THE TYRANNY OF NUMBERS: WHY MARKING CDIO ACTIVITIES COULD BE DIFFICULT

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ABSTRACT

This paper offers a reflection on how traditional marking methods frequently fail to capture the deep learning students can achieve when involved in CDIO-inspired activities. Active learning activities and projects offer opportunities to learn discipline content, technical skills and graduate capabilities like communication, teamwork, conflict management, and social responsibility. Including all the possibilities in a list of learning outcomes is challenging. And since in a constructively aligned course the sole purpose of assessment is to measure the attainment of the learning outcomes, much learning frequently goes unrecognised. Most educational institutions use numbers to "measure" students' achievement but, what do these numbers really mean? This paper argues that numbers are very blunt instruments to measure the learning students achieve when involved in projects, and calls for more qualitative, student-driven approaches.

KEYWORDS

Qualitative Assessment, Project-Based Learning, Standards 2 and 11.

INTRODUCTION

Since its inception in the year 2000 the CDIO framework has effectively supported universities responding to the challenges and requirements of the 21st century, as outlined in ABET's (Accreditation Board of Engineering and Technology) expectations for graduating engineers (ABET, 2025). Many institutions around the world, members and not members of CDIO, are adopting teaching strategies that are student-centred, open-ended and focus more on the process than the product. Consequently, students' learning has broadened, i.e. along with discipline specific information, they are learning skills and competencies that are sought after by employers. Today, most graduates leave university ready to work and contribute immediately after they complete their program[1].

In many cases, the rapid diversification in teaching activities is still unmatched by improvements in assessment methods. To respond to Covid challenges some universities started a move from the Assessment of Learning to Assessment for Learning, and finally to Assessment as Learning (Yang & Xin, 2022), but many institutions are still 'stuck' in the assessment of learning model. At individual level, many academics prefer the use of quantitative assessment methods to mark students' work. They use tests and rubrics to produce a number that reflects the student's competency (knowledge and skills) in the subject. Numbers are useful and have a place, but much of what students learn in projects and other active learning experiences is difficult to capture using quantitative assessment methods. The problem arises because learning outcomes (LO's) cannot capture the whole spectrum of what students learn while working in teams to complete projects, and in a structurally aligned course assessments only evaluate the declared LO's (Biggs, 2014).

The following sections present some reflections about the role of universities in today's world, followed by a brief outline of constructive alignment to highlight the importance of aligning assessments to learning outcomes, then some comments on the use of quantitative and qualitative techniques to assess students' work, and finally some suggestions on how to transform assessments to capture more of what students learn in CDIO-inspired activities.

WHY DO STUDENTS GO TO UNIVERSITY?

Before the introduction of online repositories of information like IEEExplore, Google, Wikipedia and YouTube, students came to university looking for information. Books in libraries contained the information students needed to become doctors, lawyers and engineers. Professors were the "sage on the stage" whose role was to make information in books more accessible to students, with different levels of success. Lectures were not recorded, hence there was no need to make attendance compulsory, students wanted to attend because if they skipped a lecture, it was their responsibility to find the missed information on their own, in a book or a classmate's notes.

With the advent of the internet in the 1990's, information is no longer confined to books and libraries; it can be accessed anywhere, any time and in various formats. Hence students no longer attend university to acquire information, they now come looking for experiences. Furthermore, the amount of information in every discipline is continuously growing, making it impossible for universities to teach students everything they will need to succeed in their

[1] In this paper the word *course* will be used to refer to the collection of activities and assessments involved in the delivery of a subject. Courses are called or subjects in different institutions. The word *program* will be used to refer to the collection of courses that a student must complete to graduate. Programs are called courses or degrees in different institutions.

careers. Content must be carefully curated and delivered. The role of teachers has gradually shifted to become a “guide on the side”, helping students develop skills to find, classify, and use information to solve problems (Christersson, 2019).

From an ontological perspective, students come to university to ***become*** engineers, or doctors, or architects. After graduation engineers do not say “I do engineering”, they say “I **am** an engineer”. A big part of the role of educators should be to facilitate this transition, but how? Students become professionals by adopting the distinctive behaviours of the profession. A good engineer is not only knowledgeable in Physics and Mathematics but is also expected to be a good problem-solver, communicator, team member, resourceful, disciplined, responsible and a long et cetera. To what extent are university programs designed to purposely develop all these skills in students? Programs need to provide opportunities for students to practice the behaviours of their profession and reflect about their transformation. Academics must be role models, projecting the behaviours they want their students to adopt (Barbarà-i-Molinero, 2017).

In this context, assessment needs to shift its focus from content to skills, and from product to process to be more effective. It needs to shift from quantitative approaches (numbers) to more qualitative techniques (statements).

CONSTRUCTIVE ALIGNMENT

Constructive alignment is a teaching method that focuses on the learning outcomes students achieve, rather than the topics taught. It draws on constructivist learning theory, which assumes that students construct their own knowledge (McLeod, 2024). The process to design constructively aligned courses follows these steps (Biggs, 2014):

1. Define learning outcomes. Bloom’s taxonomy (Bloom, 1956) is frequently used to describe the level at which students need to demonstrate the learning outcomes.
2. Design learning activities to support students’ attainment of the LO’s. This involves the matching of topics from the syllabus with activities where students learn from what they do, not from what the teacher does (active learning) (Bonwell & Eison, 1991).
3. Design assessment tasks to evaluate if the LO’s have been achieved. Assessments must give students opportunities to demonstrate what they know and can do, focusing on the high levels in Bloom’s taxonomy.
4. Reflect on student performance and review LO’s if necessary. Start again from step 1.

In theory, a properly aligned course ensures that students engage in learning activities that will help them achieve the desired outcomes while supporting teachers creating a learning environment that supports students' learning. However, in practice learning outcomes fall short at capturing all the learning that can occur when students engage in CDIO-inspired learning activities like project-based learning and role-playing. Much learning goes unnoticed and ignored because it is not part of the stated learning outcomes and therefore it is not assessed.

QUANTITATIVE AND QUALITATIVE ASSESSMENT

The CDIO framework is a good guide to design activities conductive at attaining Bloom’s high levels of learning behaviours. However, appropriate assessment methods need to be chosen to effectively capture and evaluate students’ learning, even when this learning is not part of the official course learning outcomes.

Quantitative assessment is good to evaluate Bloom's taxonomy lower levels. Multiple-Choice Questions, short answers, and use of formulae are examples of assessments that evaluate students' ability to retain and recall information. Since only one correct answer is possible, these assessments are generally easy to mark. In some instances, automated marking is possible (and recommended).

Numeric results are very useful to rank students and create reports but, how accurately do they reflect student learning? What does it mean that a student achieved 75% in teamwork? Did they complete 75% of their work? Did they attend 75% of the meetings? Did they contribute 75% of ideas? When designing quantitative assessment artifacts, it is important to keep in mind all the learning that remains unrecognised.

Open-ended projects, problem-solving in teams, conceive, design and implement artifacts to meet specific requirements are examples of activities that help developing Bloom's higher learning behaviours. Qualitative instruments like reflective statements, surveys with Likert scale questions, interviews, and focus groups are good to evaluate Bloom's high levels.

However, there are challenges: these instruments are more difficult to design, it takes longer to complete the marking, and assessment is usually subjective. Rubrics can support qualitative assessment, but they must be designed with care to avoid students working to the rubric, instead of focusing on the overall process.

Ideally, both quantitative and qualitative assessments should be used to obtain a good grasp of students' progress. Quantitative approaches are better suited for assessing performance, while qualitative approaches provide more valuable insights into the student's developmental processes.

One example of project-based learning is the "Crazy Machine" Project (CMP) electrical engineering students complete in the third year of their program. This project was presented at the CDIO conference in 2013 (Maynard and Ortega-Sanchez, 2013). The project is so successful that it has remained practically the same over the years. Student feedback consistently reports high satisfaction levels, for example one student declared during an interview at the end of semester: "I really enjoyed [the Crazy Machine Project] because I have developed so many different things like technical skills or working with a team or spending time problem-solving things. It was a really good project all around".

In its current edition the Crazy Machine project is assessed with the following submissions:

- **Progress report** (25%). Submitted at the end of week 6 of semester.
- **Crazy Machine video** (25%). Produced by the team to describe the design process and implementation and testing of their machine. An example is available in this link.
- **Crazy Machine demonstration** (20%). On the last week of semester students explain and demonstrate their machines.
- **Final report** (30%). Submitted at the end of semester. Formal report covering the design process including Conception, Design, Implementation and Verification of the machines.

Additionally, students submit a video where they declare, to the best of their ability, all the learning that took place during the development of the CMP. Self-declared learning is possibly the most valuable kind of assessment, and it rarely matches well with the course learning outcomes.

SUGGESTIONS TO IMPROVE THE ASSESSMENT OF CDIO-INSPIRED ACTIVITIES

Any discussion about assessment must take place in the context of the learning outcomes. To discuss changes in assessment it is necessary to start by reviewing and changing, if necessary, the learning outcomes. What students can learn in hands-on, practical courses is very broad and varied. Most likely, each student learns different things from completing the same activity.

To support the construction of useful learning outcomes, they could be classified into at least two categories: essential and desirable. Essential LO's are those that all students must achieve. These are non-negotiable and failing to demonstrate any should result in failing the course. It is recommended that each essential LO is explicitly stated in at least one of the course learning outcomes.

Desirable learning outcomes are those that some students may attain while others do not. These outcomes can be amalgamated into abstract categories like communication skills or social responsibility which encompass a big number of skills and competencies. Declaration of learning is the most effective way to capture desirable learning.

Once the CLO's have been established, assessments should focus mainly on essential LO's while leaving room to include desirable LO's. The use of rubrics is highly recommended to evaluate the attainment of both essential and desirable LO's. A good rubric uses levels of achievement rather than numeric scales to evaluate students' work. For example, an item on communication skills could be evaluated as 'developing', 'competent' and 'proficient'. A description of what each category means must be shared with students as the minimum amount of feedback they can receive. These descriptions should provide information that helps students understand what abilities they need to develop to improve their performance.

The following list shows the LO's of the course where students complete the CMP:

1. Describe and implement digital systems using VDHL and FPGAs.
2. Use commercial Field Programming Logic Device development tools to implement embedded systems.
3. Explain and apply the Universal Design Methodology (UDM).
4. Work as part of a group to develop a project
5. Report your experiences in an orderly and effective format.

All learning outcomes in the list are essential, i.e. every student is expected to demonstrate their attainment to pass the course. Rubrics are extensively used to let students know the expectations.

The importance of the student voice

To deal with the facts that learning is individual and that after completing an activity each student will learn different things at different levels of understanding, assessments should provide opportunities for students to declare their own learning. Reflective statements, surveys, videos and interviews are excellent vehicles to capture students' self-declared learning. This is the kind of learning that will possibly stay with students for the rest of their lives and very frequently passes unrecognised.

In assessing student's self-declared learning, it is important to keep the following question in mind "to what extent did the student use this assessment to demonstrate they are becoming the best possible engineer/lawyer/architect/doctor they can be?". And if marks are necessary,

marks should be allocated to self-declared development. In the CMP the final mark is determined by combining the assessment of essential and desirable LO's.

Reflective statements are particularly useful to capture students' perception of their own learning and development. In reflective statements students are asked to declare how they have applied their knowledge and understanding in a new situation; for example, in solving a problem. Reflective practices help students turn surface learning into deep learning. One of the challenges of assessing reflective statements is that it is very difficult to allocate a numeric mark to them. We could give marks for things we can count like the number of words, the number of grammatical mistakes or the number of times they start a sentence with 'I'; e.g. "I learned that…", "I believe…", "I noted that…", etc. Other than that, all sincere, well-written reflections have the same value as they mean something to the students who wrote them.

FINAL REFLECTIONS

In this paper the following ideas have been developed:

- CDIO-inspired activities are very good to teach students the knowledge, skills and competences required by industry in the 21st century.
- Students come to university to become the best possible professionals they can be.
- Constructive alignment and Bloom's taxonomy support the design of outcomes-based courses.
- Assessments very rarely capture the learning involved in the development of the students' identity as a professional.
- Quantitative assessments, i.e. evaluating student learning with numeric scales, are very blunt instruments to measure students' learning.
- Qualitative assessments provide more opportunities for students to demonstrate their learning, but they are more difficult to design, and their evaluation is subjective.
- A combination of quantitative and qualitative assessment instruments is recommended to capture students' competence and development process.
- Reflective statements are particularly good instruments to capture students' perception of their own learning and development.

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BIOGRAPHICAL INFORMATION

Cesar Ortega-Sanchez is Associate Professor of electrical engineering at Curtin University. He is a Computer Systems Engineer from the Metropolitan Autonomous University, Mexico, Master of Science in Digital Systems from Brunel University and Doctor of Philosophy in Electronics from the University of York, UK. He joined Curtin University in 2005 where he has designed and delivered courses in digital design and embedded systems and is also a recognised leader and innovator in teaching and learning. He has supervised over 100 undergraduate and postgraduate theses and has published over 60 papers on Electronics and Engineering Education. His research interests are in embedded systems, bio-inspired architectures, intelligent systems, assessment, and curriculum design. In 2015 he won a citation from the Australian Office of Learning and Teaching for his outstanding work facilitating activities to improve students' employability skills. Cesar is Senior Fellow of the Higher Education Academy (Advance Higher Education), Fellow of the Curtin Academy, Senior member of the IEEE and Curtin's representative for CDIO. He has done consultancies on curriculum design, assessment, capstone project and first year experience; and is an active reviewer and keynote speaker in higher education conferences.

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