TRAINING WELL-EQUIPPED DESIGN-READY ENGINEERING PROFESSIONALS

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ABSTRACT
Industrial recruiters are increasingly seeking engineers that possess a unique combination of competencies that include creative design engineering skills, sound technological knowledge, hands-on shop floor experience, and clear understanding of business-related issues. A design-intensive undergraduate engineering curriculum has been developed in a brand new entirely laptop-based university around three core design courses, a program-specific capstone design course, and a design thesis. These courses were designed to provide a continuum of carefully crafted project-based team and individual design engineering experiences. The capstone design course serves as one of the final preparations for students entering into industry eager to assume the role of the new kind of preferred “hybrid” design-ready engineering profile. This paper explores the role of a capstone design course that has been developed at UOIT with a sensitivity to respond to the emergence of this demand. It also proposes a rubrics-based method of guidelines useful for clearly assigning capstone design projects as well as for assessing and evaluating students’ performance on such projects in a fair and consistent manner.

Keywords: Engineering and design education, Capstone design, CAD/CAM/CAE

1 INTRODUCTION
Whenever feasible, but especially during the final year of their engineering program, students should be exposed to solving real-world design engineering problems preferably within settings that closely emulate industrial engineering situations. Engineering curricula usually accomplish this by developing a capstone design course where students divided into teams undertake different design projects that provide them with a unique opportunity to apply knowledge and technical skills learned in their previous years of study to a design problem. At UOIT, by the time they graduate, engineering students are given several opportunities to directly experience both team-based and individual design engineering project activities. These projects normally involve demands for the transformation of information such as objectives and constraints into the design and development of an engineering structure which is capable of fulfilling these objectives. For example, students specializing in the area of manufacturing may be required to develop manufacturing systems and/or processes intended for the fabrication of given or newly-designed engineering artifacts. Students are required to provide detailed analyses of their design and validate whether requirements were met through prototyping, testing, and correct implementation of their design specifications. Thereby they become well-equipped to quickly adopt and master state-of-the-art CAD/CAM/CAE tools and technologies as a day-to-day routine [1-4].
2 PERTINENT LITERATURE

2.1 Capstone Project Models
The CDIO (Conceiving-Designing-Implementing-Operating) approach [5-7], may serve well as a model for assigning a capstone project in the fourth year of an engineering design program. This approach was developed through collaborative efforts of several academic institutions developing a model for engineering education through a joint four-year program. The purpose of this program was to provide students with an education that stresses fundamental engineering systems and how to sustain productivity, innovation and excellence.

The CDIO approach defines the levels of creating an engineering design as follows [5]:
- **Conceive** – defining the need and technology; considering the enterprise strategy and regulations; and developing the concept, architecture, and business case.
- **Design** – creating the plans, drawings, and algorithms that describe what will be implemented.
- **Implement** – transforming the design into the product, including manufacturing, coding, test and validation.
- **Operate** – using the implemented product to deliver the intended value, including maintaining, evolving and retiring the system.

Such an approach allows students, for example, to learn about conceiving a product as start-up companies do, as well as exercise engineering reasoning to solve problems that are open-ended and ill-defined. In conjunction with this type of program, an evaluation method is necessary to gauge the level students have applied their knowledge.

Kundu and Raghunathan [8] point out the need for design education to meet industry requirements and propose an approach of interdisciplinary interaction between academic departments and industry contacts, creating a ‘Virtual Company’ for the design of a small aircraft, including production considerations.

2.2 Rubrics as Evaluation Roadmaps
A rubric based on the recently developed ICE (Ideas, Connections, and Extensions) philosophy [9] is developed herein to provide an evaluation roadmap for the capstone course to gauge students’ level of understanding and application of engineering knowledge. Each component of ICE represents a level of application – **Ideas** being just the basic understanding of a concept, **Connections** describing the ability of one to relate knowledge and articulate relationships among elements of the fundamentals, and **Extensions** showing the ability of one to take knowledge and apply it to a novel situation. The advantages of ICE rubrics have been cited by Colgan [10] versus “shareware” rubrics, the latter of which are considered relatively poor tools for evaluating students. The ICE rubrics eliminate fuzziness in descriptions between categories, as well as student behaviours and creative expression from evaluating a student’s understanding of a given subject.

3 THE CAPSTONE DESIGN EXPERIENCE AT UOIT

3.1 Course Importance
The capstone design course represents a culminating major design experience for engineering students at UOIT. The paramount goal of the course is to allow senior-level students to integrate their engineering knowledge and produce useful engineering creations by successfully implementing appropriate engineering design methods into creatively solving design problems conditioned with realistic constraints. This course is offered during the fall semester and it lasts 13 weeks. It is worth 3 credits. The course delivery is organized through two 75-minute lectures (design engineering and product development methodologies and tools) and one tutorial per week (project consultations).
3.2 Course Objectives
There are three important objectives in the course which were given in the course outline and are as follows:

- Expose engineering students to successfully implementing appropriate engineering design methods to creatively solve design problems conditioned with realistic constraints while using state of art engineering CAD/CAM/CAE tools and while incorporating engineering standards.
- To train design engineering students to focus on a variety of considerations with respect to their designs, such as economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.
- To focus on improving the students’ soft skills that include: working in teams, project planning and scheduling, giving presentations, and dealing with uncertainties in a professional manner.

3.3 Learning Outcomes
In the capstone design course, students gain proficiency in: (i) applying principles of mathematics, science, and engineering science to solve problems, (ii) demonstrating the ability to understand and design a useful product in the context of solving a design problem, (iii) working effectively as part of a team, and (iv) communicating effectively design contents.

3.4 Typical Capstone Design Project Scope
A wide range of engineering design-related product, process, technology, or system development topics may be covered in this course, including study of an engineering design topic of interest to a group of students that may be proposed by them, or an original design project proposed and sponsored by an industrial partner, or a design project on a topic proposed by the academic advisor. The following sample description is provided to outline the level and scope of a typical capstone design project:

Design, build a prototype, and use it to demonstrate the functionality of an innovative non-fixed transportation device that can load, move through the air, and safely unload a payload of 4 unopened pop cans from point A to point B (min 10 m distance) without touching the ground surface. Design a suitable manufacturing system for device production. Assume additional constrains if needed. Provide all necessary paperwork, engineering calculations and documentation for both the device and its manufacturing system. Provide a project poster as well as a press release.

3.5 Required Deliverables
Each group of 4-5 students is required to submit the following 7 deliverables with respect to their project, which forms in total 40% of their course grade:

- **Requirements Document (5%)**: Clearly describes the project requirements, demonstrating that students understand the problem they are trying to solve.
- **Project Management Plan/Schedule (5%)**: A MS Project 2003 document describing project timelines.
- **Specification/Design Document (5%)**: Clearly specifies the solution and includes a design. Also demonstrates the feasibility of the design.
- **Midterm Progress Report (5%)**: Includes the engineering analysis and/or motion simulation of the design demonstrating successful application of knowledge from
The final submission, worth 60% of the total course mark, consists of a project report write-up for both the device and manufacturing facility. It includes a logbook describing dates of group meetings, interaction details, literature and patent surveys, addressing issues such as brainstorming, concept generation, freehand sketches, communication via e-mail, etc., design decisions made with reasoning and rationale implemented, design description, and owner’s and assembly manual. The final submission also includes oral presentation overheads, a physical proof-of-concept prototype, the poster, and press release, as well as a self-and-group self evaluation sheet.

### 3.6 Assessment and Evaluation

An evaluation guide is proposed using the course requirements. These requirements were used to create the rubric, which will serve as a roadmap for future offerings of the course in evaluating students’ work, as well as to determine to what level students have applied their knowledge and skill in each of the requirements for this and similar fourth-year engineering design courses. Table 1 outlines the proposed rubric intended for assisting instructors with the assessment and evaluation of capstone design projects.

### Table 1: Rubric Developed for the Assessment and Evaluation of Capstone Design Projects

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ideas</th>
<th>Connections</th>
<th>Extensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logbook</td>
<td>Provides chronological order of meetings and assigned tasks to members</td>
<td>Clearly outlines steps to show design progression</td>
<td>Includes email correspondence with step-by-step, daily log</td>
</tr>
<tr>
<td>Requirements Document</td>
<td>Lists requirements of design and considers customer needs</td>
<td>Relates customer needs to design requirements</td>
<td>Suggests optimization of design methods to accommodate needs</td>
</tr>
<tr>
<td>Project Management Document</td>
<td>Provides project schedule of events and submissions</td>
<td>Organizes plans/schedule by milestone deliverables</td>
<td>Considers consequence of late submissions and plans for advanced completion of deliverables (margin of error)</td>
</tr>
<tr>
<td>Specification/Design Document</td>
<td>Provides outline of approach to design problem</td>
<td>Shows several possibilities of solutions based on design requirements</td>
<td>Considers iterative nature of design and incorporates what-if branches to flowchart</td>
</tr>
<tr>
<td>Midterm Design Document</td>
<td>Provides minimal amount of background search, concept generation, and design ideas</td>
<td>Shows coherent information flow from significant background search to potential design solution</td>
<td>Demonstrates preliminary results of final design</td>
</tr>
<tr>
<td>Test Plan Document</td>
<td>Identifies possible experiment for validating design</td>
<td>Uses analytical solution to hypothesize behaviour of actual system</td>
<td>Considers possibility of unexpected behaviour as related to predicted and measured results of testing procedure</td>
</tr>
<tr>
<td>Background Search</td>
<td>Lists products and available patents</td>
<td>Discusses pros and cons of existing patents and products</td>
<td>Relates existing products to needs of new design</td>
</tr>
<tr>
<td>Brainstorming</td>
<td>Comes up with sufficient ideas to satisfy them</td>
<td>Provides organized list of ideas with simple freehand sketching</td>
<td>Provides logical sequence in developing new ideas</td>
</tr>
<tr>
<td>Sketching Ideas</td>
<td>Suggests several designs and provides sketches</td>
<td>Shows organization of ideas</td>
<td>Provides realistic visualization</td>
</tr>
<tr>
<td>Concept Development and Screening</td>
<td>Compares existing concepts Derives new design from best one Demonstrates moderate use of the House of Quality</td>
<td>Discusses feasibility of each concept Provides organized charts for evaluating designs Generates modular concepts Proficient user of House of Quality</td>
<td>Addresses the entire system (global picture)</td>
</tr>
</tbody>
</table>

- **Prototype Demonstration (10%)**: Demonstrates important features and functions of product for customers and is used to determine any outstanding needs as well as suggest design improvements.
- **Test Plan Document (5%)**: Demonstrates validation of requirements and verifies application of specifications in design via a test case.
- **Practice Presentation (5%)**: Feedback provided to help students prepare for their final presentation and prototype demonstration.
3.7 Students’ Comments

“The course is a great deal of work, but does an excellent job at preparing us for the personal thesis. The layout of the course was excellent and allowed us the time to fully complete a well laid out project that encompasses all the things we’ve learned through the past 3 years.”...“The content of this course will prove later in industry to be very helpful.”
4 CONCLUSIONS
The development of a capstone design course is a key component in the engineering curriculum and is the culmination of the entire engineering design experience of undergraduate engineering students. A chart with rubrics was proposed as an assessment and evaluation roadmap for capstone design projects. The rubric outlines three levels of learning according to the ICE methodology for each deliverable and the various important components expected from students. Instructors may find these rubrics useful to assist students with understanding the expectations of the course for satisfactory marks and/or use them as a consistent guide to grade the submitted projects.

REFERENCES

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