Engagement and Learning from a Team-Based Mini-Project in Mechatronic Engineering

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Abstract. We outline our experiences with hidden and unsignposted learning by us and by our students arising from a team-based project activity in a 3rd-year undergraduate engineering module in the general Mechatronics area. We discuss the hidden learning achieved in areas such as team communications, team management, problem-solving skills, and communication through the media of student-produced video and presentations, as well as technical engineering reports. We describe the enablement of student reflection on their learning and its benefits and use these reflections to evidence various aspects of their learning. The work is situated within the literature on innovations and quality of STEM education.

Keywords: Engagement, engineering project, student-centered learning.

1 Introduction

The results described in this paper were not derived as part of a research project that set out to answer particular questions about collaborative, team-based and peer-based learning. Instead, the developments were driven by challenges to innovate, to collect and act on feedback, and to aim for continuous improvement [1]. The means offered for recognizing the learning needs and delivering improvement were, and are, engagement with students, flipping the classroom, searching for motivation, teachers as partners in learning, and putting learning into the context of the students' future needs.

However, in terms of helping other teachers to innovate, it is useful to contextualize the un-anticipated learning-for-teaching that happened as a part of the aim for continuous improvement, in the context of the literature on collaborative teaching methods for improving student learning outcomes. Ralston *et al* [2], for example, set out to investigate why, although the literature shows that almost any active or collaborative approach will improve learning outcomes as compared to traditional lectures, these methods have not been universally, or even widely, embraced. They cite the reasons for this as

- lack of pedagogical support from institution and colleagues,
- losing control of content coverage,
- student attitudes, expectations and resistance to change,
- lack of ongoing professional development,
- personal beliefs and expectations about teaching and learning.

The outcome of the developments described in this paper is that many of these barriers can be overcome, not by assuming collaborative learning is the ‘solution’ and promoting ways of adopting it, but by setting *continuous improvement* as the objective, with listening and innovation (by the teacher) as the methods. As continuous improvement is actually about *quality of learning*, we see the progression as being one from quality to student engagement. Then, one natural expression of student engagement is collaborative learning – this now being an outcome and conclusion rather than a starting point.

Although Wittek and Kvernbekk [3] point out that ‘quality of learning’ is an elusive concept in higher education, assessment of teaching and learning is often considered as the means for ‘achieving’ it [4], and the enhancement of quality of learning can be linked to the quality of the student experience [5]. Klemenčič [6] focused on student-centered learning (SCL) as being a sort of ‘litmus test’ for quality, noting that student-centered learning features in the 2015 version of the European Standards and Guidelines for Quality Assurance in Europe (ESG), which in turn, strongly influences national and institutional policies. This is a reflection of the fact that policies for quality have shifted from student satisfaction to *student engagement*, and research on student engagement has been the cornerstone upon which policies and practices have been positioned over the last 10 years or so.

Indicators for student engagement are ‘groupings of related items designed … to measure the extent to which an institution’s environment promotes effective educational practices’ [8]. For the Irish Survey of Student Engagement, there are nine such engagement indicators: higher-order learning, reflective and integrative learning, quantitative reasoning, learning strategies, *collaborative learning*, student-faculty interaction, effective teaching practices, quality of interactions and supportive environment [9]. Focusing on the collaborative learning element, Ralston *et al* note as benefits: improvements in student achievement (content learning and understanding), the quality of interpersonal interactions (communication and social skills), self-esteem, self-confidence and student retention. Collaborative learning – which could be considered as any structured form of small group interaction [10] – is generally associated with active learning in the literature.

To situate the change process that led to the learning described here, it is useful to consider Borrego and Henderson’s categorization of innovations in STEM teaching and learning into eight change strategies. In their terms, this work arose from individual ‘reflective teachers’ forming informal ‘reflective communities’, cross-fertilizing and supporting each other’s innovations. However, there are also elements of the ‘shared vision’ strategy with its subcategories of ‘learning organizations’ and ‘complexity leadership’. In the complex and disruptive educational environment in which we now find ourselves, these categories can help us to structure our efforts so that they support the agility and innovation that will characterize successful educators in the future.

2 Module Overview

Electromechanical Systems is a module in the first semester of the third year of related four-year (Bachelor) programmes in Electronic and Computer Engineering and in

Mechatronic Engineering in DCU. This is where five years of post-second-level engineering education to Masters level is required to satisfy the educational requirements for Professional/Chartered Engineer status. This 5-ECTS credit module focusses on the sensors, actuators/motors and interfacing electronics that are key elements in a mechatronics system. Typical class sizes are in the range of 45-60 students.

Notwithstanding earlier modules on digital and analogue electronics and circuit theory, including associated labs, on commencing this module, the majority of the students are not competent or confident in designing and implementing straightforward interfaces between general analogue or digital devices and machines. Hence these learning outcomes are targeted by the inclusion of a team mini-project in the second half of the semester. Here we describe the nature of this project, and discuss the hidden and unsignposted learnings that the students encounter, evidenced by their own reflections.

The unsupervised team mini-project is carried out by groups of three with a standard kit (comprising components and tools), available to be taken off-campus if the team wishes. It is worth 17% of the module mark and is assessed on the basis of a team presentation to their peers, a short video produced by the team, and a written team technical report – all evaluated by rubric-based marking.

There is a marked tendency for students in the class to consider earlier years in their programme as ‘hurdles’ to be overcome and left behind, achieving superficial levels of retained knowledge, and not solid platforms on which to build further learning. Hence, there is guidance for student revision at the start of the module. This also supports student-centered design and implementation throughout the practical learning. To action this revision, specific local material and links to general external references (such as [12]) are provided to the class by way of the VLE. The individual student’s mastery of this material is encouraged by a combined diagnostic and competency MCQ test. This test may be taken multiple times, as it has a pass mark of 70%, and any subsequent CA mark awarded to the student is zeroed until the diagnostic/competency test is passed.

3 The Team-Based Mini-Project

The team-based mini-project is timetabled for six 3-hour lab sessions in the second half of semester, but teams can work outside this time if they wish, as all components are selected to be safely used without supervision. The teams spend this time on constructing, debugging, testing and operating a microcontroller-based 2-wheeled robot from a kit of components, with technical officer support during the scheduled lab times. The teams are usually self-selected, with the stipulation that each of the two programmes must be represented on a team. In the last week of the teaching part of the semester, each team makes a presentation to the class, and shows a short video that they have produced about the building and operation of the 2-wheeled robot. About a week or so later, they also need to submit a single agreed technical report per team.

One of the explicit aims of the mini-project is to move the students to the ‘understanding’, ‘application’ and ‘analysis’ levels of learning in Bloom’s taxonomy, and this helps to prepare them for their fourth-year individual engineering project where they should be achieving at these, along with ‘evaluation’ and ‘creation’ levels of learning.

The MSP432P401R LaunchPad^{TM} development board was chosen as the target embedded microcontroller to avoid the 'path-of-least-resistance' associated with the Arduino. The same processor is used for a more challenging project-based module on Mobile Robotics in the second semester, so the students benefit from the time and effort invested in learning about the MSP432 during the first semester.

The (returnable) kit is distributed without charge to each team. It is up to each team to decide what is done with the available components. The main objective is that they demonstrate a capacity to interface sensors and actuators/motors to the microcontroller for '*some constructive outcome*'. Marks are awarded (with rubric-based marking) for

- functionality and achievement of the objectives of the prototype;
- quality, structure and technical content of the written (team) report;
- quality and content of a video;
- quality and content of a team presentation.

The teams are asked to use at least 80% of the supplied components as a core part of their design, with up to 10% of the marks for the project being awarded for a team successfully interfacing to an additional, unspecified sensor that does not feature in the original kit. It turns out that a very positive and constructive direction to the students is that they should "*Feel free to surprise me here*". A 'Getting started guide', along with all necessary datasheets are provided through the VLE. The students are encouraged to use digital oscilloscopes for debugging.

The projects are assessed on a per-team basis by default. However, the students are asked to give a "clear and detailed" description of their personal contributions in the joint technical report, with advice at the start that they keep individual or team logs of contributions and progress throughout the project, including possible means for doing this. Follow-up action can be and is taken when a discrepancy in the extent of contribution within the team becomes apparent, either from the assessment materials or from direct inputs by students themselves.

Feedback on the mini-project consists of the selected assessment rubric levels in each category, along with additional textual descriptions of both positive and negative issues that are not captured by the rubric text. In addition, the technical reports are corrected within the VLE with detailed corrections visible to the team. The feedback includes notes on the quality of the presentations and the video, including advice on how to perform more effectively in front of an audience, and a class-wide message with generic areas for improvement that were common across many of the technical reports.

3.1 Sources of Innovation on this Module

The idea of getting the teams to present their work through the medium of a short video, along with other aspects of how the Electromechanical Systems module operates, came from a presentation given in DCU by Marc Prensky in Sept 2011, called "*Engage me or Enrage me*"[1]. In this challenging and provocative presentation, Prensky talked *inter*

[1] The content of the presentation is no longer available online, but sources containing similar advice are described on [2].

alia about engagement, listening, balancing top-down with bottom-up, flipping the classroom, peer-to-peer learning, mutual respect, motivation, partnering, and module coordinators not as lecturers but as coaches, guides and partners in learning: asking questions, adding quality and rigor, and putting learning into context. He pointed out that while yesterday's literate person might write a letter, report or essay, and the 2011 literate person might write an email, make a slide presentation or create a blog post, tomorrow's literate person would work in a virtual community, make a video or write a computer program. He challenged his audience with questions such as:

"Have I innovated today?"
"Did I get feedback and act on it?"
"Do I have a continuous improvement plan for my teaching?"
"Am I sharing the innovations that work with my colleagues?"

One of the reasons for writing this paper is to share the lessons learned from adopting and innovating around these ideas in one particular module delivered over more than a decade. The implementation of such innovations can make the educator a more effective fosterer of learning and can indeed make their work easier rather than harder.

4 Student Evidence of their Learning Experiences

A notable aspect of the technical reports submitted on the project was the number of teams that undertook extensive introspection and self-analysis of their work and their experience under headings such as Learning Outcomes, Project Management, Team Operation and Conclusions and Evaluation. They understood that the relatively unstructured nature of the mini-project and the requirement to operate as a team were aspects that were foundational for their learning experiences, and could not easily have been 'taught' in other ways. Several teams came to understand that problems, hurdles, obstacles, mistakes and unforeseen issues were actually valuable learning opportunities, rather than impediments to learning. In the following sections, we outline some of the experiences described in the reports.

4.1 Team Communications

Some of the teams discussed the need for, and operation of, communications within the team. For example, Team M say:

> *Since the lab was open the whole week, we were able to work out times that best suited each other to work outside of the lab time slot. We had to make sure we clearly communicated to each other to ensure we were meeting deadlines and that everyone attended any extra sessions that we had … Since each member would work on a different aspect of the project during each session, we would have a quick debrief at the end of these sessions. This was when each member talked about what they had done that day. This allowed each member to understand every aspect of the project even if they weren't directly involved in the building of a specific aspect.*

Team R report that:

> *The importance of adequate communication was evident during the project. Soft skills such as communication are invaluable in any industry and this project provided students with the opportunity to develop these skills in various ways, such as the presentation, or just simply communicating as a team in general.*

Not everything was 'rosy', however, in this team:

> *There were some issues with communication and as a result it was difficult to allow the team to perform to its utmost potential, but regardless, the significance of communication and teamwork were evident throughout the project.*

4.2 Consolidation of Learning for Targeted Outcomes

Team G say in their report,

> *The mini project was a great introduction to microcontrollers and interfacing with various sensors and actuators. Exposure to electronics in a practical way was informative and useful when the results are able to be seen firsthand, giving a sense of familiarity. Having gained this experience, the team feels confident heading into the next semester: Mobile Robotics*.

Team N conclude in their report that,

> *Overall, the team greatly benefitted from this project. Each team member acquired new knowledge and skills throughout the entire development of the project.*

Team J give good descriptions of the problems that they encountered and how they debugged them. In the report, they say:

> *Not only did these problems help us to better understand the equipment and components, but [they] also taught us problem-solving, critical thinking and how to work together as a team.*

Another student from Team J outlines her experience as follows:

> *I also wired up the H-Bridge … [which] gave me the knowledge and information … that I needed to fully understand them, why we use them and how to use them. This also gave me experience in reading data sheets and circuit diagrams as I had to use them both to figure out which wire needed to be connected to where.*

The same student mentions about learning to use a multimeter:

> *Doing this enhanced my knowledge on how to use a multimeter correctly − which may seem like a trivial skill, however, this is a piece of equipment we will always need to use and need to know how to use properly.*

This reminds the lecturer that no matter how mundane or trivial a fact or skill seems to us, if a student doesn't know it, then it's an impediment to their further learning and thus of crucial importance that they acquire it. A student from Team Q shows that notwithstanding the relatively unstructured and independent nature of the mini-project, even the straightforward engineering objectives of the module were achieved for her:

> *This project deepened my knowledge of basic electronic components and circuitry … My participation in this project proved extremely beneficial towards my individual knowledge of the use and applications of microcontrollers … Overall, the challenge was difficult at times but thoroughly engaging and eye-opening to the applications of microcontrollers and circuits working simultaneously.*

4.3 Learning Problem-Solving Skills

The effective practice of problem-solving is notoriously difficult to teach well. However, if we can put our students in the way of having 'light bulb moments', then it seems that we are facilitating the right type of learning. A Team J student says:

> *In the final weeks we kept running into issues and we could not figure out what the problem was. After reading through the lecture notes again and through vigorous problem solving, I realised that the cause to our problem was likely due to noise caused by ground loops … I have now learned a valuable lesson: to always double check with the oscilloscope for noise or interference in the circuit when the circuit suddenly stops working for what seems like no reason.*

A female student also from Team Q outlined her revelation:

> *The main point of learning throughout this project although challenging, was troubleshooting! At the time of the problems I felt them unfortunate but once solving these issues I knew it was quite the opposite. From rewiring the entire bread board to rewriting the code, although these activities were troublesome, it was where I learned the most. I thoroughly enjoyed this project, and look forward to using microcontrollers again in the future.*

Comments like these illustrate the learning benefits of innovating in pedagogy in order to positively engage students. Team R report that

> *… the ability to problem-solve and debug errors is a crucial skill to have as an engineer, and this project greatly enhanced that ability. The available equipment (oscilloscopes and multimeters) was especially useful for this.*

4.4 Communication through the Medium of Video

Team M programmed the car to do the "Cha Cha Cha", shown to impressive effect in their video, with a really excellent soundtrack that reflected the mood of different stages of development. They talked in the report about "keeping the video entertaining" and "motivating people to take up engineering", which certainly constitute aspects outside the scope of the original module descriptor.

The members of Team G mention, in relation to their excellently produced, well-edited and very entertaining video that its style was based on

> *… an 'old-school' over the-top infomercial, using the iconic black and white filter to highlight negative elements and an upbeat tune.*

This choice of design indicates an expression of motivation and talent that is far outside anything normally envisaged for an electromechanical systems module. The video for Team L was quite consciously directed and edited, and they used a voice actor from outside the team working to the team's script to give it a strong storyline, which was very effective.

4.5 Communication through the Medium of a Technical Report

Team H mentioned that they divided up the writing of the report according to what each team member focused on during the build, and after combining all the sections they read through each other's sections to ensure no grammatical mistakes were made and all statements were factual. It was clear from other reports that this wasn't universally the case. Technically, and in terms of the care taken with the writing and presentation, the report from Team C was one of the best reports that I received. At the other extreme, Team K received quite negative feedback for the language and structure of the report, which had a level of informality entirely unsuitable for a technical report. These two extremes remind us that where a learning outcome activity is challenge-based and less structured, the learning can be quite inconsistent across teams. Where there are very clear standards expected, such as for a written technical report, we need to provide explicit guidance, templates, and minimum standards to be achieved universally.

4.6 Students' own Reflection on their Learning

Team N referenced Bloom's Taxonomy and understood that one aim of the project was to move to the 'apply' and 'analyze' stages of learning and be able to understand the material at a deeper level than before. They understood the need to recognize and learn from mistakes, to exploit knowledge gained in earlier modules, and to recognize and work around their shortcomings. Team J recalled the stated Learning Outcomes of the mini-project, and claimed to have achieved these. They also mentioned that it was

> *important to note that other valuable learning outcomes … not categorically outlined at the beginning of the project, were achieved.*

Then, after listing the levels of Bloom's taxonomy, they pointed out that

> *this project helped the students to remember and understand (level 2: Understanding) what they learned [in lectures], apply this knowledge to the project (level 3: Application), analyse any errors that occurred (level 4: Analysis), evaluate how best to fix these errors (level 5: Evaluation) and finally to create the wheeled robot (level 6: Creation).*

This may not be a perfect mapping, but it is interesting how giving students tools to understand the nature of learning, as well as appropriate opportunities, can be strongly enabling. Team J also pointed to 'soft' skills gained by the team members throughout the project, and they explicitly call out interpersonal skills, teamwork, time management, problem solving, creative thinking, critical thinking and decision-making.

4.7 Team Management and Dysfunctional Teams

Team F describe in their report that they

> *decided on who will manage the team and ensure all the deadlines for the various tasks are complete. This meant that the project leader has to conduct five processes to successfully manage the project which are initiating, planning, executing, monitoring and closing, the main objectives were to ensure that the team achieves each and every task effectively.*

From information received after the fact we believe that this team had an issue with one member dominating the others. It is not hard to imagine which student may have written the above text. A later paragraph talks about how [one student] "was lead in the role of the robot's hardware and software", and the other students "assisted" that student, while they were responsible for non-technical aspects such as the presentation and the video. In the conclusion, reported as written by one of the non-dominant students, we read that the project "… enhanced my learning in interfacing electromechanical systems, and it turned out to be a project worth doing", which is some distance from the 'glowing' reports of students in other teams of their learning experience. There is an opportunity to 'repair' the lack of learning opportunities for students in this team in the subsequent Mobile Robotics module, but more importantly, this occurrence points to the need to provide students with the skills necessary to manage such situations as they arise.

Team N were very clear in the report when one team member didn't contribute, and they didn't try to cover up the fact out of a misplaced sense of loyalty. One of the students in Team J reports that:

> *I helped my teammates practice for the presentation by giving constructive feedback about their body language and the importance of projection of their voices and organising a choreography so that each member who spoke would be standing in the center of the room to command attention and the following person was ready to take over, with the last person controlling the slides.*

Interestingly, it was also clear from the Team J report that this team had a member who contributed significantly less than the others. This was not explicitly stated, but there is little doubt that the students knew what they were implicitly communicating.

For Team K,

> *Teamwork was a core soft skill learned throughout this project. Working in a team can often be quite challenging and difficult due to conflicting ideas or someone not pulling their weight. The team learned that good project management skills are … vital in making sure that everyone in the team is on the same page and that everyone knows what needs to be done.*

5 Conclusions

It has been a very useful exercise to reflect on the results of the learning innovations introduced to this module. These were significantly inspired by Mark Prensky's presentation, but also derive from a project-based and student-centered learning ethos in our School that has existed for at least the last two decades. We have learned that given the right motivations, challenges, freedoms and supports, that our students can achieve in ways that we could never have imagined, and that different students will achieve in ways that are particular to them. If we needed to be reminded of the Confucian truism: "I do and I understand", we can see it reflected here in the reports of many of these teams. We can see the benefits of giving them the tools to enable introspection, to enable students themselves to give names to the types and natures of their learning experiences. We can see the unintended lessons or the hidden lessons that contribute to the broader education, maturity and professionalization of the students.

It is not all positive, however. While dysfunction within teams can provide an opportunity for learning, without appropriate preparation or structures or framework guidelines for teamwork, it can also be a significant impediment to effective learning.

Critical thinking may have been developed, but these students have only just set out on this journey. They have much more to learn in this area. While problems encountered and, in many cases, overcome have encouraged the students to become more careful, systematic, orderly, and patient, these qualities are still not universal. The logical, rational, rigorous thinking needed to be an effective debugger or problem-solver still needs more structured opportunities, more experiences and more or more appropriate targeted interventions to develop this skill and expertise to its full extent. The production of videos may allow creative talents to emerge and be encouraged, but creativity alone does not help to improve the standard of technical writing. This will need more specific guidelines and more explicit standards to be set so that students can learn in a consistent way what is required to be effective and professional in this area.

We feel that the lessons on hidden learning that we have uncovered will benefit our teaching, our students' learning and the wider academic community into the future.

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