competitive job market, it was suggested that the technical and vocational system develop some form of partnership with the industrial sector to provide the much sought after exposure for engineering students. With this collaboration it is anticipated that the gap between real world practice and engineering education would be reduced. This idea was brought up because of the limitation of the educational infrastructure to produce the desired outcome for actual industry settings [7].

Undoubtedly an internship program is a challenging endeavour for many educational institutions to incorporate into their current offerings; however, any program designed to build holistic characteristics in a student in the education field is certainly worth the effort.

4.8 Continuous Quality Improvement (CQI)

Quality culture is one of the most important factors that are to be considered not only for improving the processes in the education system but also to be leveraged on to increase enrolment, monitoring of poor progression and passing rate, to reduce attrition rate as well as to ensure employability of its graduates. This is because higher education has become more commercialized and is now treated as a market commodity. As education is becoming more service-oriented, graduates are viewed as the product that is to be well groomed in view that it will be tapped by future employers [22].

It is of great importance that developed curriculum is reviewed periodically for improvement in order to sustain production of holistically competent graduates for the workforce. Improvement process phase base on input from various stakeholders enables identification of defects in the curriculum development that hinders the process of nurturing graduates with desirable traits. As such, it ensures that tailored courses have kept in view and have synergised with developments and trends in technology and the industry's needs. This move should provide young graduates the opportunity for better employment and room for development as they are well prepared to adapt to the impact of rapid globalization, blend and contribute towards the advancement in technological breakthrough as well as to intensify the pace of the nation's growth and development [6].

5. Research Overview: Application of Six Sigma– DMAIC Methodology

Recently six sigma as an improvement approach has gained wide popularity in many service sectors such as banks, healthcare centres, utilities services and airline industry primarily to gain customer confidence and to boast business growth. In fact education segment is of no exception as it is fast inclining as a profit generating business enterprise with minimal impact towards nation building [22].

Six-sigma is an improvement strategy geared towards reducing defects on existing products and strategies efforts in improving business growth and sustainability. This methodology has two techniques which are known as DMAIC

(Define, Measure, Analyse, Improve and Control) and DFSS (Design for Six sigma). The main difference between these techniques is that DMAIC is a process improvement strategy applied on developed and existing project or system while DFSS is geared towards designing new product or process. Furthermore, DFSS is a resource intensive method that is very expensive [23].Hence, DMAIC, a five step process is adopted in this study.

It must be noted that in the engineering education system, there are many stakeholders like students, engineering educators, management leadership team, governmental agencies and industrial players. It must be highlighted that students are primary stakeholders and how they are nurtured within the engineering curriculum to acquire knowledge, technical skills and related competencies has a great impact towards exhibiting their innovative talent at workplace.

However, in order to understand the nature of this study, a 'chain of causation" structure is created as shown in Figure 1 base on valuable investigation and contribution of a researcher [22].
Base on this structural flow, the applied methodology could identify the success factors linked for the development of innovative talent graduates. However, in this scenario, the engineering education curriculum critically requires infusing of strategies that enables graduates to harness their full potential to play an Innovator role upon gaining employment rather than knowledge base graduate.

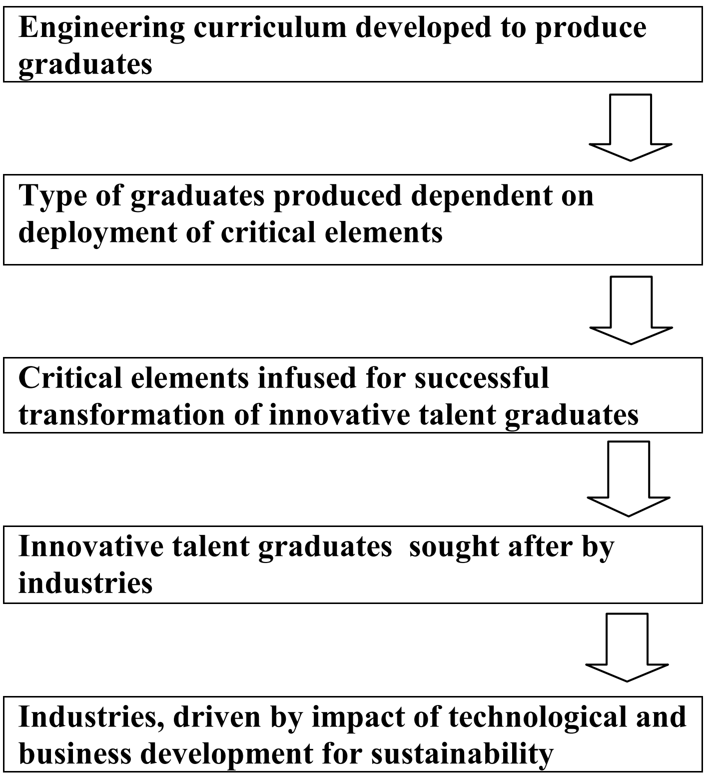

Figure 1: Chain of causation

(Source: Interpretation of research work *Kaushik & Khanduja ,2010*)

The five step improvement phases are expected to undergo investigation on the propose scope as outlined below:

Define phase:
The major purpose of this phase is aim to study the critical success factors in the engineering education curriculum development to produce innovative talented graduates for the workforce. Additional benefit of this investigation enables faculty to focus on investment of staff development towards specific factors that creates huge impact towards this study.

Measure phase:
In view of this, there is need to identify the key factors that positively impacts the engineering education to produce innovative graduates. Hence, this phase is to identify the critical to quality (CTQ) characteristics which is the key success factors that are to be adopted in the engineering curriculum in view of generating graduates of innovative talent to the workforce. This phase is to collect data that are administered through surveys and questionnaires to industry of various demographics which would be used for the next phase.

Analyse phase:
The purpose of this phase is to analyse the data sets and define exact cause of the problem. The factors influencing the critical success factors were listed by a cause and effect diagram.

Improve phase:
This purpose of this phase is to generate possible solution to overcome the identified problem. The optimal solution of identifying the critical success factors in producing innovative graduates is determined in this phase. The improvement actions are carried out on the elements that are creating positive impact towards producing innovative graduates.

Control phase:
The purpose of this final phase is evaluate the outcome obtained from improve phase in view of establishing new process consideration.

6. Conclusion

In this study, the DMAIC, a standard six sigma process is proposed as it has gained vast positive reviews of its capabilities. Furthermore, an attempt has been made to establish a relationship between this popular industrial methodology and the scope of study in an academic environment involving undergraduate engineering program. This is to ensure that academic institutions are committed towards producing innovative talent graduates and are not deviated towards commercial motives

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