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Approximating Professional Practice in a First-Year Engineering Curriculum: The Wind Turbine Maker Project

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Abstract

In 2020, the Energy Engineering programme team at University College Cork undertook a redesign of the introductory first-year module in Energy Engineering. The aim was to introduce a more experientially-based learning experience and to allow first-year students greater opportunity to develop and demonstrate performance-based understanding. The key material change to the module was to incorporate design and group work in the first year of the programme. In the Wind Turbine Maker Challenge, groups of 4-5 students were tasked with designing and building a working wind turbine. Students were provided with kits comprising some basic elements of turbines including small generators and gearboxes and simple, flat blades. However, the focus of the exercise was on original design, particularly of the aerodynamic rotor components of the turbines. The participants had to source their own materials for the wind turbine rotors, and were encouraged to use recovered or recycled materials. Students were also asked to consider ethical aspects of wind energy generation. In developing this approach, the conceptualisation of teaching as setting up and facilitating students' performance was to the forefront. The formal classroom instruction was limited to only the core knowledge required to enable students to begin to consider suitable materials, geometries for their turbine designs through hands-on experimentation.

Survey feedback from students showed that they had strongly focussed on the environmental and sustainability aspects of the exercise. Students were asked what they thought the goal of the exercise was. Students' reported understandings of the main goal varied widely, for example "Learning how wind turbines work" and "Working as a team towards a common goal". However, all of the students' reported goals were compatible with the module's learning outcomes.

1 Introduction

When designing any new course it is useful to refer to the four dimensions of understanding (McCarthy, 2008a). In the case of introductory first-year Energy Engineering, the dimensions can be understood as follows:

- The knowledge base: here the relevant fundamental concepts in the discipline are the properties of materials, and the mechanisms of energy conversion
- The methods of disciplined reasoning and inquiry: in this case, the methods are discovery through supported experimentation and measurement
- The purposes of the discipline: this was strongly linked to ethical aspects – creating a renewable energy device has a benefit to society through mitigation of climate change and air pollution
- The forms of expressing understanding: energy engineers may express understanding through realisation of designs for systems or devices, or through oral and written communications

Adopting a Teaching for Understanding (TfU) / Universal Design for Learning (UDL) approach supports the development of the Engineering "Habits of Mind" (EHoM) described by (Lucas and Hanson, 2016), namely:

"systems-thinking"	seeing whole, complex systems and recognising linkages
"problem-finding"	examining needs and existing approaches and contexts
"visualising"	transitioning from abstract to concrete, trialling design solutions
"improving"	experimenting, designing, conjecturing; prototyping
"adapting"	testing, re-thinking, iterative design improvement, changing
"creative problem-solving"	applying techniques from other domains, critiquing

A design goal for new Engineering modules or sub-modules is to draw on as many as possible of the multiple intelligences and entry points to learning (Gardner, 1999; K, Davis, Christodoulou, Seider, & Gardner, 2011). These can be linked to the three principles of Universal Design for Learning (Rose and Gravel, 2010):

1. Multiple modes of engagement (via learners' different intelligences)
2. Teachers must represent knowledge in different ways, and not only through traditional lectures. For example, videos or objects may be used.
3. Multiple means of action or expression, feeding into the Performance of teaching and learning, broadening the focus beyond traditional exam-based assessment.

Engineering students attend lectures and laboratories, write lab reports and assignments, and take end-of-term exams. There are particular expectations as to what constitutes a lecture or a laboratory. These form some of the "signature pedagogies" of engineering education (Shulman, 2005). Identification of the signature pedagogies, in particular the Engineering lab, allows their didactic conventions to be studied, and leads to consideration of how to make them accessible to a broader cohort of students, for example, by using multiple entry points, and engaging multiple intelligences. The performative element of learning for understanding is emphasised by McCarthy (2008b), who draws a contrast between an approach based on students' application of their intelligence, or what might be termed "active understanding" where students are "encouraged to work things out for themselves", and the representational approach where knowledge or facts are transmitted from teachers to students. Ethical issues are to the fore in contemporary engineering education. Howard Gardner advanced his definition of what constitutes professional work that is good: it must be "excellent in technical quality", be "carried out in an ethical manner" and be "engaging and personally meaningful" (Gardner, 2008).

1 Background to the Wind Turbine Maker Exercise

Introduction to Energy Engineering & Engineering Ethics is an introductory module taken by all first year Engineering students at University College Cork. The previous design of the module was based on a traditional lecture format, with written essay assignments.[1] The previous learning outcomes of the module incorporated many aspects of the "GoodWork" philosophy (Gardner, 2008) and embrace the complexity of modern engineering practice (Shepphard *et al.*, 2008) while also incorporating the ethical requirements of the profession and building students' teamwork skills. However, Shepphard *et al*. (2008) point out a deficiency in engineering education, namely that *"the lab is a missed opportunity: it can be more effectively used in the curriculum to support integration and synthesis of knowledge, development of persistence, skills in formulating and solving problems, and skills of collaboration. Design projects offer opportunities to approximate professional practice, with its concerns for social implications; integrate*

[1] Previous module descriptor for NE1001:
https://www.ucc.ie/admin/registrar/modules/?archive=y&archive_year=2018/2019&mod=NE1001

and synthesize knowledge; and develop skills of persistence, creativity, and teamwork. However, these opportunities are typically provided ***late*** *in the undergraduate program"* [authors' emphasis].

2 Design of Exercise and Assessment

The module learning outcomes were rewritten to incorporate a new sub-module "Wind Turbine Maker", to provide a more experientially-based learning experience. The following new learning outcomes were added:

- Describe energy conversion in a renewable energy device.
- Use basic principles of operation to design an energy conversion subsystem.
- Carry out a Risk Assessment.

Sheppard's (2008) recommendation for the use of labs to "support integration and synthesis of knowledge, development of persistence, skills in formulating and solving problems, and skills of collaboration" was applied in the creation of the Wind Turbine Maker. The use of problem-based learning approaches has been shown to be beneficial in developing important skills such as an ability to work within a team, understanding of how to approach a design process and self-directed learning (Beagon et al., 2019). This paper places emphasis on the importance of design projects, for professional preparation. The key material change to the module was to incorporate *design* and *group work*.

In the Wind Turbine Maker Challenge, groups of 4-5 students were tasked with designing and building a working wind turbine. Students were provided with kits comprising some basic elements of turbines including small generators and gearboxes and simple, flat blades. However, the focus of the exercise was on original design, particularly of the aerodynamic rotor components of the turbines. The participants had to source their own materials for the wind turbine rotors, and were encouraged to use recovered or recycled materials. The Challenge had a strong emphasis on independent learning, as students were encouraged and facilitated to experiment with new materials and configurations. The exercise comprised the following elements:

- An Introductory Lecture on Wind Turbines & Aerodynamics including a Classroom Assessment Technique test (Angelo and Cross, 1993).
- An Introduction to Risk Assessment & Mini Assessment
- Ethics of Wind Energy Mini Seminar
- Three 2-hour practical Wind Turbine Maker Sessions focussing on:
    - Basic design, materials selection, group organisation
    - Technical feedback, initial testing, design refinement
    - Final design iteration, performance and robustness testing
- A public Grand Finale event organised at a large hall including high-speed tests using high-power fans on test benches, with electrical power output measurement meters for turbines, and expert judging on three criteria: technical achievement, use of sustainable materials and aesthetic design.

A deliberate decision was made to limit the amount of classroom instruction associated with the Wind Turbine Maker, and instead to allow students to explore the science and technology of energy conversion through hands-on design and experimentation. In developing this approach, the teaching was focussed on preparing students and facilitating their performance. The formal classroom instruction was limited to only the core knowledge required to enable students to begin to consider suitable materials, geometries for their turbine designs. This new exercise opened up a much wider set of Entry Points to Learning than the previous assessments of the module. The following entry points were explicitly featured:

- Narrational: via the written report
- Experiential: through the “doing”, physically making and testing the turbine
- Logical/Quantitative: The final performance of the turbine was quantitatively measured in the laboratory and in the Grand Finale event.
- Aesthetic: This was reinforced through the focus on visual design and appearance in assessment
- Participatory / Interpersonal: the Maker challenge was conceived as a group exercise.
- Foundational/Existential: only basic instruction on aerodynamics was supplied, instead students had to build prototypes and measure the results

Students were introduced to some ethical issues surrounding the siting of wind energy developments (i.e. concerns of people living near them such as noise, ecological, visual or health impacts), which they were asked to consider and report on. The requirement to use recovered and/or sustainable materials in the wind turbines also encouraged students to think of wastes as resources, and fostered circular economy thinking. The students had to produce a working wind turbine of their own design and incorporating recovered or recycled materials and they were incentivised by the offer of three group prizes for:

- Best overall design – this was based mainly on the measured technical performance of the turbine (i.e. maximum power production under controlled conditions)
- Best use of sustainable materials – students were briefed and encouraged to use recovered or ‘upcycled’ materials to design the wind turbine rotors.
- Best visual design.

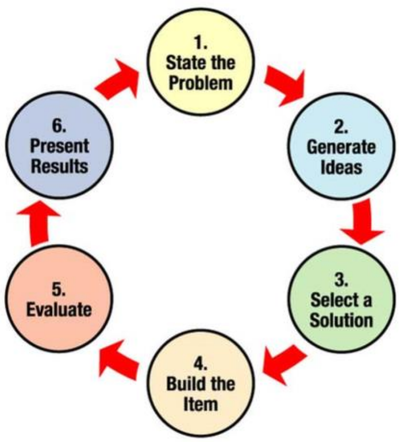

Figure 1. NASA Engineering Design Process (reproduced from (Rahman, 2014))

By incorporating these three strands into the competition, and the assessment, students were encouraged to approach the design assignment from different perspectives. This had the added benefit of leading students to consider ethical aspects of engineering design such as sustainability and environmental and social impacts, which would not normally be considered in an introductory first-year assignment.

The philosophy underlying the Wind Turbine Maker sub-module design was to hand over the freedom to students to “design, test, fail, improve, test again” and to facilitate them to achieve this, rather than to instruct them according to a set plan. This approach is grounded in practice, as it reflects the NASA Engineering Design Process (Figure 1). The Wind Turbine Maker Sessions were supported by student assistant demonstrators. The demonstrators and staff were available to students in the sessions to make suggestions, offer advice and constructive criticism on aspects of the designs. The demonstrators also led the testing of the designs using portable fans to generate airflow.

Figure 2. (a) Student turbine under test at Grand Finale event; (b) Test benches with fans at the Grand Finalé event

The different modes of assessments of the Wind Turbine Maker allowed for the three principles of UDL to be invoked. Students were tasked with producing an actual artefact, i.e. the wind turbine; a written report summarising their design process, and any challenges encountered and steps taken to overcome them; and a short video submission describing the turbine. In addition, students had to interact with the panel of judges and the testers on the Grand Finale day. The design of the assessment was such that technical and non-technical aspects were considered. This allowed multiple points of entry to the students, and allowed members of the groups with different preferred learning styles to contribute equally to the group design objective.

3 Results and Discussion

In Figure 3 some examples of the finished wind turbine designs produced by student groups are shown. A wide diversity of designs can be seen, in terms of the number of blades, the orientation of blades (horizontally or vertically oriented), and the shapes of the blades. Different approaches to stabilising the turbine are also apparent, and a wide variety of materials have been used. The freedom given to students to experiment resulted in this wide variety of finished artefacts. In addition, the students were only presented with the bare minimum information on wind turbine rotor designs prior to undertaking the Maker exercise, which meant that all the design choices embodied in the examples of Figure 3 had to be made through reading, group discussions, engagement with demonstrators, trial and error, and refinement.

The students were interviewed[2], as part of a short video documenting the event which provided some insights into their experiences of the exercise. Different points of entry to learning were evident, such as; enjoyment of the designing/building of the turbine, enthusiasm for a 'hands-on' practical exercise, or focus on the aesthetic appeal of their turbine designs. An indicative excerpt from a written student report show evidence of the student's learning from the exercise.

"There are a plethora of airfoil shapes that could have been used for the blades. The airfoil design had to maximise lift and minimise drag. This task was achieved using a cambered airfoil. Cambered airfoils are non-symmetrical; this means that the camber line and the chord line are un-aligned. Cambered airfoils reduce the effect of drag, generate and maintain lift with greater ease making cambered airfoil an

[2] Energy Engineering Wind Turbine Maker Event, February 7^{th} 2020
https://www.youtube.com/watch?v=DY9ULCgdN2k&ab_channel=MaREI

ideal shape for the blade. This shape was produced by cutting open soft drink cans, as they are made from aluminium which is extremely malleable and one hundred per cent recyclable and wrapped around the rotor plate which had three lollipop sticks were taped onto it."

This excerpt shows a nuanced understanding of airfoil aerodynamics, far beyond what was outlined in the classroom. The student's choice of aluminium soft drink cans is informed by a good basic understanding of the material's relevant properties (malleability and good strength-to-weight ratio), and finally the reinforcement with lollipop sticks is evidence of an emergent understanding of structural mechanics and composite materials, again, none of which were taught in the classroom session.

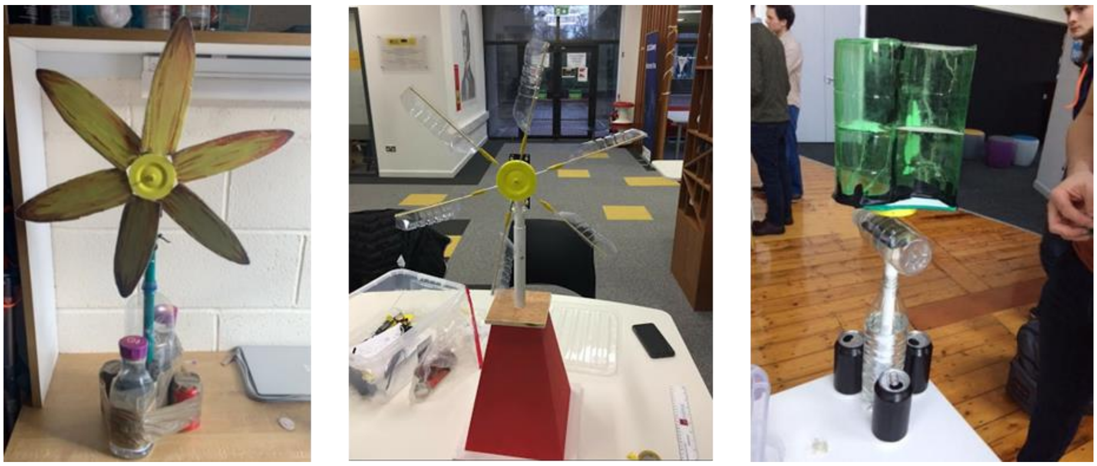

Figure 3. Examples of Student Wind Turbine Maker Designs

Students were asked to complete a voluntary and anonymous online survey after the completion of the Wind Turbine Maker exercise[3]. Of the 130 students in the cohort, 33 responded. The following questions were asked:

1. What do you think was the main learning goal of the Wind Turbine Maker exercise?
2. In your opinion, was the goal successfully achieved?
3. Which of the following subjects do you think the exercise related to?
   Options: Electrical / Electronic Engineering; Structural/ Civil Engineering; Properties of Materials; Mechanical Engineering; Environmental Science/ Sustainability; Computing / ICT; Maths; Energy Conversion; Ethics; Other (specify)
4. How much did the exercise add to your understanding of the topics?
5. How much did the final assessment allow you to demonstrate your understanding of these topics?
6. How would you improve the Wind Turbine Maker exercise?

The design of the feedback questionnaire was open-ended in order to avoid leading questions and to solicit students' genuine experiences of teaching and learning during the Wind Turbine Maker. There was a very diverse array of responses to Question 1. Students' own understandings of the main goal were different, for example "Learning how wind turbines work" and "Working as a team towards a common goal". However, all the declared goals were compatible with the module's learning outcomes. Despite the wide range of responses to Question 1, there was good agreement that the goal was actually achieved. The

[3] NE1001 Wind Turbine Maker Feedback, Google Forms, https://docs.google.com/forms/d/e/1FAIpQLSfDX89Hc-K5XwO4fZ2htA9JKDgL0M7PGj2K1uSDUildHtOUQA/viewform?usp=sf_link

mean score on the range 1-5 (where 1=not at all achieved and 5=strongly achieved) was 3.88, with a standard deviation of 0.78.

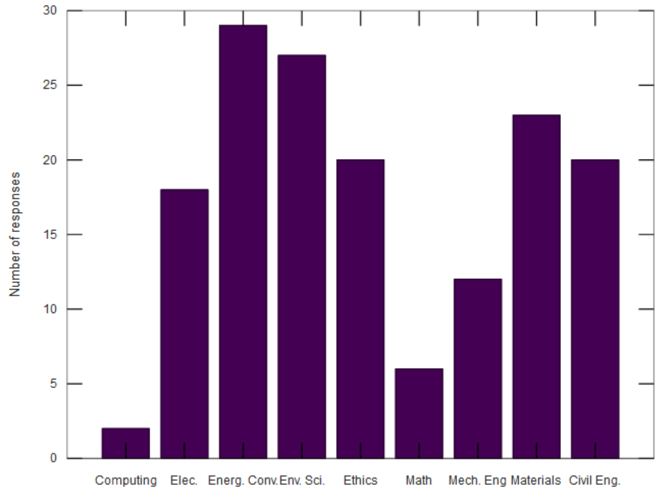

Figure 4. Student responses to question 3 in survey (multiple selections were allowed).

Several students responded that three maker sessions was not sufficient to fully develop and test their designs. The students would have appreciated more time to experiment and develop their understanding, but the exercise was heavily constrained by timetable factors as part of a busy first-year engineering semester. The responses to Question 3 were broadly in line with the authors' expectations, and with the module learning outcomes (Figure 4). The most-selected option was 'Energy Conversion' which was the main goal for student understanding in the Maker exercise, and aligned with the revised module learning outcomes. Students strongly focussed on the environmental and sustainability aspects in their responses. Ethics was weighted slightly less in the responses, and the individual Engineering disciplines such as Civil, Electrical, Mechanical Engineering received lower weights.

4 Conclusions

One of the main insights gained from the Enactment phase of the Wind Turbine Maker, was the level of student engagement and enthusiasm for the project. The sustainability aspect of the Wind Turbine Maker was taken to heart by the students. The students' suggestions for improvements to the exercise contain several useful points which could enhance the overall understanding of the topic. Based on the feedback from students and the insights gained during the exercise, the authors propose making adjustments to the learning outcomes in order to reflect a more student-centred approach and to help foster greater student understanding in the assessments:

- Describe energy conversion in a renewable energy device.
- Demonstrate team working skills
- Use basic principles of operation to design, test and refine an energy conversion subsystem.
- Assess the risks associated with construction and operation of energy conversion systems, and implement control measures.

The short duration of the exercise meant that it was difficult to gauge the long-term development of students' understanding. However it is held that the Wind Turbine Maker exercise allowed students to progress along the pathway to Understanding, not through the acquisition of subsidiary knowledge, which

Bass cautions against (Bass, 1999), but rather, through exploring, testing, failing, improving, failing again, and succeeding. In this way, it is hoped that the Wind Turbine Maker has played a small part in the formation of Engineering Habits of Mind for this cohort of students.

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