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# A HOLISTIC APPROACH TO DEVELOP ENGINEERING PROGRAMME OUTCOMES: A CASE STUDY OF TAYLOR'S UNIVERSITY

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**Abstract**

Part fulfilment of providing an engineering programme which implements outcome based education includes various outcomes that are tied to what the graduate should achieve after, during and before graduation. The programme outcomes are specifically crafted to encapsulate attributes that must be attained by a student upon graduation. The following paper details the principles used to craft the programme outcomes of an engineering undergraduate degree programme. The principles used were chosen based its importance and innovative content as well as being aligned to the purpose of the university which is running the degree programme. Upon crafting the prescribed outcomes, the paper will also detail how stakeholders were engaged and how their opinion was accounted for in the final crafting of the new set of programme outcomes. The paper also highlights how a gap analysis was performed to capture areas which were not covered by the previous programme outcomes.

Keywords: Outcome based education, Programme outcomes, Attainment, CDIO.

## 1. Introduction

Engineering programmes are required by the stakeholders, especially employers, to train engineers in a continuously expanding list of competencies that extend from hardcore technical skills to soft skills and personal attributes to teamwork. One way to account for and address these requirements is through the adoption of the Outcome Based Education (OBE) in which clear statement of the students learning and required achievement is prescribed upfront and used to measure the success of both students and educational programmes. Critics of OBE claim that it may not be suitable for certain educational systems [1] and that it dehumanises education by reducing it to a rather mechanical process resulting in limiting the enquiry and speculation of students because of the development of very specific programme outcomes [2]. Despite those perceived shortcomings, OBE is gaining grounds progressively as a reliable educational framework. Malaysia is currently a full member of the Washington Accord, which requires the embracement of the Outcome-Based Education (OBE) for the engineering degrees accredited under its jurisdiction [3]. Besides grading system, Institutions of higher learning are required to balance accreditation requirements of providing specific and measurable programme outcomes while maintaining sufficient openness for students to realise and celebrate their individualism. Hashim and Din [4] reported on the use of OBE with project based learning.

This objective is to report a process used to develop programme outcomes for engineering programmes at Taylor's University that satisfy the OBE requirements while providing the necessary space for a holistic students experience. The process draws on the generic programme outcomes (POs) published by the Engineering Accreditation Council (EAC) [5]. To provide for the breadth of education the POs are aligned to the Grand Challenges for Engineering [6], CDIO Syllabus [7], UNESCO pillars of learning [8] and Taylor's Graduate Capabilities (TGC).

## 2. Principles Used for Crafting Programme Outcomes

The generic POs provided by the Engineering Accreditation Council (Malaysia) [5] represent the starting point for any curriculum design. These POs represent the minimum requirements and universities are expected to personalise them. It resulted in differentiating graduates that can support various economical activities and requirements. The different principles used to design the POs are discussed below.

### 2.1. EAC Generic Programme Outcomes (POs)

The EAC POs are given below [5].

1. **Engineering Knowledge** - Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialisation to the solution of complex engineering problems;
2. **Problem Analysis** - Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences;
3. **Design/Development of Solutions** - Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations;
4. **Investigation** - Conduct investigation into complex problems using research based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions;
5. **Modern Tool Usage** - Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction

and modelling, to complex engineering activities, with an understanding of the limitations;

6. **The Engineer and Society** - Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice;
7. **Environment and Sustainability** - Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development;
8. **Ethics** - Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice;
9. **Communication** - Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions;
10. **Individual and Team Work** - Demonstrate knowledge and understanding of engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments;
11. **Life-long Learning** - Recognise the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.
12. **Project Management and Finance** - Demonstrate knowledge and understanding of engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

## 2.2. CDIO Syllabus

CDIO (Conceive, Design, Implement, Operate) is an initiative to reform engineering education aiming at producing “engineers who can engineer.” It aims at achieving this through developing a learning experience that mirrors the lifecycle of a product. The CDIO Syllabus is outlined below [9].

The CDIO Syllabus is divided into four categories:

1. **Technical Knowledge and Reasoning**: defines the mathematical, scientific and technical knowledge that an engineering graduate should have developed.
2. **Personal and Professional Skills and Attributes**: Deals with individual skills, including challenge resolving, ability to think creatively, critically, and systemically, and professional ethics.
3. **Interpersonal Skills, Teamwork and Communication**: Skills that are needed in order to be able to work in groups and communicate effectively.
4. **Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context**: About what engineers do, that is, conceive-design-implement-operate products, processes and systems within an enterprise, societal, and environmental context.

These categories are further detailed below

1. Technical Knowledge and Reasoning
1.1 Knowledge of Underlying Mathematics, Science
1.2 Core Engineering Fundamental Knowledge
1.3 Advanced Eng. Fundamental Knowledge, Methods, Tools

2. Personal and Professional Skills and Attributes
2.1 Analytical Reasoning and Problem Solving
2.2 Experimentation, Investigation and Knowledge Discovery
2.3 System Thinking
2.4 Attitudes, Thought and Learning
2.5 Ethics, Equity and Other Responsibilities

3. Interpersonal Skills, Teamwork and Communication
3.1 Teamwork
3.2 Communications
3.3 Communication in Foreign Languages

4. Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context
4.1 External, Societal and Environmental Context
4.2 Enterprise and Business Context
4.3 Conceiving, Systems Engineering and Management
4.4 Designing
4.5 Implementing
4.6 Operating

A number of world universities are using the CDIO framework to guide their curricular and programme design as it is expected to help with proficiency development [10] and accreditation [11]. Taylor's School of Engineering is a member of the CDIO initiative and the CDIO Syllabus represents important design criteria for the POs educational programmes offered at the School.

## 2.3. Grand Challenges Scholar Programme (GCSP)

The National Academy for Engineering identified 14 Grand Challenges for engineering that need to be addressed by this century in order for the human race to make it sustainably into the next century. These challenges are

1. Make solar energy economical
2. Provide energy from fusion
3. Develop carbon sequestration methods
4. Manage the nitrogen cycle
5. Provide access to clean water
6. Restore and improve urban infrastructure
7. Advance health informatics
8. Engineer better medicines
9. Reverse-engineer the brain
10. Prevent nuclear terror
11. Secure cyberspace
12. Enhance virtual reality

13. Advance personalised learning
14. Engineer the tools of scientific discovery

The Grand Challenges Scholar Programme (GCSP) is designed to integrate the engineering and non-engineering curricular and meta-curricular expertise necessary to develop engineers who are ready to address the Grand Challenges. The five curricular components of a GCSP are listed below [6].

1. **Project or research activity engaging a GC theme or challenge**: Working to solve the NAE Grand Challenges is the motivation for the GCSP. Each GC scholar must participate in a substantial team or independent project relating to a Grand Challenge theme or specific Grand Challenge problem. Examples: formal undergraduate research programs, senior theses, graduation with distinction, on-site internships, or cap stone design projects.
2. **Interdisciplinary curriculum**: Bridging engineering to other disciplines is essential for solving the NAE Grand Challenges. An "Engineering-Plus" curriculum should be devised that prepares engineering students to work at the boundary between an engineering and non-engineering discipline, such as public policy, international relations, business, law, ethics, human behavior, risk, medicine and the natural sciences. However, this must be more than simply double majoring or picking up a minor in a non-engineering discipline. Specifically, each GCSP should have an institutionally tailored mechanism that thematically draws together the engineering and non-engineering curricular components of each student's course of study. Examples: an explicitly interdisciplinary course, a GCSP seminar series or presentation sequence.
3. **Entrepreneurship**: Implementing innovation is central to technology development. Each GC scholar must participate in a curricular or meta-curricular component on the process of translating invention and innovation into market ventures. This may be either risk-taking ventures for business or introducing technology for not-for-profits in the public interest. Examples: submitting an invention disclosure, participating in start-up competitions, campus or community engagement, and/or formal classes in marketing, patent law, intellectual property.
4. **Global dimension**: Global awareness is necessary for working effectively in an interdependent world. Students may participate in a curricular or meta-curricular component that instills elements necessary to develop innovations in a global economy, or address ethical issues of global concern. Domestic activities that stress global or cross-cultural implications may satisfy this component. Examples: completing formal classes, participating in internships, or conducting research in global health, global environmental challenges, non-profit marketing or low-cost manufacturing, study and/or internships abroad.
5. **Service learning**: Working for the benefit of others is the foundation of a civil society. Students may participate in a curricular or meta-curricular component that deepens their social awareness and to heighten their motivation to bring their technical expertise to bear on societal problems. Examples: completing formal classes in social action, participating in internships, global service organizations such as Engineering World

Health or Engineering without Borders, or conducting research in an area with a clear component of improving the human condition, or participation in an institution's community service or tutoring program.

### 2.4. The UNESCO Four Pillars of Learning

UNESCO defines the four pillars of learning as the fundamental principles for reshaping education [8]. These pillars are given below and they are to be considered we developing the engineering POs.

1. **Learning to know**: to provide the cognitive tools required to better comprehend the world and its complexities, and to provide an appropriate and adequate foundation for future learning.
2. **Learning to do**: to provide the skills that would enable individuals to effectively participate in the global economy and society.
3. **Learning to be**: to provide self-analytical and social skills to enable individuals to develop to their fullest potential psycho-socially, affectively as well as physically, for a all-round 'complete person.
4. **Learning to live together**: to expose individuals to the values implicit within human rights, democratic principles, intercultural understanding and respect and peace at all levels of society and human relationships to enable individuals and societies to live in peace and harmony.

## 3. Taylor's University: A Case Study

The purpose of Taylor's University is to "educate the youth of the world to take their productive places as leaders in the global community." Its mission is to be "top employers' top choice university."

### 3.1. Taylor's Graduate Capabilities (TGC)

Every student who undertakes a Taylor's University programme will be given an ample opportunity to develop a set of capabilities that will prepare the graduates not only for employment but also for life in an increasingly complex and changing environment. These 8 capabilities range from discipline specific knowledge to other essential interpersonal skills. The list of capabilities is

1. **Discipline Specific Knowledge**
   1.1. Able to put theories into practice.
   1.2 Understand ethical issues in the context of the field of study.
   1.3 Understand professional practice within the field of study.
2. **Lifelong Learning**
   2.1. Learn independently.
   2.2. Locate, extract, synthesis and utilise information effectively.
   2.3. Be intellectually engaged.
3. **Thinking and Problem Solving Skills**
   3.1. Think critically and creatively.
   3.2. Define and analyse problems to arrive at effective solutions.
4. **Communication Skills**
   4.1. Communicate appropriately in various settings and modes.

5. **Interpersonal Skills**
    5.1. Understand team dynamics and mobilise the power of teams.
    5.2. Understand and assume leadership.
6. **Intrapersonal Skills**
    6.1. Manage oneself and be self-reliant.
    6.2. Reflect on one's actions and learning.
    6.3. Embody Taylor's core values.
7. **Citizenship and Global Perspective**
    7.1. Be aware of and form opinions from diverse perspectives.
    7.2. Understand the value of civic responsibility and community engagement.
8. **Digital Literacy**
    8.1. Effective use of Information and Communications Technology (ICT) and related technologies.

## 3.2. Taylor's Programme Outcomes (POs)

Taking into consideration all the design criteria, the POs are given below.

1. Apply the knowledge of mathematics, science, engineering practices, innovation techniques, entrepreneurship and human factors to provide value-adding solutions to complex Chemical Engineering challenges.
2. Identify, formulate, analyse and document complex engineering challenges to arrive at viable solutions and substantiated conclusions.
3. Conceive, Design, Implement and Operate solutions for complex engineering challenges that meet specified requirements with appropriate consideration for public health and safety, cultural, societal, environmental and economical considerations.
4. Conduct research and investigation into complex challenges using methods which include experiment design, analysis of data and synthesis of information to provide valid conclusions.
5. Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an awareness of the accompanying assumptions and limitations.
6. Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal, economical and cultural issues and the consequent responsibilities relevant to professional engineering practice.
7. Explain the global impact of professional engineering solutions in societal, economical and environmental contexts and demonstrate knowledge of and need for sustainable development.
8. Apply professional and ethical responsibilities of engineering practice.
9. Effectively communicate complex engineering activities, both orally and in a written form, in both technical & non-technical contexts.
10. Function effectively as an individual and in multidisciplinary settings with the capacity to be a leader.

11. Recognise the importance of lifelong learning and engaging in continuous professional development activities in accordance with technological change.
12. Effectively manage projects in multidisciplinary environments and apply project management tools and techniques to one's own work, as a member and leader in a team to satisfy stakeholders requirements.

Mapping of the POs to the different design criteria is given below.

**Taylor's POs Mapping to EAC POs**

For ease of mapping, Taylor's POs are directly mapped the EAC POs one by one.

**Taylor's POs Mapping to CDIO Syllabus**

The mapping of POs against the CDIO syllabus is given below

| CDIO Syllabus Content | POs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Technical Knowledge and Reasoning | ✓ | ✓ | | ✓ | ✓ | | | | | | |
| Personal and Professional Skills and Attributes | | | | | | ✓ | | ✓ | | | ✓ |
| Interpersonal Skills, Teamwork and Communication | | | | | | | | | ✓ | ✓ | |
| Conceiving, Designing, Implementing and Operating Systems | | | ✓ | | | ✓ | ✓ | | | | |

**Taylor's PO Mapping to Grand Challenges Scholar Programme (GCSP) Curriculum**

The mapping of Taylor's POs against GCSP Curriculum is given below.

| GCSP Curriculum | POs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Project or research activity engaging a GC theme or challenge | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | |
| Interdisciplinary curriculum | | | | | | | | ✓ | ✓ | ✓ | ✓ |
| Entrepreneurship | ✓ | | | | | | | ✓ | | | |
| Global dimension | | | | | | | ✓ | | | | |
| Service learning | | | ✓ | | | | ✓ | | | | |

**Taylor's POs Mapping to the UNESCO Four Pillars of Learning**

The mapping is given below

| UNESCO Pillars of Learning | POs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Learning to know | ✓ | ✓ | | ✓ | | ✓ | | | | | |
| Learning to do | ✓ | | ✓ | | ✓ | | | | | | |
| Learning to be | | | | | | | | ✓ | | | ✓ |
| Learning to live together | | | | | | | ✓ | | ✓ | ✓ | |

**Taylor's POs Mapping to Taylor's Graduate Capabilities (TGC)**

The mapping is given below

| TGC | POs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Discipline Specific Knowledge | ✓ | | ✓ | ✓ | ✓ | | | | | | |
| Lifelong Learning | | | | | | | | | | | ✓ |
| Thinking and Problem Solving Skills | | ✓ | | | | ✓ | | | | | |
| Communication Skills | | | | | | | | | ✓ | | |
| Interpersonal Skills | | | | | | | | | | ✓ | |
| Intrapersonal Skills | | | | | | ✓ | | ✓ | | | |
| Citizenship and Global Perspective | | | | | | | ✓ | | | | |
| Digital Literacy | | | | | ✓ | | | | | | |

## 3.3. The Enhanced Taylor's POs

Based on the above 5 curriculum design guiding principles, the enhanced Programme Outcomes are designed. After performing the gap analysis, the following key aspects needed to be addressed.

1. Ability to solve complex engineering challenges
2. Conceive, Design, Implement and Operate complex engineering systems
3. Ability to conduct research
4. Ability to use innovation techniques
5. Ability to apply ergonomic principles
6. Ability to use standard project management tools
7. Having a global dimension

A plan has been implemented to address these gaps as shown in Table 1. Upon identifying the gaps, the first cut of PO statement drafted by the Schools management underwent the School process with respect to PO formulation. This process is shown in Fig. 1.

As a result of the input from all stakeholders, the final version of the POs now read as highlighted in section 3.2.

## 4. Conclusions

This paper outlines a progressive design process that can be used to develop POs for engineering programmes that follow the OBE framework. The process utilises institutional, national and international standards to ensure that the POs are crafted to facilitate the development of engineers who are able to positively contribute to the national and international development in a sustainable manner. The crafting of the POs followed a structured approach and made use of five guiding principles, mainly EACs generic POs, the CDIO syllabus, UNESCOs four pillars of learning, the Grand Challenges Scholar Programme and Taylor's Graduate Capabilities. The first draft of the POs was then mapped to all five principles and then went through a review process by all of the appropriate stakeholders. Upon gaining all feedback from the stakeholders, the final POs were then confirmed and appropriately implemented.

**Table 1. Implementation Plan to Address Gaps.**

| Key Aspect | Proposed Solution | Implementation Plan |
|---|---|---|
| 1. Ability to solve complex engineering challenges.<br><br>2. Conceive, Design, Implement and Operate complex engineering systems | At present, LOs in the design modules in each semester address this aspect. | Implemented prior to September 2012 and to be implemented in the future semesters with relevant CQI actions for these modules. |
| 3. Ability to conduct research | At present, LOs 1 through to 5 addresses this aspect in FYP1 as well as LOs in FYP2. | Implemented prior to September 2012 and to be implemented in the future semesters with relevant CQI actions for these modules. |
| 4. Ability to use innovation techniques | At present, LOs 1 through to 5 address this aspect in Engineering Design and Innovation and LOs 4 through to 6 in Globalisation, Innovation and Creativity. | Implemented prior to September 2012 and to be implemented in the future semesters with relevant CQI actions for these modules. |
| 5. Ability to apply ergonomic principles | At present, LOs 1 through to 4 address this aspect in Engineering Design and Ergonomics, however one cohort of CE students did not take up this module. | Implemented prior to September 2012 and to be implemented in the future semesters with relevant CQI actions for these modules.<br><br>To capture the students who did not take the modules earlier, a short course will be developed to address this. |
| 6. Ability to use standard project management tools | At present, LOs 1 through to 4 address this aspect in Managing Projects for Success. | Implemented prior to September 2012 and to be implemented in the future semesters with relevant CQI actions for these modules. |
| 7. Having a global dimension | At present, LOs 1 through to 3 address this aspect in Globalisation, however this was offered as an elective and not all students took up this module. | Implemented in September 2012 and to be implemented in the future semesters with relevant CQI actions for these modules.<br><br>To capture the students who did not take the modules earlier, a short course will be developed to address this. |

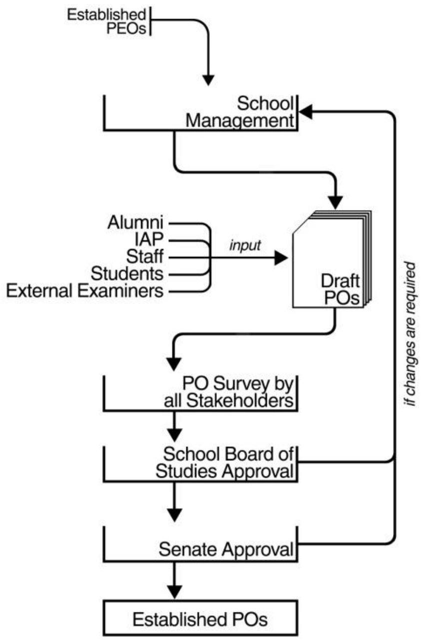


**Fig. 1. SoE's PO Formulation Process.**

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