In facing the challenges of the 21st Century, nations across the globe are emphasizing the importance of Science, Technology, Engineering and Mathematics (STEM) Education to prepare for the needed human capital of the future. STEM education throughout the world is undergoing changes to address the requirements of the future to attract students to the field and develop them into graduates who can contribute and adapt to the changing world.

Gone are the days when STEM graduates are just required to be knowledgeable in their fields. Other than content knowledge, graduates of the new millennium are required to possess professional skills, such as lifelong learning, team working, problem-solving, and thinking skills. The demand for such knowledgeable and innovative workforce initiates changes in university education, expanding from an emphasis on content knowledge to a more comprehensive notion of what students will need to know and be able to do and how they can respond to a changing world innovatively and creatively.

The outcome-based approach to design and implement curricula gained wide interest throughout the world, especially in engineering, because of the requirement of the Washington Accord (WA). WA acknowledges the substantial equivalency of programs accredited by those bodies and recommends mutual recognition of graduates from accredited programs of member countries for entry to the practice of engineering. Members of WA include, among others, Australia, Canada, South Africa, Malaysia, the United Kingdom, and the United States. Currently, more countries are gearing towards becoming full WA signatory member for global employability of their engineering graduates. Since Outcome Based Education is strongly emphasized for accreditation of engineering programs under the WA, engineering programs offered in member countries as well as those vying to be members went through a transformation to comply with this requirement. In some countries, like Malaysia, the effect had even spilled over to all programs recognized by the Malaysian Qualification Agency.

This book aims to put forth scholarly innovative ideas and practices aligned to the outcome-based approach that provide insights and initiatives to enhance the quality of undergraduate STEM education from throughout the world. Altogether, there are eighteen chapters written by authors from different parts of the world. While many of the implementations given as examples in the chapters are those in engineering programs, the concepts and approaches put forth can be transferred to other fields, even those from the non-STEM areas. Findings and experiences written in the chapters undoubtedly promote excellence and inspire new thinking about undergraduate STEM education.
SECTION 1

The chapters in Section 1, Chapters 1, 2, 3, and 4, describe guidelines and examples in designing curricula at the course and program level for the outcome-based approach. A good program starts with good design and planning; the chapters are highly relevant in providing ideas for scholarly initiatives that are helpful for the design of STEM education curricula. Each chapter provides actual examples that illustrate the application of the underlying principles or concepts.

Chapter 1 aims to show the readers how curriculum (or content), assessment, and delivery should be integrated as one, instead of considered separately. This chapter put forth methods to align content, assessment, and delivery systematically using the engineering design approach, consistent with the Scholarship of Teaching and Learning (SOTL). Using Bransford's How People Learn framework and Wiggins and McTighe’s Backward Design approach, the authors clearly put forth steps and considerations that must be taken into account in designing courses that are well aligned between content, assessment, and delivery in the context of outcome based education. The guide and example given in this chapter are clear and simple for STEM educators to follow when designing courses for OBE.

A real case study of curriculum development spanning over twenty years for the undergraduate Chemical Engineering Program at the University of Cape Town, South Africa is presented in Chapter 2. The author aptly provides the definition of curriculum to be more than just the outcomes and content of the program, but also in understanding and supporting learners, planning and implementation of assessment and delivery methods, as well as the evaluation of the overall effectiveness of the curriculum. The shared insights and challenges in designing an innovative curriculum taking into consideration the context and culture of the institution in ensuring graduates who are ready for the challenges of the 21st Century will definitely inspire STEM educators in developing high quality curriculum within the context of their own institutions.

Chapter 3 provides a down-to-earth approach in transforming curriculum to problem based and project based learning (PBL), which has garnered a lot of interest in higher education because it can enhance learning and a multitude of skills in students. Factors that must be considered at different levels of implementation are given: course level, multiple course level, and institutional level. Even though there are different problem based and project based learning models as highlighted in the chapter, the factors and strategies for initiating the change are applicable for the different models. The insights provided in designing and managing the change process is valuable in guiding academics from all fields in planning the transformation to problem based and project-based learning.

A systematic guideline in crafting problems for PBL is the subject of Chapter 4. Problems are central in PBL, because they serve to engage and motivate student learning, as well as integrate a variety
of content and skills in the context that it is used in. Based on principles and characteristics found in
the literature, a framework to craft problems for STEM education and an effective step by step guide
for crafting problems are presented. These steps are further illustrated with an example to develop an
engineering problem, showing how it is mapped to the principles of an effective problem. The example
also shows how problems can be organized for a whole course to successively enhance skills in students,
which is beneficial for STEM educators who plan to implement PBL for a whole course.

SECTION 2

The eight chapters in this Section 2, Chapters 5, 6, 7, 8, 9, 10, 11, and 12, describe the implementation of
innovative practices at two different levels: the program level and the classroom level. Practical aspects
 gained from the vast experience of the authors in employing the innovative and scholarly practices in
actual settings result in chapters that are useful for STEM educators who are seeking exemplars to be
adapted into their own programs.

Chapter 5 details two initiatives to support engineering students learn and develop themselves to be
engineers. The efforts are indeed admirable, considering the challenges faced from the diverse student
population in South Africa, many of whom previously have disadvantaged schooling and family back-
ground. The first initiative aims to improve student learning through computer simulations and problem-
based learning. The second initiative support students to grow through building a community amongst
students since the first year, and forming their identity as engineers. Both initiatives are rooted in three
concepts: 1) learning is through participation, 2) curriculum should be based on three pillars, which are
knowing, acting, and being, and 3) variation theory of learning. This chapter serves as an inspiration for
STEM educators in developing initiatives to support and enhance student learning.

The Problem Based Laboratory (PBLab) model implemented in the Faculty of Electrical Engineering
is put forth in Chapter 6. Final year electrical engineering undergraduates take this two-credit labora-
tory course that employs open-ended problems for students to solve using equipment in the faculty’s
laboratories. This chapter gives an overview on the implementation of the PBLab in terms of steps in
conducting the laboratory, facilitation, activities, and assessment. With the importance of inculcating
professional skills among graduates, the PBLab is a plausible approach to consider in undergraduate
STEM education.

Chapter 7 features a framework of processes to guide and foster the development of a specific set of
personal roles to successfully develop an e-portfolio that supports students and professionals in docu-
menting attainment of outcomes and competencies. The roles in the framework are: Job Clarifier, Asset
Builder, Competency Tracker, and Reflexive Narrator. In each role, students are supported through the
various stages of development, starting from novice in the first year, to finally reaching mastery in the
final year. Without developing these roles, there is no guarantee that the adoption of e-portfolio in an
institution can be successful, even with access and support to the necessary physical infrastructure.

Chapter 8 delves into the design and development of a 3-dimensional animation multimedia com-
puter science learning courseware called Operating Systems in Memory Management (OSiMM), based
on Mayer’s Cognitive Theory of Multimedia Learning and instructional design based on sound learn-
ing theories. A survey conducted on user’s overall instructional value and satisfaction on the prototype
developed showed that most respondents gave a positive response towards using the courseware and its
instructional value as a supplement to learning. On the whole, this chapter offers a good guideline for
designing and developing multimedia learning applications for STEM education.

Strategies in transforming the teaching and learning strategies in Engineering Mathematics to fulfill
the requirements of Outcome-Based Education (OBE) are detailed out in Chapter 9. Meaningful math-
ematical learning and skills were identified and used to determine the desired learning outcomes and
to examine the relationship between the content, assessment, and teaching and learning approaches.
Strategies employed in engaging students in learning and constructing knowledge as well as initiating
and supporting students’ thinking and communication in the language of mathematics were discussed
in the chapter. Also highlighted were indications of students struggle, progress, and growth that were
taking place and the authors’ own difficulties encountered in the implementation of the research.

Chapter 10 contains strategies in utilizing a computer algebraic system, Maple, to enhance engineering
technology students’ understanding in the learning of ordinary differential equations (ODE). Maple was
introduced as an alternative teaching strategy in engaging the students in their learning. Using Maple,
students were able to visualize the solutions of the given mathematics problems. The learning of dif-
ferential equations has become meaningful in such a way that they could see the relationship between
mathematics and the application in the real world.

A blended learning model to support the development of mathematical thinking is described in Chapter
11. In blended learning, learning in a face-to-face classroom is supplemented with the use of computers,
not only during the class time, but also outside the class time using an e-learning platform. The blended
learning model given in this chapter was developed based on a study that identified learning difficulties
in a Multivariable Calculus course, and from recommendations for improving learning from lecturers
and students. The outcomes of the study are useful for STEM educators in designing activities and tools
in supporting students’ learning.

In Chapter 12, the development of students’ skills in interpreting the literature and structuring a
literature review in an Engineering Communication course at the University of Adelaide, Australia,
was elaborated. The scaffolded-learning approach supports students in improving their skills through a
staged-design of materials, and detailed feedback on students’ attempts according to assessment criteria.
By utilizing on-line resources, this process can also be facilitated in large classes. This chapter provides
STEM educators with a systematic approach to assist students in writing good literature review, instead
of simply copying and pasting.

SECTION 3

The six chapters in Section 3, Chapters 13, 14, 15, 16, 17, and 18, concern the assessment of student
learning. Assessment has always been challenging in the outcome-based approach because knowledge
or skills must be assessed to show the attainment of outcomes at the given level. Therefore, the various
assessment techniques at different levels of implementation described in the chapters in this section are of interest for STEM educators seeking appropriate assessment methods.

Chapter 13 describes the use of multiple methods to assess the oral communication skills of electrical engineering students in the Final Year Project seminar to ensure validity of the assessment. The results obtained from two chosen methods of assessment were analyzed and used as the basis for further improvement in the oral presentation assessment tool. The rubrics tested are good examples of performance based assessment for STEM educators in assessing oral communication skills of students.

In Chapter 14, a study investigated the effectiveness of using e-learning platform as an online assessment tool in an engineering course for first year students. The author clearly elaborated the steps taken to prepare the online quiz that was given to the students. Compared to paper-based assessment in terms of difficulty of questions and students’ performance, the on-line assessment was found to be effective and thus can be an alternative for paper-based assessment in STEM education, especially since it reduces the burden of marking the quiz.

Chapter 15 puts forward the use of fuzzy inference system (FIS) in criterion-referenced assessment (CRA) as an alternative approach on how a total-score can be aggregated. Although the use of FIS in CRA has been reported in the literature, it is still scarce. Nevertheless, a large set of fuzzy rules is required, and with grid partitioning strategy, the number of fuzzy rules required increases in an exponential manner leading to rigorous and tedious work in obtaining a full set of rules. To overcome this problem, the FIS-based CRA with rule selection and analogical reasoning (AR) technique is proposed as a solution. By investigating the use of a threshold value in AR, less important known fuzzy rules can be ignored in the deducing process, leading to a reduction in the computation time. The case study included in this chapter serves as a good example for STEM educators to understand the use of FIS in CRA.

A study that shows practical intelligence can predict a student’s ability to diagnose experiment faults is discussed in Chapter 16. Utilizing tools used by psychologists to measure practical intelligence, the score of this outcome was found to be proportional to the outcome on the ability to diagnose equipment faults. The findings of this chapter, therefore, are very useful in assisting STEM educators to measure the outcomes of practical intelligence gained from laboratory courses.

In Chapter 17, the conceptual knowledge required to develop Three Dimensional Computer Aided Design (3D CAD) model is elaborated. The conceptual knowledge is as important as procedural knowledge because having conceptual knowledge allows the user to transcend beyond the type of software used for 3D CAD. Unfortunately, acquisition of the conceptual knowledge is usually inadequate in institutions of higher learning, where teachings of 3D CAD are mostly emphasized on developing procedural knowledge. Result from an assessment method developed in the study taken by a group of final year Mechanical Engineering students for their conceptual understanding on 3D CAD provided empirical evidence of the students’ lack of conceptual understanding of modeling techniques in the context of their discipline. This assessment method can be used by STEM educators to determine the conceptual understanding of students in 3D CAD so that corrective action can be taken.

Chapter 18 describes a research conducted to investigate engineering undergraduates’ accuracy in perception of cognitive ability and its relationship with academic achievement and metacognitive skills.
Results indicate that high achievers are more accurate in their perception of their ability and meta-cognitive skills compared to students with lower level of achievement. The authors conclude that students’ lack of metacognitive skills not only make students unaware of their true potentials, but may also hinder other processes required to become successful learners. The results of research have important implications that STEM educators should enhance efforts to improve students’ metacognitive skills through teaching, learning and assessment as well as academic advising.

As the Editors of this book, we truly hope that the material presented in these chapters will be useful for STEM educators in inspiring and driving innovative practices in their institution, programs, and courses. Happy reading!

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