Undergraduate Mechanical Engineering Design Courses at the University of Johannesburg from an Accreditation Perspective

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***Abstract*— The undergraduate Mechanical Engineering Design curriculum in the Department of Mechanical Engineering Science at the University of Johannesburg is discussed in this paper. The emphasis is on accreditation by the Engineering Council of South Africa (ECSA) and accompanying international accreditation through the Washington accord. The course content in the four undergraduate years of study is given in short. Measures to meet accreditation targets, including required exit level outcomes, set by ECSA are spelt out. The CDIO principle is also considered and the level of compliance with the CDIO requirements is indicated.**

Keywords—design, mechanical, accreditation, assessment, CDIO

I. Introduction

Mechanical engineering design subjects are compulsory for students in the Department of Mechanical Engineering Science (DMES) in all four years of the undergraduate programme at the University of Johannesburg (UJ). These subjects mainly aim to prepare graduates to work in industry and to pursue postgraduate study. The Design subjects also form a significant part of the broader undergraduate curriculum and as such are integrated with other courses lectured by DMES.

The undergraduate programme of DMES is accredited by the Engineering Council of South Africa (ECSA), which is a statutory body with legal power to register and deregister engineering professionals working locally in South Africa (SA) and abroad. Under authority of legislation, ECSA reserves certain categories of engineering work for registered professional engineers. It is currently in the process of passing a law through the South African parliament that will ensure that reserved engineering work is only done by registered professional engineers in SA.

This paper discusses the undergraduate Design curriculum at UJ, the content of each module in the Design silo of subjects, the required exit level outcomes (ELOs) [1] for the modules, and the measures applied by DMES to meet these ELOs. The degree of success of the UJ DMES Design curriculum and the challenges it still faces are discussed.

II. ECSA Accreditation

The purpose of accreditation is to ensure that the undergraduate engineering courses offered by South African universities are of a sufficient standard for graduates to work as engineers and to register as professional engineers in SA. ECSA accreditation further opens doors to South African engineering graduates to work and study abroad, mainly in countries who have signed the Washington Accord. ECSA also evaluates the quality of degrees obtained abroad by graduates who apply to work and pursue post-graduate study in SA.

International comparability of the qualification standard is ensured through the Washington Accord, an agreement for the mutual recognition of professionally-oriented bachelors degrees in engineering. The standards are comparable with the Washington Accord Graduate Attributes. Washington Accord signatories in July 2014 were: Australia, Canada, Chinese Taipei, Hong Kong China, India, Ireland, Japan, Republic of Korea, Malaysia, Russia, New Zealand, Singapore, South Africa, Sri Lanka, Turkey, United Kingdom, and the United States of America. Comparability is audited on a six-yearly cycle by a visiting Washington Accord team.

Undergraduate mechanical engineering curriculi are typically made up of subjects in so-called knowledge areas, i.e. Mathematical-, Natural- and Engineering Sciences, Design and Synthesis, and Complementary Studies. ECSA requires that each of these knowledge areas carry a minimum number of weights, or credits. The credits reflect the number of hours spent per subject and one credit is the equivalent of 10 notional hours of study. Notional study time includes lecturing contact time, self-study, practical work, assignments, projects and examinations. The required minimum number of credits for each of the abovementioned knowledge areas is given in Table 1.

From Table 1, the number of credits required for Design and Synthesis is 72, which is approximately 13% of the total number of credits required for the entire undergraduate programme. Design and synthesis, as a knowledge area, requires the second highest number of credits, and is second after engineering science.

TABLE I. MINIMUM CURRICULUM CONTENT BY KNOWLEDGE AREA

Knowledge area	Minimum credits
Mathematical sciences	56
Natural sciences	56
Engineering sciences	180
Design and synthesis	**72**
Complementary studies	56
Subtotal	420
For reallocation	≥ 140
Total credits	≥ 560

The "For reallocation" component must be taken up by allocating additional knowledge content to the other five knowledge areas, to form a coherent, balanced programme.

III. REQUIRED LEARNING OUTCOMES

ECSA requires South African undergraduate engineering curriculi to meet prescribed outcome levels, known as Exit Level Outcomes (ELOs). A total number of 11 ELOs are prescribed. Subjects are not each required to meet all the ELOs. However, each module which has ELOs associated with it must be assessed both internally and externally.

ELOs required for the Design subjects are applied particularly strictly and the final year Design course must meet most of the required ELOs. The UJ Design curriculum is therefore set up to meet the relevant ELOs in accordance with ECSA requirements. The 11 ELOs are given below, together with a short description of each.

- ELO 1: Problem solving

Identify, formulate, analyse and solve complex engineering problems creatively and innovatively.

- ELO 2: Application of scientific and engineering knowledge

Apply knowledge of mathematics, natural sciences, engineering fundamentals and an engineering speciality to solve complex engineering problems.

- ELO 3: Engineering design

Perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.

- ELO 4: Investigations, experiments and data analysis

Demonstrate competence to design and conduct investigations and experiments.

- ELO 5: Engineering methods, skills and tools, including information technology

Demonstrate competence to use appropriate engineering methods, skills and tools, including those based on information technology.

- ELO 6: Professional and technical communication

Demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.

- ELO 7: Sustainability and impact of engineering activity

Demonstrate critical awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment.

- ELO 8: Individual, team and multi-disciplinary work

Demonstrate competence to work effectively as an individual, in teams and in multi-disciplinary environments.

- ELO 9: Independent learning ability

Demonstrate competence to engage in independent learning through well-developed learning skills.

- ELO 10: Engineering professionalism

Demonstrate critical awareness of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence.

- ELO 11: Engineering management

Demonstrate knowledge and understanding of engineering management principles and economic decision-making.

The applicable ELOs will be indicated for the two Design modules which have been identified to address ELOs for ECSA accreditation purposes. These modules are Design (Mechanical) 3A, a third-year, first semester module, and Design and Engineering Practice, the final year module (module codes OWM3A and OIP 4000 respectively).

IV. THE DMES UNDERGRADUATE DESIGN MODULES, LEVELS, CREDITS AND PREREQUISITES

The Design modules run from the first to the final year of undergraduate study. The modules are evaluated in terms of their academic level as defined by the South African National Qualification Framework (NQF) [2]. The introductory (first year modules) have an NQF-level of 5. The level increases every subsequent year, ending in a Level 8 for the final year module.

The module content of each Design subject, its purpose, the semester in which it is presented, its NQF level and number of credits are given below.

First year

Module:	**Introduction to Engineering Design 1A (IIN1A)**
Semester:	First semester module
NQF level:	5
Credits:	8
Purpose:	To introduce students to engineering and enable students to solve fundamental engineering problems
Prerequisite:	None, as it is an entry level course

ELOs: None

Module: **Introduction to Engineering Design 1B (IIN1B)**
Semester: Second semester module
NQF level: 5
Credits: 8
Purpose: To enable students to design simple standard machine elements and mechanical assemblies, and to communicate their work
Prerequisite: Introduction to Engineering Design 1A (IIN1A)
ELOs: None

Second year
Module: **Design (Mechanical) 2A (OWM2A)**
Semester: First semester module (started in 2015)
NQF level: 5
Credits: 12
Purpose: To enable students to further develop spatial perception abilities, techniques and communication skills using computer based systems including CAD, CAM and CAE
Prerequisite: Introduction to Engineering Design 1B (IIN1B)
Comment: This subject has replaced Applied Mechanics 2A and serves as a prerequisite for Theory of Machines 3B (MKE3B)
ELOs: None

Module: **Design (Mechanical) 2B (OWM2B)**
Semester: Second semester module
NQF level: 5
Credits: 12
Purpose: Further development of engineering skills at component and simple systems level
Prerequisite: Introduction to Engineering Design 1B21 (IIN1B)
ELOs: None

Third year
Module: **Design (Mechanical) 3A (OWM3A)**
Semester: First semester module
NQF level: 7
Credits: 12
Purpose: To enable the student to design machine elements and mechanical assemblies, duly considering function, performance, safety, environmental and social impact, manufacture and cost. To further develop student's ability to design machine components and more advanced systems.
Prerequisite: Design (Mechanical) 2B (OWM2B)
ELOs: 3 (Engineering Design)
8(b) and (c) (Team and multi-disciplinary work)

Module: **Design (Mechanical) 3B (OWM3B)**
Semester: Second semester module (as from 2016)
NQF level: 7
Credits: 12
Purpose: To further develop student design skills at component and systems level
Prerequisite: Design (Mechanical) 3A (OWM3A11)
ELOs: None

Fourth year
Module: **Design and Engineering Practice (OIP 4000)**
Semesters: Full year module
NQF level: 8
Credits: 32
Purpose: To further develop student design skills at component and systems level
Prerequisites: Design (Mechanical) 3A (OWM3A)
Design (Mechanical) 3B (OWM3B)
80% of all third year modules passed
ELOs: 1 (Problem solving)
2 (Application of scientific and engineering knowledge)
3 (Engineering design)
5 (Engineering methods, skills and tools, including information technology)
6 (Professional and technical communication)
7 (Sustainability and impact of engineering activity)
8 (Individual, team and multidisciplinary work)
9 (Independent learning ability)
10 (Engineering professionalism)
11 (Engineering management)

V. Assessment of Exit Level Outcomes

Although the structure, content and assessment of the Design modules are all aimed at satisfying the ECSA ELO requirements, Exit Level Outcomes in the Design silo are only assessed in the third year, first semester design module (OWM3A), and in the final year, capstone design module (OIP 4000) [3], [4]. The assessment details of the ELOs for these modules are presented below [3] - [6].

A. Third year

Module: Design (Mechanical) 3A (OWM3A)
ELOs: 3, 8(b) and 8(c)

ELO 3: Engineering design

Perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.

Range Statement: Design problems used in exit-level assessment must conform to the definition of a complex engineering problem. A major design problem should be used to provide evidence. The design knowledge base and components, systems, engineering works, products or processes to be designed are dependent on the discipline or practice area.

Assessment:

The candidate is lectured in, and executes, an acceptable design process encompassing the following:

- Identifying and formulating the design problem to satisfy user needs, applicable standards, codes of practice and legislation.
- Planning and managing the design process: focusing on important issues, recognising and dealing with constraints.
- Acquiring and evaluating the requisite knowledge, information and resources: applying correct principles, evaluating and using design tools.
- Performing design tasks, including analysis, quantitative modelling and optimisation.
- Evaluating alternatives and a preferred solution: exercising judgment, testing implementability and performing techno-economic analyses.
- Assessing impacts and benefits of the design: social, legal, health, safety, and environmental.

These elements are assessed through an individual design project, a team design project, two semester tests and one examination. The examination is externally moderated and must be passed for the candidate to be eligible to pass the module.

ELO 8: Individual, team and multi-disciplinary work

Demonstrate competence to work effectively as an individual, in teams and in multi-disciplinary environments.

Range Statement: Multi-disciplinary tasks require co-operation across at least one disciplinary boundary. Co-operating disciplines may be engineering disciplines with different fundamental bases other than that of the programme or may be outside engineering.

Assessment:

This ELO requires the candidate to demonstrate competence to work effectively as (a)an individual, (b)in teams, and (c)in multi-disciplinary environments. Although the student also carries out individual work in this module, only outcomes (b) and (c) are assessed.

ELO 8(b): Team work

Each candidate must participate in a team design project which contributes 25% towards the final year mark. In addition to the exam, the team project must be passed in order for the candidate to be eligible to pass the module, since it addresses the ECSA ELO requirements. The team design project report is also externally moderated. The candidate demonstrates effective team work by means of the following:

1. Making an individual, measured contribution to team activity.
2. Performing critical functions.
3. Enhancing work of fellow team members.
4. Benefitting from support of team members.
5. Communicating effectively with team members.
6. Delivering completed work on time.

ELO 8(c): Multi-disciplinary work

Tasks require co-operation across at least one disciplinary boundary. Disciplines may be other engineering disciplines or could be from non-engineering fields. Lecturers from the UJ Electrical and Civil Engineering Departments respectively provide formal lecturing and valuation support in the multi-disciplinary elements, and the application of these elements must be shown in each team design project. The candidate demonstrates multi-disciplinary work through the following:

1. Acquiring a working knowledge of the work done in the electrical and civil engineering disciplines.
2. Using a systems approach.
3. Communicating across disciplinary boundaries.

Since this ELO element is also included in the team design project report, it is assessed with ELO 8(b), both internally and externally.

B. Fourth year

Module: Design and Engineering Practice (OIP 4000)
ELOs: 1, 2, 3, 5, 6, 7, 8(a), 9, 10, 11

This module comprises an individual, complex design project which must be completed during the course of the year, as well as various lecturing components that address specific subject material and ELOs. Various assignments - project report phases, engineering drawing work, oral presentations, a test on lectured material, and ELO assignments - must be completed during the course of the module and a final design report is assessed at the end of the year, both internally and externally. The ELOs assessed in this module are presented below.

ELO 1: Problem solving

Identify, formulate, analyse and solve complex engineering problems creatively and innovatively.

Assessment:

The candidate must demonstrate, throughout the course of the module, competence in the following elements as applicable to the design project and the assignments:

- Defining appropriate goals and objectives for the problem to be solved.
- Using a systematic approach to solve the problem.
- Analysing and modelling the problem.
- Formulating and presenting the solution in an appropriate form.

ELO 2: Application of scientific and engineering knowledge

Apply knowledge of mathematics, natural sciences, engineering fundamentals and an engineering speciality to solve complex engineering problems.

Range Statement: Mathematics, natural science and engineering sciences are applied in formal analysis and modelling of engineering situations, and for reasoning about and conceptualizing engineering problems.

Assessment:

The candidate must demonstrate competence in the following:

- Using mathematics appropriately to analyse, model and/or reason on relevant aspects of the problem. The mathematics can include formal analysis, modelling, numerical techniques, probability and statistics.
- Using mathematics to communicate concepts and ideas.
- Using the principles of relevant physical sciences (including physics and chemistry) appropriately to model and conceptualise the problem.
- Using the relevant engineering sciences (hydraulics, structures, etc.) appropriately to model and conceptualise the problem.
- Working in at least one specialist area of mechanical engineering.

ELO 3: Engineering design

Perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.

Range Statement: Design problems used in exit-level assessment must conform to the definition of a complex engineering problem. A major design problem should be used to provide evidence. The design knowledge base and components, systems, engineering works, products or processes to be designed are dependent on the discipline or practice area.

Assessment:

The candidate must demonstrate competence in the following:

- Identifying and formulating the design problem to satisfy user needs, applicable standards, codes of practice and legislation.
- Planning and managing the design process: focusing on important issues, recognising and dealing with constraints.
- Acquiring and evaluating the requisite knowledge, information and resources: applying correct principles, evaluating and using design tools.
- Performing design tasks, including analysis, quantitative modelling and optimisation.
- Evaluating alternatives and a preferred solution: exercising judgment, testing implementability and performing techno-economic analyses.
- Assessing impacts and benefits of the design: social, legal, health, safety, and environmental.
- Communicating the design logic and information.

ELO 5: Engineering methods, skills and tools, including information technology

Demonstrate competence to use appropriate engineering methods, skills and tools, including those based on information technology.

Range Statement: A range of methods, skills and tools appropriate to the disciplinary designation of the program including:

- Discipline-specific tools, processes or procedures.
- Computer packages for computation, modelling, simulation, and information handling.
- Computers and networks and information infrastructures for accessing, processing, managing, and storing information to enhance personal productivity and teamwork.

Assessment:

The candidate must demonstrate competence in the following:

- Applying the methods, skills and/or tools correctly and within their limitations.
- Critically assessing the results.
- Creating computer applications (including software programmes, spreadsheets, macros, etc.).

ELO 6: Professional and technical communication

Demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.

Range Statement: Material to be communicated is in an academic or simulated professional context. Audiences range from engineering peers, management and lay persons, using appropriate academic or professional discourse. Written reports range from short (300-1000 words plus tables and diagrams) to long (10 000 to 15 000 words plus tables, diagrams and appendices), covering material at exit-level. Methods of providing information include the conventional methods of the discipline, for example engineering drawings, as well as subject-specific methods.

Assessment:

The candidate must demonstrate competence in the following written communication elements:

- Using appropriate structure, style and language for purpose and audience.
- Using effective graphical support (working drawings, etc.).
- Applying methods of providing information for use by others involved in engineering activities.
- Meeting the requirements of the target audience (study leader and examiners).

The candidate must also demonstrate competence in the following written communication elements:

- Using appropriate structure, style and language.
- Using appropriate visual materials.
- Delivering the oral presentations fluently.
- Meeting the requirements of the intended audience.

ELO 7: Sustainability and impact of engineering activity

Demonstrate critical awareness of the sustainability and impact of engineering activity on the social, industrial and physical environment.

Range Statement: The combination of social, workplace (industrial) and physical environmental factors must be appropriate to the discipline or other designation of the qualification. Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: health, safety and environmental protection; risk assessment and management and the impacts of engineering activity: economic, social, cultural, environmental and sustainability.

Assessment:

A lecture is given to the candidates in respect of the ELO 7 scope and requirements, and a specific assignment must be completed by each candidate. The candidate must further demonstrate competence in the application of this ELO in the design report in terms of the following elements:

- The impact of the design on society.
- Occupational and public health and safety.
- Impacts on the environment.
- The values and requirements of those affected by engineering activity.

ELO 8: Individual, team and multidisciplinary working

Demonstrate competence to work effectively as an individual, in teams and in multi-disciplinary environments.

Range Statement: Multi-disciplinary tasks require co-operation across at least one disciplinary boundary. Co-operating disciplines may be engineering disciplines with different fundamental bases other than that of the programme or may be outside engineering.

Assessment:

This ELO requires the candidate to demonstrate competence to work effectively as (a)an individual, (b)in teams, and (c)in multi-disciplinary environments. Only outcome (a) is assessed in this module.

ELO 8(a): Individual work

Demonstrate competence to work effectively as an individual in respect of the following:

- Identifying and focusing on objectives.
- Working systematically and strategically to solve the project investigation problem.
- Executing tasks effectively.
- Delivering the completed work on time.

ELO 9: Independent learning ability

Demonstrate competence to engage in independent learning through well developed learning skills.

Range Statement: Operate independently in complex, ill-defined contexts requiring personal responsibility and initiative, accurately self-evaluate and take responsibility for learning requirements; be aware of social and ethical implications of applying knowledge in particular contexts.

Assessment:

The candidate must demonstrate competence in the following:

- Following a strategy to learn about the assignment topic.
- Gathering relevant information through literature and internet searches, interviews, etc.
- Evaluating and using the information correctly.
- Showing an understanding of the research topic gained through independent learning.
- Critically challenging assumptions and embracing new thinking.

ELO 10: Engineering professionalism

Demonstrate critical awareness of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence.

Range Statement: Evidence includes case studies typical of engineering practice situations in which the graduate is likely to participate. Ethics and the professional responsibility of an engineer and the contextual knowledge specified in the range statement of Exit Level outcome 7 is generally applicable here.

Assessment:

The candidate must demonstrate competence in the following:

- Accepting responsibility for own actions.
- Displaying judgement in decision-making during problem solving and design.
- Working within the area of current competence.

ELO 11: Engineering management

Demonstrate knowledge and understanding of engineering management principles and economic decision-making.

Range Statement: Basic techniques from economics, business management; project management applied to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments

Assessment:

A lecture is given to the candidates in respect of the ELO 11 scope and requirements, and a specific assignment must be completed by each candidate. The candidate must further demonstrate competence in the application of this ELO in the design report in terms of the following elements:

- Applying project management to the project.
- Displaying judgement in decision-making based on economics and business principles.
- Displaying judgement in decision-making related to multi-disciplinary aspects of the project.

VI. COMPLIANCE OF UJ WITH CDIO STANDARDS

CDIO is an acronym for **C**onceive – **D**esign – **I**mplement – **O**perate. It is a framework for engineering education for the future, particularly for planning curriculi and outcome-based assessments. The vision of the project is to provide students with an education that stresses engineering fundamentals, set in the context of **c**onceiving, **d**esigning, **i**mplementing and **o**perating real-world systems, processes, and products [7].

The CDIO initiative was formally founded by the Massachusetts Institute of Technology (MIT) and three Swedish Universities (Chalmers University of Technology, Linköping University and the Royal Institute of Technology) in 2000. In 2004, the CDIO adopted 12 standards to describe CDIO programmes. Currently, universities of more than 30 countries worldwide collaborate in the initiative. Only one South African university, the University of Pretoria, participates in the CDIO programme.

The CDIO programmes are too comprehensive to fully discuss in this paper. In short, the 12 standards address the following:

- Programme philosophy (standard 1).
- Curriculum development (standards 2 to 4).
- Design-implement experiences and workspaces (standards 5 and 6).
- Methods of teaching and learning (standards 7 and 8).
- Faculty development (standards 9 and 10).
- Assessment and evaluation (standards 11 and 12).

Each standard has a description, rationale and rubric. The latter provides a criterion for university curriculi, on a scale from 0 to 5, to determine to what extent they meet the CDIO standards.

The UJ Design curriculi are not set up to specifically meet the CDIO standards. Furthermore, the purpose of this paper is not to compare the ECSA requirements with the CDIO standards on a one-on-one basis. However, similar criteria, in the form of the abovementioned ELOs are set by ECSA.

With regards to Standard 1, the UJ curriculi do not comply with the standard as it is not the intention of DMES to transition to CDIO at this stage. The CDIO Integrated Curriculum Standard (Standard 3) is addressed by both non-ELO and ELO DMES Design subjects in terms of the curriculi content.

With regards to Standards 2, 5 and 7, the UJ curriculi comply with the standard requirements as courses and their ELOs are regularly reviewed and revised, both internally by UJ and ultimately externally by ECSA during each accreditation process. This is a rigorous process with strict evaluation criteria, which, if not met, results in loss of ECSA accreditation, and the relevant accompanying international accreditation.

With regards to Standards 9 and 10, the UJ DMES is in a unique, privileged position to have attracted a number of national and international lecturers with PhDs, some with more than 25 years lecturing and/or industry experience. DMES staff are also required to continuously develop their competencies, skills, knowledge and research activities. The continuous improvement and updating of engineering skills of professionally registered engineers is required by ECSA, in the form of continued professional development (CPD) programmes. Every registered professional engineer is also required to renew his/her registration every 5 years. A minimum number of CPD points are required for renewal of registration. Although professional registration is not yet compulsory for lecturing staff, ECSA does require engineering lecturing staff to be at least registerable. Several DMES staff members are registered professional engineers, with the remainder actively following the prescribed programme towards registration with ECSA.

The equivalents of Standards 11 and 12, i.e. learning assessment and programme evaluation, are applied as follows at UJ: For ELO subjects, Teaching and Module Evaluations ("TEs" and "MEs") are required every year for year modules, and every semester for semester modules. For non-ELO subjects, the evaluations are required every second year. The TE and ME evaluations are done by students in the respective courses, and have a prescribed number of standard questions to be answered. The lecturer may add questions from a given bank if he/she so wishes.

From the above discussion it is clear that although UJ does not currently participate in the CDIO initiative, the DMES Design subjects substantially comply with the standard CDIO requirements.

VII. CONCLUSION

The undergraduate Mechanical Engineering Design courses at the University of Johannesburg are accredited by the Engineering Council of South Africa. The requirements set by the Council are discussed together with the measures taken in the compilation of the courses to meet these requirements. Comparisons are drawn between the requirements and CDIO standards.

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