2019-08-08

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Recommended Citation

Delaney, K. & Nagle, G., (2019), Teaching Approximations of Mechanical Engineering Practice through Designing and Building Robots: An Approach Inspired by Monozukuri. *WERA 2019,* Tokyo (Japan) 5th-8th August 2019. doi:10.21427/3r4d-jx53

Teaching Approximations of Mechanical Engineering Practice through Designing and Building Robots: An Approach Inspired by Monozukuri

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ABSTRACT

Engineering design is a complex subject and 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. Upon entering the workforce engineering graduates must be able to do a great deal more than solve the technical problems taught in engineering school. To help students develop 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) for Third Year Mechanical Engineering students in 2005.

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 lead author's experience of monozukuri, the art of making, through his employment in Japan and numerous visits there, significant changes were implemented in 2017. Based on the Japanese concept of monozukuri, Mechanical Engineering students now design, build, and test real machines within the constraints of a strict budget and time limit. For the last two years the challenge assigned to students was to construct robots to perform specific functions. This paper analyses the experience to date and shows 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 careers.

Keywords: Engineering education, monozukuri, engineering practice, robots

1. INTRODUCTION

Employers expect that engineering graduates are ready to contribute to the employer's enterprise immediately after being hired. Therefore graduates may have little time to develop certain skills "on the job" and must be able to do much more than simply solve engineering problems taught in school before beginning employment. To do this, engineering students 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 paper presents a case study of how TU Dublin addressed the question of how to teach students real world engineering skills relating to design and manufacturing so that engineering graduates can be more effectively prepared for the challenges of professional engineering practice.

According to Shulman professions such as engineering, medicine, teaching, nursing, law and the clergy share a common set of tenets (1998). Shulman stated that those engaged in such professions 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. In developing a framework for thinking about the teaching of practice in the context of a university, these are key attributes that educators must strive to inculcate in their students. Grossmann et al have identified three key concepts for understanding pedagogies of practice in professional education: representations, decomposition, and approximations of practice (2008).

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.

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 and 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”. This paper explains how 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.

2. PREVIOUS EFFORTS AT PROVIDING APPROXIMATIONS OF PRACTICE

Mechanical Engineering students in TU Dublin 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 multi-disciplinary 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 suggests that students were over-confident in the ability of their designs to solve the assigned problems and insufficiently aware of how components designed can be realised through manufacturing, refined, and how they would actually function once completed. This review was prompted by comments from external examiners, industry panel advisors and comments from Engineers Ireland (2019) accreditation panel members. 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 have 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).

In addressing these concerns the module co-ordinators have reviewed how manufacturing concepts are taught to mechanical engineering students. The lead author has extensive experience of product development and manufacture in Japan from both working there and numerous visits over the last twenty years. In Japanese the 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 monozukuri concept embraces more than just “making things”. It offers the idea of possessing the “spirit to produce excellent products and the ability to constantly improve a production system and process”. These are important concepts for engineering students to grasp; they must strive for excellence and understand the need for continuous improvement and refinement as they develop new products and machines.

This concept of monozukuri and a variety of case studies relating to teaching it, such as from Tominaga et al (2018) have inspired significant changes to this Design Projects module for third year Mechanical Engineering students.

3. REVISED MODULE STRUCTURE

Students take the revised module, which is 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 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. In performing these tasks 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 and in doing so 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. The 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.

So 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 block dispensing robot built by that student group in 2017-18 is presented in **Error! Reference source not found.**.

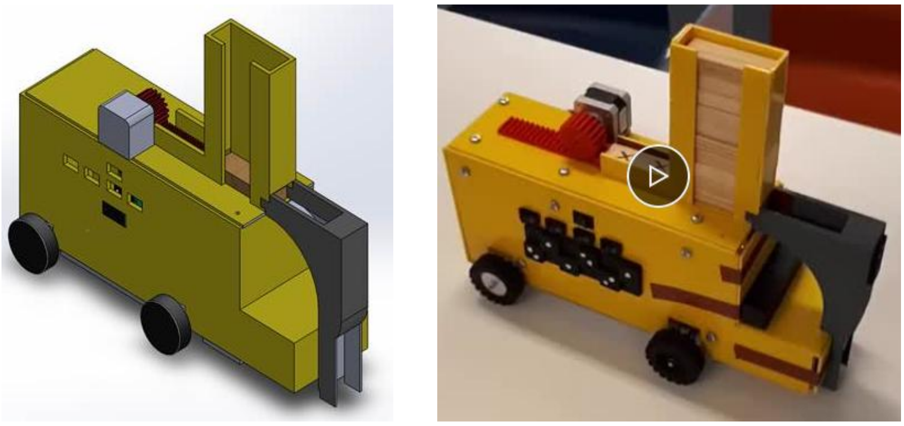

Figure 1: An example of the interim CAD model and final block dispensing robot built by students in 2017-18

The 2018-19 machine goal was to design and build a scaled semi-autonomous warehouse picker, examples of which are shown in Figure 2. 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.

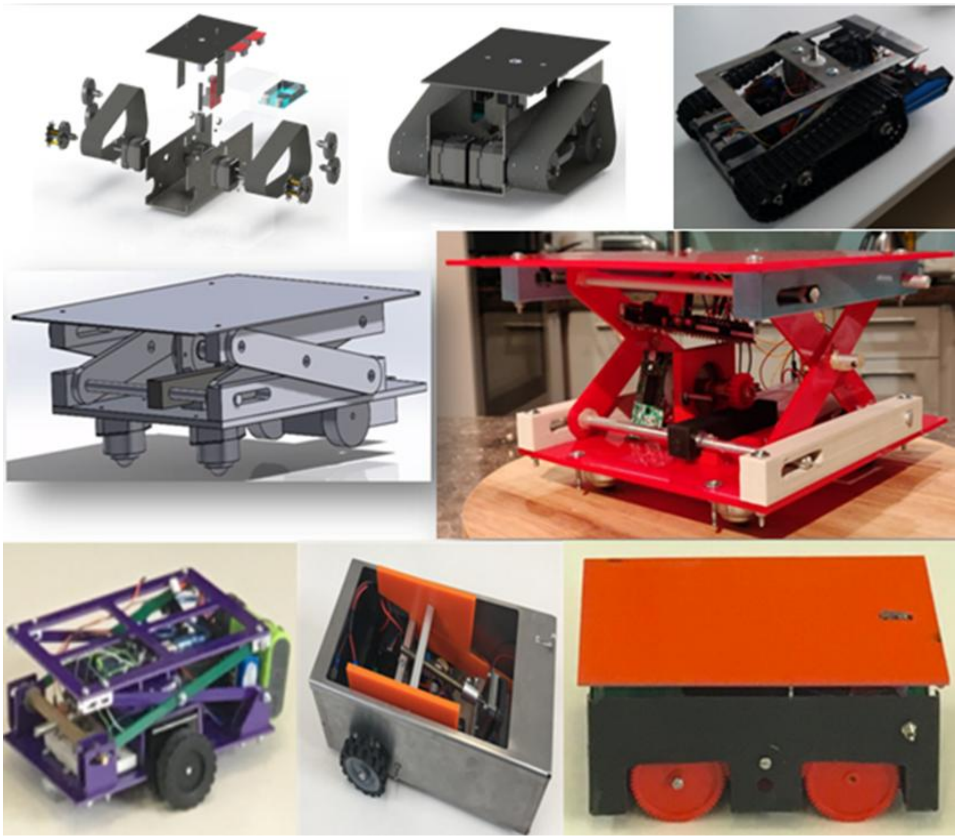

Figure 2: Examples of CAD models and some of the semi-autonomous warehouse picker robots built by students in 2018-19

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.

4. EVALUATING THE NEW COURSE 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.

In satisfying these learning outcomes all students must submit a device completed to specification, present at milestone reviews and submit a summary poster and report documenting the 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.

Each of these deliverables is assessed in 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 are 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/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."

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. Work is ongoing to address a call for cross-discipline interaction in the program which has been proposed by Engineers Ireland. In pursuit of this goal a pilot change is proposed for 2019-20 where electronic engineering students will work as "external suppliers" to design and supply particular sensing elements for the 2019-20 project, to design a scaled robotic fire tender, which will begin in September 2019. The mechanical engineering students will be expected to specify their sub-system requirements, review the proposals and then perform field acceptance tests so that they might deem the final proposals from their suppliers acceptable for integration into their overall machines.

5. CONCLUDING REMARKS

The revised module has resulted in more confident, resourceful and motivated 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. Monozukuri-style projects are more time consuming for students, lecturers and support staff since open ended self-directed design projects require many variations to be accommodated.

The precise Japanese meaning of monozukuri is broader than the literal interpretation which inspired the changes to this Design Projects module. It displays the Japanese culture's deep respect for the world at large and the need to use resources in a way that will not be wasteful. The monozukuri concept can help students to understand that a balance between production, resources and society needs to be maintained (Zokaei et al, 2014). In this way it reinforces the idea of sustainable manufacturing and will introduce 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

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/

Engineers Ireland. (n.d.). Accreditation requirements. Retrieved June 21, 2019, from https://www.engineersireland.ie/groups/students/accreditation.aspx

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.

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

Tominaga, H., Mori, M., Iida, N. and Hirose, K. (2018). A Study on Monozukuri Education in Karakuri Doll Production. In *International Conference on Geometry and Graphics* (pp. 2262-2265). Springer, Cham.

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/