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Using student-led manufacturing in makerspaces to support transition into engineering higher education

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Abstract

This paper reports our preliminary findings from utilising The iForge, a student-run makerspace, as a resource for curriculum-based learning, in place of traditional timetabled workspace access for students. We show how this enabled us to offer projects that were less structured, less constrained by timetables, and more open-ended. We also explain how we were able to embed the development of professional skills – particularly teamworking – into the curriculum. Results show no negative impact on student satisfaction or grades, and positive impact in terms of staff time and flexibility for students to work independently around their individual timetables. We conclude by highlighting some areas for further work, and make recommendations for colleagues wishing to explore more creative practical projects in their own contexts.

Keywords: *makerspace; design; manufacturing; professional skills.*

1. Introduction

For the majority of students beginning an undergraduate degree in engineering in the UK, the discipline is new, since it is not offered as an A-Level subject. Science and maths form the basis of admission to most engineering programmes. However, we have learnt through recent student engagement work that students expect engineering to be fundamentally different from those pre-requisites in that they anticipate engineering being about doing and not just knowing; they expect to gain practical experience of putting knowledge to work (Wood & Gibbs, 2019). Industry partners also highlight the value of practical skills in engineering, when they report skills gaps between their expectations of new graduates and graduates' actual capabilities (Royal Academy of Engineering, 2010). A challenge for engineering educators working with first-year undergraduates is therefore to help students transition into a new discipline, whilst building foundational knowledge, technical and professional skills that enable success in studying and beyond. Responding to this challenge requires us to rethink traditional approaches to teaching engineering, where the focus in the early part of degree programmes is on engineering science, with limited opportunity to apply it.

In 2017, inspired by visiting the Invention Studio at Georgia Institute of Technology and by students' desire to *do* engineering instead of just *learning about* it, we worked with a team of students to launch a student-led makerspace. The iForge encouraged students to use and develop their skills through competitions and themed events. As we observed students using the space, working and learning together, we gained a better understanding of how our students most effectively learned to be engineers. We began to reimagine curriculum-based practical teaching, seeing new opportunities to enhance learning whilst overcoming barriers to large-scale, in-curriculum practical projects.

This paper reports our preliminary findings from utilising a student-led makerspace as a resource for curriculum-based learning. In the spirit of Wilczynski (2015), who notes the need to document and share best practice as we develop UK makerspaces, we show here how The iForge enabled us to offer projects that were less structured, less constrained by timetables, and more open-ended. We explain how we were able to embed the development of professional skills – particularly teamworking – into the curriculum, and the value we have seen in explicitly teaching students these skills, rather than assuming students would develop them through experience alone. We conclude by highlighting some areas for further work, and make recommendations for colleagues wishing to explore more creative practical projects in their own contexts.

2. The iForge at The University of Sheffield

The iForge provides students with access to 3D printing technology, laser cutters, a CNC router, bench-mounted power tools, and hand tools. Materials and components are available for purchase using student cards, so they can be charged either to teaching budgets or personal funds. A select team of trained student 'Reps' runs and manages the space, providing training and supervision for students using it. They each volunteer three hours per week to open the space for 40 hours each week, supervising and supporting other students, and in return they are permitted 24-7 access to the space.

Alongside a desire to provide space for enterprise activities and extracurricular groups, we hoped that The iForge would improve students' experience of current design and manufacturing teaching and encourage the design of new self-directed manufacturing experiences. After a couple of pilot activities, it was clear that there were benefits to using The iForge to support curricular activity, including a reduction in staff hours required to supervise student projects, and increased student motivation. Over the summer of 2018, The iForge was expanded from an initial space of $90m^2$ to around $250m^2$, in preparation for our wider usage of the space to support a new Mechanical Engineering module.

3. Reimagining first-year design and manufacture projects: A case study of MEC115 Design and Manufacturing

Traditional approaches to design and build modules provide schedules classes in a staffed manufacturing space. We recognised a number of problems arising from this scenario:

- Difficulty accommodating increasing cohort sizes in very full timetables, leading to some groups manufacturing out of phase with each other;
- Manufacturing processes and materials being limited, due to lack of available supervision or equipment, which in turn limited the project scope; and
- Lack of support to help students scaffold and plan the process, and lack of communication between departments, leading to excessive pressure on resources as deadlines approach.

In 2018-19 we redesigned our first-year Design and Manufacturing module, seeking to address the challenges identified immediately above by using The iForge, whilst providing more structured scaffolding for the development of teamworking skills.

3.1. The project

The redesigned twelve-week module presented students with a brief to design, manufacture, and showcase three novel, compact and low-powered musical instruments.

The stated aims of the module were that students should:

- develop an understanding of design methodologies applicable to engineering products;
- learn to employ design techniques and methodologies in the creation of a device to fulfil a given function; and

- gain a basic understanding of customer needs, marketing, and enterprise.

3.2. The students

A cohort of 149 first-year mechanical engineering undergraduate students were enrolled in the module. We divided them into teams of approximately 12 and tasked them with determining their own internal structure and creating a project plan to meet the brief.

3.3. Training and support

Previous module evaluations demonstrate students' dissatisfaction with team activities and desire for grades to reflect individual performance. However, employers and accrediting bodies require graduates to be able to work effectively in teams. We sought to address this problem by equipping students with skills to manage the process as well as the output of the project.

In the first two weeks of the module, students engaged in workshops exploring effective teams, team roles and dynamics, and project planning; and tutorials on creating Gantt Charts to structure and manage projects. At the end of the initial six-week design phase, students completed a formative peer assessment. This formed the basis of individual feedback to students. In addition, a mid-point point tutorial gave each group the opportunity to discuss and reflect on teamworking with a module tutor, and thus to address any issues that were arising.

3.4. Design and manufacturing

In the first six weeks, in addition to the professional skills training and a sketching class to help them to communicate their ideas, the students developed their design concepts. During this time each group was required to book a review with staff to discuss the progress of their design, groups submitted an 'Ideation Report' which acted as a milestone to ensure they had converged on their designs.

In the next stage, the students developed, built, tested and refined their designs, with another mid-stage review to check progress. Teams were encouraged to organise themselves to manufacture their instruments in The iForge at a time that suited them, with no timetabled manufacturing sessions. They had approximately four weeks after submitting the Ideation Report to complete the manufacturing and testing of their prototype instruments. Each group had a budget to manage, which could be spent either in The iForge or by requesting specialist parts through an online form. Supervision was provided entirely by iForge Reps, who were available to provide advice on design and manufacturing. Technical support from staff was confined to the organised review sessions.

Each group created a crowdfunding video and performed with their musical instruments in front of the whole cohort, who voted on various aspects of the instruments and performance. A final report was produced consisting of an evaluation of the manufacturing process and the instruments themselves.

4. Results

We used several measures to consider the impact of the innovations described on three important areas: the student experience, as evidenced in student evaluation data and engagement in manufacturing; the extent to which the module aims were achieved, as evidenced in student attainment; and the effect on staffing costs and space requirements.

4.1. The student experience

Student satisfaction data from the module evaluation surveys for were compared with equivalent data for the same module two years previously, prior to the introduction of the makerspace. Amongst other things, students were asked to rate their satisfaction from 1 (very dissatisfied) to 4 (very satisfied). The average rating in 2016-17 was 3.07 (n = 153, SD = 0.527), whilst the average in 2018-19 was 3.16 (n = 100, SD = 0.604).

To explore these data further, we entered them into a one-way between-subjects analysis of variance (ANOVA), with student evaluation ratings as the dependent variable and *year* (*2016-17* or *2018-19*) as independent variables. This test revealed a no significant main effect of *year* ($F_{(1,253)} = 1.376$, $p = 0.242$, partial $\eta^2 = 0.005$), confirming that students' satisfaction with the module was not significantly different between the new model in 2018-19 and its previous format, without the makerspace, in 2016-17.

In the four weeks preceding the deadline, 80% of the cohort used The iForge, for an average of 9.9 hours each, engaging in a range of processes from CNC routing to 3D printing and soldering, creating a variety of outputs. In previous years, students were timetabled six compulsory hours in this period, plus another six optional hours, but many of these sessions were not fully utilised, and the flat spaces provided generally limited the students to the use of hand tools.

4.2. Meeting the module aims

We analysed student attainment using students' final module grades. The average grade for students in 2016-17 was 66.34 (n = 231, SD = 8.169), whilst in 2018-19 the average was 64.64 (n = 147, SD = 12.381). These data were entered into a separate one-way between-subjects ANOVA, with *grade* as the dependent variable and *year* as independent variables. This test revealed no significant main effect of *year* ($F_{(1,376)} = 2.582$, $p = 0.109$, partial $\eta^2 = 0.007$), confirming that student grades were not significantly different between the two academic years.

4.3. Staffing costs and space requirements

In 2016-17, 68 hours of technician time plus 390 hours of Graduate Teaching Assistant (GTA) time were used. In 2018-19, the use of student supervision in The iForge meant that only 76 GTA hours were used with around 12 hours of technician time. However, queues in excess of four hours in the final week led to us scheduling staffed spaces for students to use ad-hoc during certain hours.

5. Discussion

5.1. The student experience

Although results do not show an increase in satisfaction, the finding that satisfaction remained unaffected, in spite of the reduction in staffing levels, is a positive outcome. The community feel and student supervision model of the makerspace is surely a more appealing environment for the students and contributes to a better experience, resulting in high levels of engagement with the space. This benefit was, however, somewhat tempered by students having to wait to use the space when demand increased close to deadlines.

5.2. Meeting the module aims

Given the changing nature of module assessments from year to year, it is difficult to draw strong conclusions from the attainment data. However, the increase in creativity and variety displayed in the final outputs indicates better engagement with the ideation stage of the design process, which was helped by allowing a greater range of materials and processes. The fact that the manufacturing is carried out in an open environment alongside extracurricular activities means that "students from a variety of academic programs use the space and, as a result, offer diverse perspectives for amplifying creativity and solving problems," (Wilczynski, 2015).

The self-directed learning approach meant that groups had to organise their own schedules, giving a more realistic experience of the design and manufacturing process in industry. Although they may find this uncomfortable, it ultimately benefits their employability.

The integration of professional skills teaching, design theory, and practical application appears to have been successful, although the final outputs would have benefitted from further integrating engineering science to be able to more fully explore instrument design.

5.3. Staffing costs and space requirements

Wiczynski (2015) asserts that 'aligning access times with the student work schedules increases the utility of academic makerspaces'. In this case, the extensive availability of The iForge, particularly outside class hours, allowed students to fit access around their class schedules, and thus The iForge was at capacity throughout its opening hours for the final few weeks of the project. This increase in demand, while a positive sign of high levels of engagement, put pressure on space resources, and suggested that expansion of the facility would be required to continue to support and expand self-directed curricular manufacturing experiences.

The associated benefit, however, was that staffing costs were greatly reduced. Wilczynski also claims that ‘the impact of an academic makerspace on a campus correlates with the staff support provided in the space’. But successful student-run makerspaces such as the Invention Studio at Georgia Institute of Technology, and now The iForge, prove otherwise. Our experience is that students appreciated the specialist knowledge and enthusiasm of student Reps, and it allowed staff with extensive technical expertise to be better used elsewhere in the design process as facilitators rather than gatekeepers, to advise on design and manufacturing rather than police health and safety.

In response to the challenges of student expectations and their inexperience with self-directed learning, high levels of scaffolding were introduced, through professional skills teaching and regular reviews, in order to support the transition from more structured learning environments. It is envisaged that the level of support would gradually be reduced as students move through the course, encouraging them to seek out information and learn required skills for themselves.

6. Conclusions and recommendations

A number of papers have examined role of academic makerspaces in learning. Sheridan *et al* (2014) compared three makerspaces and concluded that:

> While it may be easier to design, teach, and study more constrained ‘making activities’, the learning in the making we observed in our studied makerspaces extends beyond this. Being a maker in these spaces involves participating in a space with diverse tools, materials, and processes; finding problems and projects to work on; iterating through designs; becoming a member of a community; taking on leadership and teaching roles as needed; and sharing creations and skills with a wider world.

The student-run Invention Studio provides a good model for this, much of which has been taken on at The iForge, but academic staff at The iForge have also proactively engaged with module leaders to create early self-directed curricular design and build experiences across the Faculty of Engineering. We have also looked to change the paradigm for teaching manufacturing. This is described well by Schön *et al* (2014):

> Looking at the teacher in a maker setting, it is obvious that traditional teacher-centred teaching does not fit. Typically, teachers in maker settings change their role to facilitators and enablers … from leading to support and tutoring … [S]tudents may be better or more experienced in one of diverse tools... But even more important, the openness of the setting

> and the creative results within this approach may lead to situations where the students may be better as the teachers... This can be challenging as well as motivating and surprising for teachers. For students, it is the chance to see teachers as inspirational partners as well as models for their own learning.

Our case study also shows that professional skills are more effectively learned when embedded in the context of a real project. Students will not see the relevance of teamworking skills training until they have experienced the peculiar challenges of designing within a team of engineers.

Using a self-directed approach to design and manufacturing bolsters learning in a number of important ways, and does not have a detrimental effect on student experience or attainment, despite being a much more efficient and scalable solution in terms of staffing and space requirements. However, it is important to consider the impact on teaching staff and to emphasise the benefits over the perceived challenges. Sharing good practice and successes will add to the body of evidence that student-led makerspaces can and should play an important part in effective teaching of design and manufacturing in HE.

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