COMBINED STRATEGIES TO PROMOTE ACTIVE LEARNING AND RETENTION

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ABSTRACT

Retention rates in engineering courses in Ireland and worldwide are an increasing problem. There are numerous reasons for students not progressing to the second year of their STEM courses, which can include everything from issues related to the transition from a school setting to University and living away from home. The volume of theoretical work undertaken in large lecture theatres can be off-putting to new students, who can feel isolated and can struggle with the new content and learning environments. In the first year, students often cannot visualize how the individual subjects covered are going to lead them to their engineering degree. This paper aims to analyze the introduction of an active learning component through the repurposing of a first-year spring semester module while maintaining the existing learning outcomes. A Design-Build-Compete (DBC) project requires students to work in teams to design and build a vehicle to transport a payload up a 15m slope. It requires students to use mechanics calculations along with engineering design and drawing principles to design this vehicle. Students are encouraged to employ related prior learning such as computer coding and mechanics equations learned in the previous semester to optimize their designs. To support students at the developmental stage of their designing, the module assessment approach utilizes Adaptive Comparative Judgment (ACJ) as a medium to engage students in peer assessment. This process is based on the students making multiple holistic comparative judgments on peers' work, presented in an e-portfolio, generating a rank order of perceived quality by the group. Students also generate formative feedback through the ACJ platform, which contributes to the knowledge-building process. This has an added meta-cognitive benefit where the student is encouraged to reflect on their own design based on their judgement activity prior to receiving feedback on their individual submission. This process is repeated later in the module when the final team report/portfolios are submitted. Students work on different sections of this report and submit it as a team and then build the vehicle in the workshop using basic workshop tools. At the end of the module, all teams take part in a timed race, sponsored by local industry (Modular Automation and J&J Automation Centre of Excellence). At this event, each team is interviewed by practicing engineers who provide feedback on the project and ultimately award a number of prizes related to performance, design and teamwork.

KEYWORDS

Design-Build-Compete; Adaptive Comparative Judgement; Integrated Curriculum; Student Retention; Active Learning; Team-Based Approach, Standards: 3, 4, 5, 7, 8, 11.

INTRODUCTION

The University of Limerick in Ireland enrolls 160-180 students each year into a general engineering program. At the end of their first year, they choose their preferred engineering discipline from one of: Biomedical Engineering; Civil Engineering; Design and Manufacture; and Mechanical Engineering. There are excellent examples of CDIO activity in these programs including aeronautical engineering's Design-Build-Fly project (Young, 2007), Problem Based Learning (PBL) activity in Civil Engineering (Cosgrove, Phillips, & Quilligan, 2010) and general work from the BE degree in Design and Manufacture since the University joined the initiative in 2010 (Ryan, Gordon, Tanner, & Williams, 2017; Ryan, 2013). Introducing CDIO into a program is not a trivial process and can take a long time to make significant changes. The aim presented in this paper is a bottom-up approach, where CDIO methods are introduced to a single module in the first year of the program and analysis is undertaken to see how this has affected the implementation of CDIO elsewhere. Senior management supports this approach in terms of resources, however, implementing CDIO in a single module clearly cannot cover all of the CDIO standards. Based on the outcomes of this module, it is hoped that other academics will also implement CDIO initiatives in their modules.

The first year of the engineering program consists of some recap of subjects covered in secondary school, such as Design Communication Graphics and Applied Mathematics, to bring all of the students to an equivalent standard. One of the modules taught in the second semester of the first year is called "Introduction to Design for Manufacture". In this module, students learn the basic principles of engineering drawing and communication through sketching and manual board drawing and cover basic manufacturing methods, including machining, joining, casting, metal forming, additive manufacture, materials selection and process capability. The first iteration of this program was implemented in 2015. It has been refined year-on-year, based on critical-reflection by the academic team and informed by student, technical and industrial feedback. Some details of an earlier iteration of the module undertaken can be found in the proceedings of the 13th CDIO conference in Calgary, Canada (Tanner & Power, 2017).

In the initial implementation of the module, some clear objectives were identified:

1) Improve retention by creating a practical "hands-on" module for first year engineers (Standard 5 – Design-Implement experiences). The University of Limerick has implemented a number of wide-ranging solutions in recent years to address first year student retention, through the "Student Engagement and Success Unit" (Diggins, Risquez, & Murphy, 2013; Gibbons & Smalle, 2017). These initiatives cover the entire range of degrees that the University offers, but as outlined in recent CDIO and engineering education literature, retention is a pertinent issue internationally for engineering programs (Bennedsen, 2011; Joyce & Rodriguez-Falcon, 2010; Knight, Carlson, & Sullivan, 2007; Godfrey & King, 2010) (Green, 2010; Godfrey, Aubrey, & King, 2010). It is interesting to note that all of these articles include active learning to help address the retention problem and this is further expanded upon by Hermon (Hermon, 2016).

2) Engage with local industry to give first year students a perspective on the world of work that will be available to them after graduation (Standard 4 – Introduction to Engineering). Recent engineering education literature suggests that developing a tangible connection with engineering practice is important for retention and ensures that graduates are ready for the

world of work (Male, King, & Hargreaves, 2016; Tio, 2016; Edelbro, et al., 2017; Chong, Yng, Kwong, & Wah, 2017; Edelbro, Eitzenberger, Edstrom, Jonsson, & Swedberg, 2017).
3) Move away from exam-based assessments to a continuous assessment and team-based approach where the assignments have a connection with industrial applications and go “beyond the classroom”. This helps to develop an integrated learning experience that also helps to introduce students to the world of engineering (standard 4 – Introduction to Engineering; standard 7 – Integrated learning experiences; Standard 8 – Active Learning; Standard 11 – Learning Assessment) (Dym, Agogino, Eris, Frey, & Leifer, 2005; Prince & Felder, 2006).
4) Use the content in this module to create a link across the first year program and to give some context for future modules (integrated curriculum – standard 3). Students complain that the mathematics that they learn is not applied and they rightfully demand that relevant examples are given to their area of study. Recent CDIO publications have sought to address these issues (Chong, Yng, Kwong, & Wah, 2017; Hallenga-Brink & Sjoer, 2017; McCartan, Hermon, & Cunningham, 2010; Enelund, Larsson, & Malmqvist, 2011).

DESCRIPTION OF DESIGN-BUILD-COMPETE PROJECT – CURRENT ACTIVITIES

The Design-Implement (DI) project is described in more detail in an earlier paper (Tanner & Power, 2017), so only a summary is given here – some images can be found in Figure 1 and a flowchart is given in Figure 2. In the first week of the semester, students are given a selection of parts including wheels, pulleys, a motor and a sheet of 1mm thick aluminum from which they manufacture the chassis. They also receive a handout, which contains a procedure from which they can optimize their designs to maximize speed and a series of reporting deadlines. There is a range of possible “correct” effective outcomes, depending on the design that students choose. The assessment considers this, as outlined in the following sections.

Figure 1 Some images from the DBC event held at the end of the semester each year. The image on the left shows the racetrack in action in front of the students union; The image on the right shows the cars being lined up at the end of the race.

First Assessment – Mathematical calculations

In the first assessment, requested at the end of week 4 of the semester, students complete a set of engineering calculations to estimate the speed of the vehicle based on their choice of pulley and wheel sizes, and overall mass of the vehicle. Students input these results through a quiz on the University Learning Management System (LME) called Sulis (based on the Sakai system). Student’s answers are opened in an excel spreadsheet from which their calculations can be checked and marks allocated accordingly. Each student receives a mark /5 for their calculations.

First Assessment – Engineering Drawings

In the first design assessment, students create individual design solutions that outline the positioning of components and chassis design using two orthographic views. They can also include two further sheets outlining their design evolution and solution. These are then uploaded onto an Adaptive Comparative Pairs software system, where students can also include an audio file to help explain their design solutions (Seery, Canty, & Phelan, 2012). Students are then required to make approximately ten judgements where they are presented with two of their peers' design solutions. The students must select which design they believe is better and justify their decision. As part of the process, they must also give feedback to their peers on observed qualities and areas for potential development or improvement. This has multiple positive outcomes including students developing a greater awareness of quality through their analysis and generation of feedback as well as receiving a wealth of feedback on their own work (Seery & Canty, 2017). The activity also produces a rank order of the quality of the work as perceived by the student-judging group, which offers potential for further discussions on quality as the module progresses. This process is moderated to ensure feedback is valid and appropriate. Further details of the alignment of this process and the CDIO framework can be found in the Proceedings of the ASEE Engineering Design Graphics Division 72nd Mid-year conference (Hyland, Buckley, Seery, Gordon, & Canty, 2018)

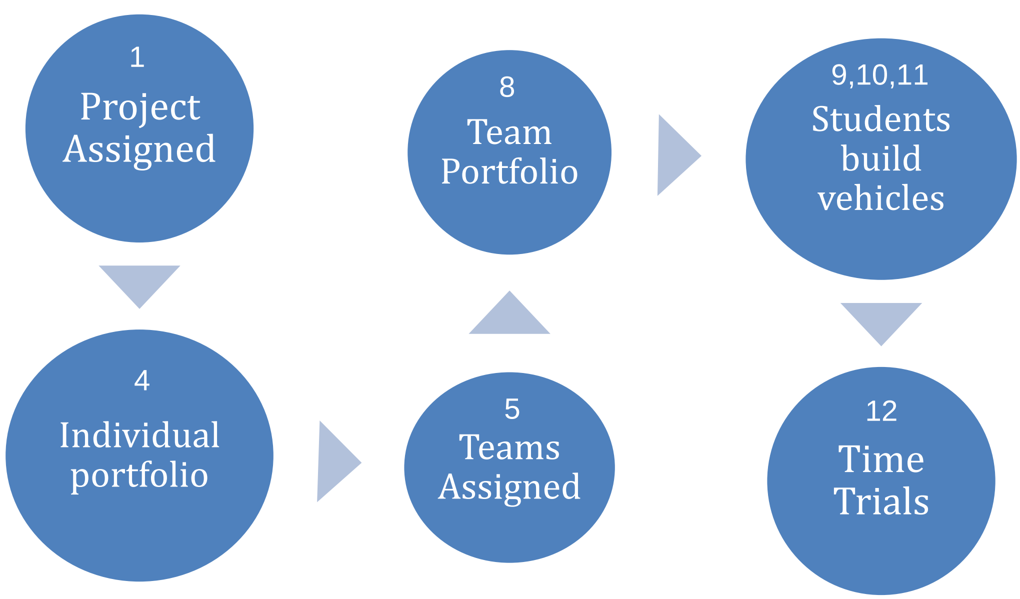

Figure 2 Flowchart indicating major events during the design build compete project. The numbers at the top of each item indicate the week during the semester when they occur.

Assignment of teams

Students are allocated to workshop groups limited to 24 students based on health and safety requirements. From these workshop groups, four students with the highest scores from the first assessment are selected as "Team leaders" around which the Design-Build-Compete teams are built. Using the LME system, students are polled on their favored role on the teams

from the following options: Project Leader; Design Leader; Mechanical Designer - Propulsion; Mechanical Designer – Engineering Drawing; Generally, not all students complete this quiz, so almost all students get their first choice in terms of role on the teams. Based on the results of the first assessment, teams are carefully created to ensure that all teams have a similar mix of abilities, so that one team does not end up with all of the students who have either not engaged or who are exceptional. This coordinated approach to group formation has been shown to increase learning outcomes and reduce negative outcomes associated with dysfunction group dynamics (Godfrey, Aubrey, & King, 2010).
Up until now, no attempt was made to ensure that female students weren't left isolated as the only female on the team. In future, every attempt will be made to ensure that each team has a minimum of two female students as emphasized by Kacey Beddoes at the CDIO Gender presentation held in Chalmers University in October 2018 (Beddoes, Panther, Cutler, & Kappers, 2018).

Second assessment – week 8

At the end of week 8, students submit a group report, which communicates all details of their design solution through the medium of sketches, drawings, photographs, mathematical calculations and justification for their chosen design. In week 11, they also submit a video of the DBC process, which is assessed using ACJ, where the focus is on establishing the team with the best communication output. Each student receives 10% for their section of the report and they receive another 10% for the overall team performance.

During week 9, 10 and 11, students are allocated to their workshop groups and have 6-hours of workshop time to complete their build. Finally, during week 12 of the semester, students are invited to take part in time trials, where each team is given three attempts to climb the hill. The teams that come first, second and third overall in the race and in the final report are awarded prizes by Modular Automation, a local automation solutions company with expertise in "Design-Build-Control" for manufacturing industry internationally. A second award is also presented for the "Best Overall Design and Team Spirit" by the Automation Centre of Excellence at Johnson & Johnson in the University of Limerick. Videos produced from previous years' race days can be found online (University of Limerick, 2017; University of Limerick, 2018).

PRELIMINARY RESULTS – SELF-EVALUATION

This section presents preliminary results from a broad self-evaluation of the degree programs that take this module. Given that the aim of the paper is to analyze the effect of a bottom-up approach to introducing CDIO, it is felt that this self-evaluation across a range of programs that share common modules is most appropriate.

Standard 3 – Integrated Curriculum

At the start of this module development, it was recognized that there was a need to analyze the curriculum and an initial map of the skills learning outcomes was undertaken (1/5 from CDIO Rubric). The module is now fully integrated into the first year engineering program and draws information from other modules in the first year, including engineering science, engineering computing, materials and engineering mechanics. At the time of planning, future work and study by the students as they progressed through their respective engineering programs as also considered. Evidence of its impact is observed when students at the University of Limerick undertake a cooperative education experience at the end of their second year and have industrial interviews for these placements at the start of their second year. Anecdotal evidence suggests that students are asked to explain their role on the team for this DBC and they discuss the teamwork aspect of the projects. Students in later years also undertake projects using finite element analysis, for example, where they re-design the original project with the new skills that they have learned. Based on the changes, that have been implemented, a self-assessment of this standard now results in a score of 3/5.

Standard 4 – Introduction to Engineering

Prior to the introduction of this module, there were two modules in the first year, which covered Introduction to Engineering. These modules have always been very strong and contain elements of active learning and an integrated curriculum in that the modules are supported but by the University “Writing center”. Anecdotal evidence suggests that when students were being questioned in relation to teamwork, leadership, communication skills etc., that the DBC activity was significant support for them to articulate and demonstrate evidence of their skillset. In spite of this, the score for this rubric has likely remained the same (3/5).

Standard 5 – Design Implement Experiences

Prior to this module, there were design-implement experiences within the programs, but there were none in the first year. CDIO experiences were also stronger in some programs. In Aeronautical engineering, for example, there has been a Design-Build-Fly project embedded within the program since 1996 (Young, 2007). As a result of the DBC integration in this first year engineering module, a proposal for government funding to further develop CDIO experiences was submitted in November 2018. Regardless of funding, there is now a distinct plan that these CDIO experiences are essential to engineering programs at the University of Limerick. Being a little conservative, a score of 3/5 can be attributed to standard number 5.

Standard 6 – Engineering Workspaces

While engineering workspaces were not part of the original objectives of this project, new engineering workspaces have been developed to help accommodate this module and a module in Civil Engineering where the students build a bridge as part of their DBC. The workshop space used for this module has also been redesigned to accommodate the students and give them improved collaborative space for projects. Since this program began, the score for engineering workspaces has increased from a self-evaluation score of 1 to 3/5. There are also plans to introduce more CDIO spaces across the faculty.

Standard 7 – Integrated Learning Experiences

The DBC project has been core to developing standard 7. Previously, students in this module worked on individual parts in the workshop and produced individual reports and artefacts. They now work as teams and are assessed as teams. They must learn to work together on the DBC project by combining their expertise to produce a common artefact and report. As part of the final assessment, a team of engineers from a local J&J company interviews all of the teams and probe the interpersonal relationships within the team. The feedback from the engineers is outstanding and they are always extremely impressed with the standard of the final builds and the personal attributes demonstrated by the students through the DBC activity. Some of the students end up taking on their cooperative education experience with these companies due to the work that they complete and their attitude in the interviews. (Score 3/5).

Standard 8 – Active Learning

Each student taking this module has six contact hours per week, where they spend two hours per week in an engineering design laboratory and two further hours in an engineering workshop using lathes, milling machines and workbench tools. The remaining two contact hours are spent in a lecture theatre. Clickers are used with powerpoint presentations in the manufacturing lectures in an attempt to keep the learning active and are now used in about 20% of the modules in the first year. In most courses, there is a plan to include active learning across the curriculum. The DBC is essentially an active learning task where the learners are required to take ownership of the task and drive it forward to meet the intended learning outcomes of the module. Supporting this through pedagogy is of critical importance to help students navigate the path of uncertainty and ultimately reach their goals. The module supports active learning with dedicated laboratory/tutorial time with tutors, with e-portfolios to help students communicate their thinking and designs and through the formation of working groups that create an opportunity for discussion and collaboration between learners. Creating and delegating roles that simulate work teams in the industry also supports the authentic development of attitudes, skills and knowledge relevant to an engineering career. Finally, the introduction of the peer assessment activity supported through ACJ provides a catalyst for the students to conduct in-depth analysis and synthesis of the quality of work and to develop skills of critique and judgment through the feedback and assessment process.   (Score 3/5)

Standard 11 – Learning Assessment

A significant innovation in relation to assessment in this module is the introduction of peer learning and assessment. The benefits of integrating this approach are that it supports the development of skills of collaboration and teamwork, develops skills of communication through the externalization of ideas and concepts to their peers and the assumption of responsibility by the group, deciding on their needs and planning a strategy to address them. Boud (Boud, Choen, & Sampson, 1999) outlines that assessment can actually foster peer learning but only with strategic planning from the outset of the design of the learning task. To this end, the module team considered the ACJ assessment process as being suitable in delivering on this requirement. The process requires the students to make holistic judgments on the quality of peer work, based on overarching criteria that are formulated as the learning progresses through the task. Students are exposed to a broad spectrum of quality of work through the judging process and both create and receive multiple pieces formative feedback on the work. This feedback is generated early in the module (Week 5) and is a central catalyst for discussions when the teams are created, and members try to finalise on one design for the group. This aligns with the principles of good peer review and assessment (Nicol, Thomson, & Breslin, 2014; Sadler, 2009). The inclusion of additional feedback from the industry partners (and the academic team complement this assessment approach leading to an inclusive and informative assessment model that supports the learner. The current score for the program for standard 11, is probably 3/5, but with the impact that ACJ has had, we would hope that the score would increase further in coming years when the opportunities that ACJ presents are better understood by fellow academics.

CONCLUSIONS

The paper aimed to look at developing CDIO in one first year module and analyze the effect that this has had in the remainder of the program. The module has gained a lot of attention from management and some of the ideas have filtered into other areas of the program and into other teaching and learning groups in the University. The introduction in this one module has clearly had an impact on standards 3, 4, 5, 6, 7, 8, and 11. There is still a lot of work to do in developing the remaining standards and applying the techniques learned here into other courses/modules. The effect on retention is difficult to assess, but retention figures have improved year-on-year since this program was introduced, but these could potentially be linked to other changes in the overall structure of the engineering program, such as the introduction of a common entry and first year. There is no doubt, though, that the introduction of this CDIO module has had a positive effect on the students and those involved in teaching first year engineering at the University.

Possibly one of the greatest finds in terms of CDIO was the link with ACJ. As previously discussed ACJ as an assessment method is compatible with the CDIO initiative and contributes to multiple standards. However, it can also be thought of as a pedagogical strategy. Requiring students to act as peer assessors provide a wealth of feedback that would not otherwise be possible without significantly increased resources. There are associated benefits when students are exposed to a wide range of quality in peer work. This allows students to form a more accurate impression of what excellence looks like and aids in self-evaluation of similar work. Similarly, it facilitated the involvement of our industry partners to engage remotely with student work prior to a competition setting. This allowed for a more complete partnership where feedback from partners could be incorporated into the module design and further developed when industry partners were engaging students in small group settings. While the ACJ system is a particularly useful tool, it should not be considered an easy fix. It requires a sound conceptual rationale for inclusion and a considerable amount of supporting structures in order to ensure students benefit from the experience.

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BIOGRAPHICAL INFORMATION

David Tanner is a Senior lecturer in Manufacturing Process Technology at the University of Limerick and Assistant Dean of Internationalization in the Faculty of Science and Engineering. He is a member of the Bernal Institute and undertakes research in the areas finite element analysis of metal working processes, additive manufacturing and investment casting. Dr Tanner has been a member of CDIO since 2009 and has developed engineering modules based on the principles of CDIO.

Jason Power is a lecturer in Engineering Education. He has worked within various aspects of STEM education while his research focuses on psychological factors that impact performance within STEM learning environment. Through this research a greater understanding of the determinants of performance within an engineering education environment has been developed, which in turn has informed the development of educational structures that seek to optimize learning outcomes. His current research is in partnership Michigan Tech University where he is contributing to a large-scale longitudinal NSF funded project.

Donal Canty is a lecturer in Initial Teacher Education at the University of Limerick. He is a qualified Post-Primary teacher with 8 years classroom experience. Donal's research interests are in the areas of pedagogy and assessment. His doctoral studies investigated the impact of holistic assessment using Adaptive Comparative Judgement (ACJ) on student learning. Donal is one of the founding members of the Technology Education Research Group (TERG) at UL and was a co-principal investigator on the EU Funded GRASS LLP project that is focused on assessment and grading of soft skills.

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