INTEGRATING CDIO PHILOSOPHY INTO MANUFACTURING ENGINEERING CAPSTONE PROJECTS

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ABSTRACT

Groover defines automation as the technology by which a process or procedure is accomplished without human assistance (Groover 2008). Automation continues to filter through all levels of modern manufacturing and with the advent of Industry 4.0 will continue to push the boundaries of manufacturing forward. Items such as robotic control, integration of vision systems, RFID and traceability are paramount to successful manufacturing facilities worldwide. Because of this level of automation in modern manufacturing it is paramount that the manufacturing engineering graduate has the skills required by industry to design, develop and evaluate solutions to industrial automation issues. Graduates typically work as part of an interdisciplinary team in close collaboration with the other members. It is desirable to develop a suitable skillset in the graduates to facilitate this type of activity.

Strobel & Barneveld indicate that "PBL is significantly more effective than traditional instruction to train competent and skilled practitioners and to promote long-term retention of knowledge and skills" (Strobel & Barneveld 2009). With this in mind, the way in which automation has been integrated into the capstone projects of a Manufacturing Engineering programme will be presented in this paper.

The integration and assessment/feedback mechanisms have been designed and constructed to reflect a CDIO learning approach, where students are assigned a typical industrial problem and asked to conceive solutions, evaluate the best alternative, optimise the design, implement and operate the solution. Students are given feedback on Design phase, Implementation and Operation of the project, with all stages contributing to the final grade in the module. Skills such as collaboration, proactive solving and subject specific knowledge are also assessed.

This paper will outline both qualitative and quantitative feedback from the students involved, outlined the project being undertaken and detail the assessment and feedback mechanisms used.

Additionally, the paper will illustrate how a CDIO approach with a specific focus on industrial problems encourages student engagement but more importantly prepares students for issues they will experience in their role as engineers in an industrial environment.

Keywords: Capstone Project, Assessment, Feedback, Standard 5, 7 & 8

INTRODUCTION

Engineering students, on graduation, will enter the field of professional practice and will be expected to provide added value in their field of engineering. It is the role of the third level institution to ensure that these graduates have the necessary skills and competencies to add this value. Through the CDIO approach students are immersed in both the technical and theoretical competencies which helps ensure that engineering graduates have skills such as communication, collaboration and problem solving. A key aspect to any undergraduate programme is the capstone project, traditionally though not always, an individual project which requires detailed planning, coordination, research and integration to develop a solution to a predefined problem.

As with all projects there are a number of key stakeholders who need to be satisfied through the project:

a. The student: Who will require mentoring/supervision throughout the project to ensure project approach is valid, analysis is complete and overall project is of the standard required;
b. Project Supervisor: Who will/should provide structured feedback throughout the project to help ensure that the deliverables and expectations are satisfied;
c. Industry: The project should reflect the content of the student's undergraduate programme and help ensure the student is ready to meet the challenges of industry expectations;
d. Accreditation Bodies: A key fundamental of accreditation is the ability of the institution to produce student work that reflects the undergraduate programme; the capstone project helps fulfil this requirement. For the purpose of this paper the accreditation requirements are those of Engineers Ireland.

It is apparent that a capstone project has a number of stakeholders, each with different expectations, each with different roles and requirements. This paper presents a format which structures the Design and Manufacture Engineering capstone project in a manner which balances the requirements of the identified stakeholders. To achieve this balance, institutions need to balance three significant pillars within the capstone project; Project Feedback, Project Structure and Project Assessment.

Project Feedback

Clynes and Faftery suggest that feedback is "an interactive process which aims to provide learners with insight into their performance" (Clynes & Faftery, 2008). The important aspect to note here is that it is an interactive process; students should be involved in the process, should have the ability to digest the feedback, question it and learn from it. Feedback should be provided in a manner which is constructive and meaningful and which promotes successful teaching. (Ovando, 1994).
By providing feedback in a structured and meaningful manner, students have the ability to learn from their mistakes, take suggestions on board and improve their work. However, if the feedback provided is merely prescriptive in nature the students' ability to learn is diminished, therefore care is required when providing feedback to ensure that errors are illustrated but students are encouraged to work through to solutions independently.
In general feedback is universally encouraged. Feedback is essential for students' growth, provides direction and helps to boost confidence, increase motivation and self-esteem (Clynes & Faftery). The format of this feedback is important – Maclellan (2001) suggested that improvement in learning occurs when students perceive feedback as enabling learning, and not just as a judgement on their level of achievement, while Wojtas (1998) claims that many students improve their work once they understand the purpose of feedback and assessment criteria. A study performed by Weaver illustrated that "An overwhelming majority of students from both Business and Design agreed with the statements 'constructive criticism is needed to know how to improve' and 'feedback is helpful to explain gaps in knowledge and understanding'". (Weaver 2006)

Feedback and Motivation:

Gorham and Millette (1997) found that student motivation was mainly intrinsic and that the way the learning experience was structured has a large part to play in how this motivation is sustained. Course design is therefore as important, if not more so, than teacher behaviour in this regard. They also highlight the link between effective feedback and motivation. Canty & Seery (2011) showed the value of peer feedback in undergraduate work.
Hattie and Tymperley (2007) presented a compelling argument in favour of implementing structured feedback at a number of levels - based on a meta-analysis of 196 studies and

6,972 effect sizes, they found that the average effect size when providing structured feedback was 0.79. To place this average of 0.79 into perspective, it fell in the top 5 to 10 highest influences on achievement, along with direct instruction (0.93). Hattie and Tymperly describe a model of feedback based on the idea of addressing the discrepancy between the current state of a learner's knowledge and that desired. They suggest that feedback operates on four levels - Task, Process, Self-Regulation and Self, as shown below in Figure 1. Feedback can be captured by answering three broad questions: "Where am I going?"; "How am I going?" & "Where to next?"

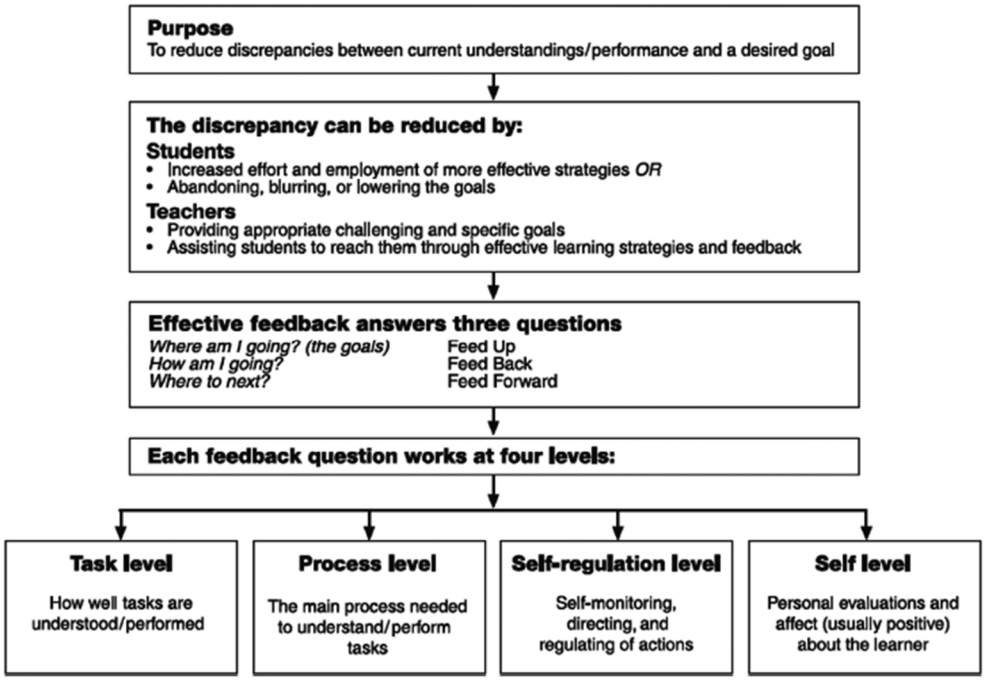

Figure 1 Model of feedback from Hattie and Tymperly (2007)

The feedback can be addressed by providing information on these three questions to the learner:

1. Where am I going? – In other words, how does the feedback clarify what the goals of the work are? (E.g. "..... The type or level of performance to be attained so that (the learners) can direct and evaluate their actions and efforts accordingly. Feedback allows them to set reasonable goals and track their performance in relation to their goals so that adjustments in effort, direction and even strategy can be made as needed...."
2. How am I going? The second question is more related to progress feedback. This entails feedback (about past, present or how to progress) relative to the starting or finishing point and is often expressed in relation to some expected standard, to prior performance, and/or to success or failure on a specific part of the task. Feedback information about progress, about personal best performance and comparative effects to other students can be most salient to this second question.
3. Where to next? The third question is more consequential. Such feedback can assist in choosing the next most appropriate challenges, more self-regulation over the learning process, greater fluency and automaticity, different strategies and processes to work on the tasks, deeper understanding, and more information about what is and what is not understood. (Hattie & Tymperly, 2007)

Therefore, it is clear that structured feedback is an essential component in maintaining student engagement and motivation in a course of study. This is particularly so in the case of a capstone project where the students work is largely self-directed.

Conversely, non-structured feedback is largely ineffective as shown previously by Clynes and Faftery (2008).

Project Structure:

The structure of a capstone project requires skills and knowledge acquired through research and study to be applied back to the problem; students evaluate the effectiveness of their research activities and the application of their research results to the problem at hand, while integrating their new learning with their existing knowledge (Dunlap, 2005). Traditionally, capstone projects in the undergraduate programmes are performed individually with a pre-defined subject area/and project brief. Students then define and scope the project, formulate a design solution, evaluate this solution and communicate findings through a final report and presentation. This paper will examine how best to implement a CDIO framework on the capstone project to ensure that students develop Problem Based Learning (PBL) skills such as critical evaluation, communication, change anticipation and the ability to make decisions in unfamiliar areas (Dunlap, 2005).

Project Assessment:

The goal of assessment is to measure the acquisition of higher-order thinking processes and competencies as well as factual knowledge and basic skills. The function of the assessment should not just be summative but should serve a formative goal of promoting and enhancing student learning (Gulikers et al, 2004).

When considering assessment, two aspects are important to consider, i) construct validity, ii) consequential validity. Construct validity refers to whether the assessment technique measures what it is supposed to measure, while consequential validity describes the intended and unintended effects of assessment on instruction or teaching (Gulikers et al, 2004).

As outlined earlier, the capstone project is the culmination of a number of years of undergraduate study, it requires a detailed assessment method which will reflect on the skills developed by the student. The assessment method should provide for a number of project stage gates to facilitate feedback to the student.

The following sections outline a potential CDIO capstone project structure to be used with a Design and Manufacturing Engineering undergraduate class.

Aim:

The aim of this paper is to develop a capstone project format which uses the CDIO philosophy and which satisfies student learning outcomes, University and industry graduate attribute requirements and accreditation body requirements. In order to determine the optimum approach, following three components of the Capstone Project are examined:

- Project Structure and how well it currently aligns with the CDIO syllabus and desirable graduate attributes.
- Current feedback mechanisms
- Alignment of the current project with the CDIO syllabus

CAPSTONE PROJECT STRUCTURE

Current format

The current capstone project format is as follows (see Table 1): students are presented with a list of possible projects, from which the student selects a project and relevant academic supervisor. The academic year in the Academic institution is split into 2 semesters, Autumn and Spring. Each semester is 15 weeks in length.

In the autumn semester students are required to commence the project and have an agreed Final Year Project (FYP) plan by Week 6 of Semester 1. Students submit an interim report in Week 8 of Semester 1, which outlines title, project justification and objectives; it should contain detailed working drawings, material requirements and costings.

Students are required to then give an oral presentation in Week 10 of Semester 1, outlining progress to date, obstacles, significant progress and detailed work plan for project. Work on the project continues until Week 8 of semester 2 at which stage the student presents a written report detailing the work undertaken, literature, methodology, results and discussion. The final report is examined in a viva voce format with a second reader who acts as moderator. Throughout the project students are required to keep a log of all project activity which is reviewed by the supervisor; this illustrates progress of student work and ensures that work is spread evenly across the duration of the project as shown in Table 1.

Table 1 Roadmap and Deadlines for Final Year Project

Year 3 **Semester 2** **Weeks 6-9**	**Year 3** **Semester 2** **Weeks 9-12**	**Year 4** **Semester 1** **Week 6**	**Year 4** **Semester 1** **Week 8**	**Year 4** **Semester 1** **Week 9 & 10**	**Year 4** **Semester 2** **Week 8**	**Year 4** **Semester 2** **Week 10**
Select number of possible project titles	Students advised of allocation	Approval of FYP planning by supervisor	Submission of interim report (Supervisor Feedback)	Interim Oral Presentation (Supervisor Feedback)	Submission of FYP report	*Viva Voce* exam and poster presentation

An analysis of the current approach indicates that there are a number of areas which could be improved, as mentioned in the introduction section , structured feedback to students is a fundamental learning experience and as such this should be incorporated into the overall FYP assessment structure. A detailed assessment rubric which clearly outlines assessment techniques and justification would help provide justification when discussing assessment with accreditation bodies.

The introduction section of the paper outlined the different stakeholders concerned in the capstone project, Table 2 outlines how these stakeholder requirements interact and how they are currently assessed. In this context, the desired student attributes promoted by the University are relevant and are shown in column 1 of Table 2.

Table 2 Stakeholder Evaluation

Graduate Attributes	Accreditation Body Requirements	Relevant CDIO LOs	Current Assessment Method
Subject specific Knowledge	The ability to contribute to the design of components, systems and processes to meet specified needs.	Standard 8	Report
Pro-activeness	The ability to identify, formulate and solve broadly-defined problems in engineering technology.	Standard 8	Report
Collaboration	The ability to work effectively as an individual, in teams and in multidisciplinary settings together with the capacity to undertake lifelong learning.	Standard 2	Not Directly Assessed
Articulate	The ability to communicate effectively on broadly-defined engineering activities with the engineering community and with society at large.	Standard 5	Presentation

As can be seen from Table 2 there are a number of opportunities for improvement, for example is the final report the best method to assess subject specific knowledge? Could collaboration be assessed directly? Could the ability to articulate engineering activities be developed further? When Table 1 and Table 2 are examined it is clear that there is formal supervisor feedback at interim report stage based primarily on the students subject knowledge. While useful and formative in nature at this stage opportunities exist for greater feedback to the students, in areas such as pro-activeness and collaboration..

Reflection on Current Capstone Format in relation to CDIO Standards

As illustrated in Table 2 one of the key weaknesses in the current capstone assessment mechanism is in relation to collaboration. While the capstone projects under consideration for this paper are individual projects, this does not mean that collaboration cannot occur. Collaboration and idea generation, feedback on others projects and opinions are a key fundamental to arriving at a solid design concept. Collaboration is directly related to Standard 2 Learning Outcomes, where learning outcomes are reviewed in relation to the interests of the graduates.

When the learning outcomes for the capstone module in question are analysed, collaboration is missing and as the learning outcomes need to be included in-order to encourage the student to illustrate they have the ability to collaborate, if required, to develop creative and original solutions to engineering problems.

Pro-activeness has been identified as a key requirement from Table 2, currently this is assessed through academic supervisor interaction and based on the final report. By analysing pro-activeness through the prism of Standard 8, the capstone project in question should look to hold demonstrations, group discussions and feedback on the content that they have learned.

A key requirement of an engineering graduate is the ability to articulate their opinions, findings and conclusions; currently this is assessed through an oral examination at the end of the project. Standard 5 recommends that students are afforded the opportunity to engage at the various levels of the project, be it the Design stage, Implement stage or Operate Stage. Not all capstone projects will offer the opportunity for a physical construction, however all students should be afforded the opportunity to illustrate their ability to articulate their findings.

To this end, the assessment mechanism devised to satisfy the student learning requirements, the academic rigour and the accreditation body expectations needs to encompass the above requirements. The following section outlines the proposed assessment mechanism which maps the CDIO standards to the assessment mechanism.

PROPOSED ASSESSMENT

Taking the information above, the key areas to be assessed are collaboration, subject specific knowledge, the ability to articulate and student pro-activeness. This section outlines a proposed Capstone Assessment methodology for measuring these key areas.

a) To develop an effective and structured method of providing feedback to the students;
b) To develop a suite of assessment instruments that effectively measure the full range of learning outcomes involved in the project;
c) To develop a Capstone Project structure that implements these methods in a structured, repeatable and demonstrable manner.

Providing Feedback:

To assess the present student perception of feedback (and to attempt to see how this may potentially affect their motivation) a short questionnaire was developed. The questionnaire was based on the Hattie and Tymperly model described above. This is shown below in Table 3. The questionnaire was administered to all (15) current Final Year Project students. Specific questions relating to students perspective of feedback included:

Table 3 Analysis of student perception of feedback

Question	Average Score (out of 5)
The feedback I have received so far has helped clarify the requirements of the project (5 being excellent clarity)	3.8
The feedback I have received so far has helped me set specific goals for my work (5 being excellent help)	3.6
The feedback I have received so far has enabled me to adjust these goals as circumstances changed. (5 being very much adjust)	3.6
The feedback I have received so far has helped me to judge how well I am making progress toward the goals of the project (1 not all, 5 very much helped)	3.2
Feedback has helped me judge how I should manage my time for the remainder of the project.(1 not all, 5 very much helped)	3.5
Feedback has directed me towards areas where I need to improve my skills in order to better complete the project. (1 not at all, 5 very much directed)	3.6

As can be seen from Table 3 it is apparent that the current assessment method does not adequately provide the students with the feedback required to learn, clarify and improve their projects. When asked what would they change, students responded varyingly with “Have group meetings for cross-project feedback”, “make presentations”, “Discussion with classmates”, “allow the student to give opinion” but students still seek to have “progress review meetings scheduled by supervisor with written feedback”. A balance therefore is needed between lecturer workload and providing the students with formative feedback to help satisfy learning outcomes of the module.

Students were asked to rank which of the following motivated/demotivated them during their project, results of which are outlined in Table 4. Here students were asked to rank most motivating/demotivating with a 1 down to a 9, therefore the lower the number the more influential the factor.

Table 4 Student Motivating/Demotivating Factors

Motivating Factor	Average Ranking	Demotivating Factor	Average Ranking
Supervisor's enthusiasm.	4.9	Supervisor's enthusiasm.	4.9
Personal interest in subject; Relevance to future career; Desire to learn material.	3.5	Personal interest in subject; Relevance to future career; Desire to learn material.	6.4
Clear objectives; fair grading.	4.4	Clear objectives; fair grading.	2.9
Supervisor's positive attitude; Approachability; Availability.	4.6	Supervisor's positive attitude; Approachability; Availability.	5.7
Supervisor's communication of high expectation; Positive feedback and encouragement.	3.0	Supervisor's communication of high expectation; Positive feedback and encouragement.	6.5
Required participation/attendance.	6.9	Required participation/attendance.	4.3
Self-motivation.	4.5	Self-motivation.	3.7
Active learning.	5.5	Active learning.	4.5
Other	7.5	Other	6.2

From Table 4 it is apparent that positive feedback and relevance to future career are among the most motivational factors for students, while unclear objectives demotivated students.

Through the analysis of the current assessment mechanism and student opinion that there are gains in student motivation to be had by altering the current approach to assessment and feedback, the following section details potential changes.

RECOMMENDATIONS TO CURRENT ASSESSMENT METHODOLOGY

The aim here is to adjust the assessment instruments used in order to measure a broader range of outcomes and included the following:

Articulation of Results:

After completion of the project, students should be in a position to synopsise their project concisely and be able to make a short presentation of less than four minutes to audiences of varying backgrounds and knowledge. Traditional methods of articulation of results and learnings include poster sessions, presentation sessions. However, while useful during assessment, these cannot be reused by students for portfolio or interview.

As such the proposal is to ask students to create a sub-4 minute video which outlines their project, with the context being to present the project in a manner which explains the content clearly and concisely to a potential future employer.

In response to the student questionnaire it is apparent that students are enthusiastic about this concept, "A video should be included", "Include a Video/ Portfolio", "An optional video would be good to display working projects".

Subject Specific Knowledge:

This is obviously central and fundamental to a capstone project; students are required to manage the project, design and develop a solution and to present this solution in a clear manner. A comprehensive technical report, detailing a clear rationale for the project, a solid foundation for methodology chosen based on comprehensive analysis of appropriate literature and a detailed analysis of work completed. The student needs to articulate that they have grasped a clear understanding of the subject matter, which can be best illustrated in a

technical report. However, as Table 3 has indicated, to help the overall project the report should also include reflections on lessons learned collaboration.

Pro-activeness:

This can be a difficult item to assess; however, it should be on the onus of the student to provide evidence for pro-activeness. This can be combined with the project hub formative feedback (which is described below). What lessons has the student learned from others, what suggestions have they made for others, how did they reflect on the formative feedback and self-assess? Unless we ask the student to do these, it may never occur to them to try.

The data can be captured through an online diary of activities which can be presented with the final report and referenced in the final report.

PROJECT STRUCTURE:

As mentioned previously these are individual capstone projects, separate titles, separate areas of investigation, some design based, some design-build and others simply operate projects. However, this should not limit the ability to collaborate; the proposal is to create a project hub. Here, four capstone students are clustered in a hub as per Figure 2.

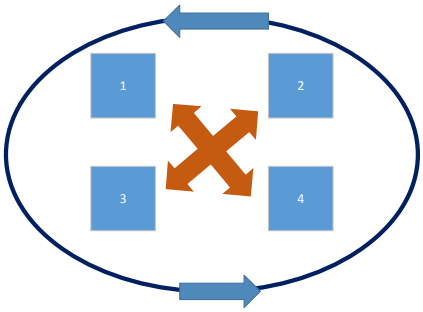

Figure 2 Student Hub Collaboration

From Figure 2, students (identified here by numbers 1 to 4) will be required to provide feedback on each other's projects, assess each other's design and collaborate to help find solutions to potential project roadblocks. Evidence of this collaboration needs to be captured and recorded. By capturing evidence of this collaboration the collaboration requirement of the accreditation body, identified in Table 2, is satisfied.

It is proposed that each hub would make 2 presentations per Semester but that rather than all 4 hub members present that a presenter be selected randomly to present not just the work of the others but also the evidence of collaboration. Self-assessment and reflection will form part of this section. The students will also be required to outline the contribution of others towards the collaboration effort. No marks will be awarded for collaboration; however it will form the basis of formative feedback given at the end of Semester 1.

CONCLUSIONS AND FUTURE WORK

This paper has examined a capstone project module through the prism of CDIO, graduate attributes and accreditation body requirements. Weaknesses in areas such as assessment of collaboration and feedback have been identified with a proposed mechanism for addressing these weaknesses established. The motivational impact of positive feedback has been verified through qualitative survey of existing students. The proposed assessment/feedback model will be implemented in the coming academic year and a comprehensive set of metrics implemented to measure the effects of this initiative

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