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Engineering Education through Problem Based Learning: a case study of teaching Mechanical Engineering Design in TU Dublin

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Engineering Education through Problem Based Learning: a case study of teaching Mechanical Engineering Design in TU Dublin

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ABSTRACT

Undergraduate students, having learnt to quantify the performance of specific elements of engineering objects, often find it difficult to integrate these elements into quite basic design concepts. Employers expect these engineering graduates to be able to do a great deal more than solve the technical problems taught in engineering school once they enter the workforce. To help students meet this expectation by developing real-world engineering skills as part of their engineering education, the Mechanical Engineering Discipline in Technological University Dublin (TU Dublin) introduced Problem Based Learning (PBL) module for Third Year Mechanical Engineering students in 2005. This module was well respected and student feedback, both during their time in TU Dublin and after graduation once they had experience "in the field" was overwhelmingly positive.

A recent review of this teaching approach highlighted deficiencies not envisaged when the initial PBL module was conceived. Examples include students' over-confidence in the ability of their designs to solve the assigned problems and a lack of awareness of how parts designed can actually be made and assembled to form completed systems. Inspired by the Japanese concept of monozukuri significant changes were implemented in 2017. TU Dublin's Mechanical Engineering students now design, build, and test real machines within the constraints of a strict budget and time limit. Since these changes were initiated the problem assigned to students was to construct robots to perform specific functions.

This article, based upon previous work by Delaney and Nagle (2019) details the theory behind the changes and reports on specifics of the module structure. It concludes that students are overwhelmingly positive in their evaluation of the changes implemented and, notwithstanding the increased course workload, they believe they are better prepared for their future professional careers.

Keywords: Engineering education, engineering practice, problem based learning, robots

1. INTRODUCTION

Recent survey results reported by Engineers Ireland has highlighted that a shortage of experienced and appropriately skilled engineers is potentially a major barrier to growth for two thirds of engineering employers and leaders in Ireland. Marguerite Sayers, President of Engineers Ireland, has written that "it is incumbent on all of us, our government and the education system to work together and collectively better develop the pipeline of engineers that is so badly needed to drive our national infrastructure development and sustainability goals".

Both society and organisations employing the engineering graduates exiting this "pipeline" of engineering courses expect that graduates are ready to contribute to the employer's enterprise immediately after being hired. Graduates must be able to do much more than simply solve engineering problems taught during their formal education and may have limited time to develop certain skills "on the job". To be effective engineers upon graduation, these engineering graduates must, as part of their formal studies, connect their experiences in university classrooms with practice in the field.

In pursuit of this goal Technological University Dublin (TU Dublin) strives to educate students who can pair engineering theory with high-level technical awareness and understanding of how to manufacture and test devices, essentially a form of "real world engineering" professional practice.

This article presents a case study of how TU Dublin has addressed the question of how to teach students real world engineering skills relating to design and manufacturing. The objective is to help engineering graduates be more effectively prepared for the challenges of professional engineering practice once they enter the workforce after graduation.

2. REPRESENTATIONS, DECOMPOSITION AND APPROXIMATIONS OF PRACTICE

Shulman stated that those engaged in professions such as engineering, medicine, teaching, nursing, law and the clergy should provide worthwhile service in the pursuit of important human and social ends; possess fundamental knowledge and skills (especially an academic knowledge base and research); develop the capacity to engage in complex forms of professional practice; make judgments under conditions of uncertainty; learn from experience; and create and participate in a responsible and effective professional community (1998).

In developing a framework for thinking about the teaching of practice in the context of a university educators must strive to develop these key attributes in their students. In this respect Grossmann et al have identified three key concepts for understanding pedagogies of practice in professional education: representations, decomposition, and approximations of practice (2008) as represented in Figure 1.

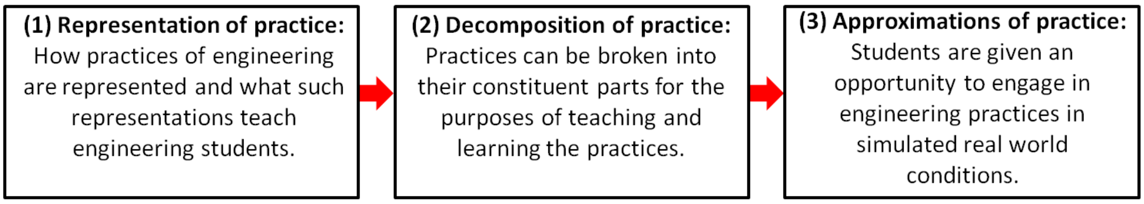

Figure 1: Representation, Decomposition and Approximations of practice

Representations of practice relate to how practices of engineering are represented and what such representations teach engineering students. In the case of TU Dublin students are taught at an early stage that engineering is much more than just a technical discipline; that it is, as described by Trevelyan, simultaneously a social discipline (2009). Through structured self-study projects, guest lectures, career development workshops and professional development in addition to examples and case studies introduced by Faculty students are taught that the technical and social aspects of engineering practice are inextricably intertwined. This important realization encourages students to try and learn more than just solving "technical" problems.

Decomposition of practice relates to how practices can be broken into their constituent parts for the purposes of teaching and learning the practices. In the case of engineering relevant elements of engineering practice are taught independently, often as separate modules or subjects. Mechanical engineering students typically study a range of specialist modules including design, materials, Computer Aided Design (CAD), stress analysis, electronics, computer programming and report writing. Decomposition of practice in relation to the practice of design includes the application of sub-skills such as identifying customer requirements, identifying and complying with relevant legislation, reviewing existing and competitor products, writing a clear and concise product design specification, developing suitable concepts, selecting the optimal concept, prototyping and testing this concept together with optimizing this concept for mass production

Approximations of practice relate to simulated real world conditions where students are given the opportunity to engage in engineering practices in a similar way to how a professional engineer would work, for example as part of a design engineering team but with some scaffolding so that they do not have the risk of applying the practice in an actual setting, thus the term “approximation”.

As described in this article TU Dublin strives to have engineering students approximate practices as part of an Engineering Design module in the third year of a four-year mechanical engineering degree program which is based in the Bolton Street campus.

3. PREVIOUS EFFORTS AT PROVIDING APPROXIMATIONS OF PRACTICE

Mechanical Engineering students on this Mechanical Engineering Program have experienced PBL and benefitted from the opportunity to develop project management, presentation and negotiation skills, in addition to an increased awareness of component sourcing and the multidisciplinary nature of Mechanical Engineering since 2005 (Delaney and Kelleher, 2008). The actual problem assigned to students taking this module at this time was to "Design an automatic assembly machine to assemble a product of your choice".

A recent module review suggested that students were over-confident in the ability of their designs to solve the assigned problems and insufficiently aware of how components designed can actually be realised through manufacturing, refined through a systematic and logical process, and how they would actually function once completed. This review was prompted by comments from external examiners, industry panel advisors and staff delivering the program. They identified capabilities, such as practical problem solving, sourcing, specifying and component sourcing, that they believe are most significant to success in the engineering workplace. In addition the proliferation of digital repositories blurred the lines between what students have created themselves and what they have integrated into their designs from cloud-based collaboration environments such as GrabCAD (2019).

These considerations have inspired significant changes to this Design Projects module for third year Mechanical Engineering students.

4. REVISED MODULE STRUCTURE

Changes to the module have been inspired by the Japanese concept of "monozukuri". The Japanese term “monozukuri” is a compound word comprising “mono” which means “products,” (literally, “thing”) and “zukuri” which means “process of making or creation” (Education in Japan Community Blog, n.d.). The concept also includes striving to constantly improve a production system and process, important concepts for engineering students to grasp.

Students take the revised module, assigned 5 ECTS credits, over the course of an academic year during which they have 26 weekly sessions scheduled with the project facilitators. They work in groups of five or six and are encouraged to self-select which group they will work with. Each group is assigned the task of designing, fabricating and sourcing all components for, assembling, and testing a robotic machine within a budget of €100. This budget relates only to components which students opt to purchase and does not include any inputs such as stock materials, access to any workshop/laboratory equipment and/or computing facilities available though the University.

Students from a variety of backgrounds with different prior learning can join the third year of this program so the first project session each year incorporates team building activities. Through these activities students can get to know each other and reflect on their behavior with a view to making more informed decisions on what might work best for future projects; in doing so they learn how to improve their effectiveness as engineers.

Previous research has shown that students can find it difficult to plan and integrate their design activities as part of a group. During the initial project sessions advice is given to students on how to implement appropriate project management techniques and how to document and record the decisions made by the team. Some students appear reluctant to make decisions; they appear afraid of being “incorrect”. This probably stems from an expectation that there is a right or a wrong answer for everything. Design problems posed have many solutions and students are encouraged to refine their concept(s) and justify their chosen solution. Students must learn to justify their decisions and record these justifications since it is an important skill for engineers.

To ensure that students will become familiar with a range of manufacturing processes each group's design must include components made using additive manufacturing, laser cutting, sheet metal forming, milling and turning processes. Appropriate electromechanical components and controllers must be included as part of the overall design. Typically students have sourced, programmed and optimised Arduino controllers for this purpose (2019).

The project assigned for 2017-18 was a machine to dispense ten rectangular blocks vertically in a straight line with variable pitch. An example of one group's interim CAD model and the final robot built by that student group in 2017-18 is presented in Figure 2.

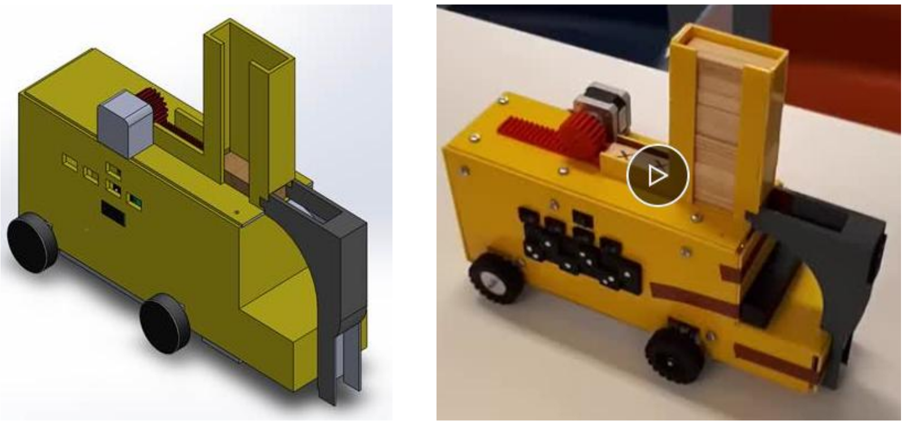

Figure 2: An example of the interim CAD model and final block dispensing robot built by students in 2017-18

The 2018-19 machine goal was to design and build a scaled semi-autonomous warehouse picker, examples of which are shown in Figure 3. The machine had to travel a predetermined path, sense where it was and pick up a load from an unknown location along this path and then deliver it to a target location close to the end of the path. It is noted that this was not a line-following robot and students were only made aware of the final path to be followed days before the final trials were to take place.

Students in their groups meet the project facilitators for an average of 2.5 hours per week for the academic year. Additional support to help each team optimise their design for manufacture and actually realise their final design is available from the technicians in charge of the workshops and laboratories available to students during the year.

Figure 3: Examples of CAD models and some of the semi-autonomous warehouse picker robots built by students in 2018-19

5. EVALUATING THE REVISED MODULE STRUCTURE

The learning outcomes prescribed for this module, which can be mapped to the program outcomes specified by Engineers Ireland for students undertaking an accredited mechanical engineering program, state that the learner will be able to:

1. Collaborate with peers to create technical designs.
2. Independently investigate a technical area.
3. Produce detailed engineering designs in specified area(s).
4. Produce safe designs following appropriate standards.
5. Select appropriate engineering components and integrate them into specific solutions.

6. Produce dimensioned drawings and perform a tolerance analysis.
7. Produce a report on an integrated design.
8. Present a report to a technical peer group.
9. Perform a cost and sustainability analysis.
10. Manufacture the device according to the finalised, approved drawings.
11. Test the device to ensure that it meets the functionality requirements laid down by the client.

To successfully achieve these learning outcomes each group must submit a device completed to specification, present at milestone reviews and submit a summary poster and report documenting all work completed. This technical report must include an overall project costing, technical drawings, consideration of safety standards and all supporting calculations and justification of all decisions taken in addition to minutes recording the happenings at each group meeting.

Assessment for each deliverable is performed under simulated real world conditions so that students experience an approximation of engineering practice. A series of inspections are made of each robot before the final tests can be performed. All faculty, friends and other students are invited to attend the final exhibition session where groups demonstrate that their robots can most closely meet the requirements.

To evaluate the module all students are encouraged to participate in surveys each year on both a module and a program basis. These surveys are anonymous and students can complete the survey using an online system and/or a paper-based system which they can complete in-class. The survey questionnaire has remained constant over several years and students have the opportunity to quantitatively rate their experience and also provide a commentary or feedback to add additional details and/or propose changes to each module.

Based on the surveys conducted, the students' responses are overwhelmingly positive:

- Almost 65% of the students highlighted the heavy workload involved with this module.
- More than 75% of the students expressed their enjoyment of the course despite the perceived heavy workload involved.
- 85% of students commented that they felt the course prepared them well for final year projects, particularly in terms of project management and presentation skills.
- One student from 2017-18 remarked that "Needless to say, this project was my highlight of 3rd year."

In separate communication several students have highlighted that this was the first module where they had to really consider health and safety in terms of using machines and conduct a risk analysis to ensure that their designs will not harm or injure themselves or any other users.

Students are typically proud of their achievements in completing these robots and informal feedback from employers interviewing students for internships has been very positive. A more extensive survey of graduates and employers will be performed once the students who have taken this module are working in industry.

Several subtle changes to the structure and organization of the module have been implemented as a result of student feedback.

The 2019-20 project, which began in September 2019, is to design a scaled semi-autonomous robotic fire tender. The approach being taken in 2019-20 addresses a call for cross-discipline interaction across programs and Schools in TU Dublin. Electrical Engineering students, taking a different project-based learning module being delivered by Dr. Gavin Duffy, from the School of Electrical and Electronic Engineering, are assigned to work as "external suppliers" to design and supply particular sensing elements which will then be integrated into the overall design. Our experience of this approach will be described in future publications. This collaboration serves to highlight the flexibility that comes with project-based learning as projects can be easily adjusted to cover topical issues, facilitate interdisciplinary collaboration or other needs as they arise. To foster the cross-discipline interaction in this case, no change to the structure or learning outcomes of either the mechanical or electrical engineering modules was required, staff simply re-wrote the project description for each group and collaboration was now embedded into the module delivery.

6. CONCLUDING REMARKS

These projects are undoubtedly more time consuming for students, lecturers and support staff since open ended self-directed design projects require many variations to be accommodated.

The revised module has resulted in more confident, resourceful and motivated mechanical engineering students with demonstrable experience of designing, manufacturing and optimizing real engineering machines as they enter their final year of study and embark on their future careers.

In addition to helping students develop core engineering skills it is noted that the module encourages students to understand the need to use resources in a way that will not be wasteful. In helping students understand that a balance between production, resources and society needs to be maintained (Zokaei et al, 2014) the module reinforces the idea of sustainable manufacturing and introduces students to a number of the United Nations Sustainability Development Goals (SDGs) such as responsible consumption and production.

REFERENCES

Arduino. (n.d.). Homepage. Retrieved January 29, 2019 from https://www.arduino.cc/

Delaney, K. and Kelleher, J.B. (2008) "Real-World Process Design for Mechanical Engineering Students: A Case Study of PBL in DIT". *Conference Papers*. 16. https://arrow.dit.ie/engschmeccon/16

Delaney, K. and Nagle, G., (2019), *Teaching Approximations of Mechanical Engineering Practice through Designing and Building Robots: An Approach Inspired by Monozukuri*. Proceedings of WERA 2019, Tokyo (Japan) 5th-8th August 2019.

Engineers Ireland Survey (2019) https://www.engineersjournal.ie/2019/11/15/engineers-positive-about-2020-business-prospects-despite-brexit-concerns-survey-shows/

Education in Japan community blog. (n.d.). Blog site. Retrieved January 29, 2019 from https://educationinjapan.wordpress.com/education-system-in-japan-general/the-mindset-of-monozukuri-and-creativity-in-a-traditional-art-form-applied-in-science-technology-today/

GrabCAD. (n.d.). Homepage. Retrieved June21, 2019 from https://grabcad.com/

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., and Williamson, P.W. (2008). "Teaching Practice: A Cross-Professional Perspective". *Teachers College Record*. 111.

Sayers, Marguerite (2019), Engineers Ireland November Connect newsletter, November 2019.

Shulman, L. S. (1998). “Theory, practice, & the education of professionals.” *The Elementary School Journal* 98.5: 511-526.

Trevelyan, J.P. (2009). "Steps Toward a Better Model of Engineering Practice". *Research in Engineering Education Symposium, Cairns, Queensland, Australia, 2009*, Paper 105 pp 1-9.

Zokaei, K., Lovins, H., Wood, A., Hines, P. (2014) *"Recapturing Monozukuri in Toyota’s Manufacturing Ethos*". Retrieved June21, 2019 from https://sloanreview.mit.edu/article/recapturing-monozukuri-in-toyotas-manufacturing-ethos/