Supporting In-Curriculum Making alongside a Student-Led Makerspace
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Introduction

Founded in 2017, the iForge makerspace at The University of Sheffield was the first student-led makerspace in the UK. It is open to all students and staff across the University, and is currently run by approximately 45 undergraduate and postgraduate students, or 'Reps', who volunteer to supervise and support students in Making. The space functions on a 'first come, first served' basis, with students able to make things for curricular and co-curricular projects, as well as non-academic applications.

Student-led makerspaces have been demonstrated to have various benefits, including health & safety [1], engagement and inclusion [2]. By providing access to Making outside the curriculum without the increase in staffing levels required for a traditional staff-supervised workshop, there is a positive impact on student experience. It is therefore important to ensure that Reps feel positively about how the space is run, particularly given the voluntary nature of their involvement. The creation of the iForge was driven by students' desire to access Making facilities for non-curricular activities, and this has remained a key motivation for the Rep team. However, the space and supporting staff are funded by the Faculty of Engineering, one of five faculties at the University of Sheffield, making up approximately 25% of the 28,000 students. In the current UK Higher Education climate, teaching staff are under pressure to maintain high student satisfaction, which is primarily measured in relation to taught activities. This creates something of a conflict, with module and course leaders keen to see whole cohorts of Engineering students supported to use the makerspace within the curriculum, while Reps' desire is to support anyone across the University who is enthusiastic to make or to learn and to encourage a diverse range of users and uses.

In this paper, we explore this tension and describe some of the solutions we have put in place to support Making in the curriculum in a way that reflects the iForge ethos whilst allowing the Reps to continue to support Making in all contexts. These solutions are specific to the particular context at The University of Sheffield, and to the point on the journey that we have reached with the iForge, but it is the authors' hope that general principles can be inferred and applied to the varied contexts in which makerspaces and making exist in Higher Education.

The problem of success

Before the creation of the iForge, students' experiences of Making at the University of Sheffield were solely within the curriculum, and limited to:

- taught, prescriptive skills introductions where students follow a set of instructions and learn a range of processes
- timetabled classes for group design-and-build projects.

These design-and-build sessions often had poor engagement and were not necessarily timetabled around when students would be ready to manufacture. Outputs were generally poor due to the lack of access to advanced equipment and the limited time students actually spent manufacturing. A key example was a third-year Aerospace Engineering module (AER385) in which students worked in groups to create an unmanned aerial vehicle (UAV). Pre-iForge, students had limited access to underequipped and understaffed facilities, and almost none of the approximately thirty groups produced a UAV that could fly.

The introduction of the iForge created a more flexible and engaging environment, with access to a greater range of tools and increased capacity, and this led to better practical outputs – the majority of UAVs flew!

However, in some ways, the iForge was a victim of its own success. The availability of such engaging facilities inevitably led to increased demand. While this demonstrated an enthusiasm amongst students for Making, it also created a problem – with the iForge regularly at maximum capacity and long queues forming (Fig. 1), students were not always able to access the iForge for sufficient hours to 'realise' their design or to at least meet the learning objectives for the module [4]. This led to reduced satisfaction amongst students, reflected in data from module evaluations, which in turn led to frustrations from module leaders and reflected negatively on the iForge.

Fig.1 Queues outside the iForge (2017)

Despite this issue, the obvious enthusiasm for Making and opportunities for more ambitious projects, coupled with the demands from employers and accreditation boards for more practical experience, created a greater demand from module leaders for the iForge to support new practical elements in design modules across engineering, including Mechatronics, Bioengineering and General Engineering. This further exacerbated the issue for the following semesters.

At this point, a further issue became apparent: Reps were regularly dealing with stressed or disgruntled students who had mixed motivations for being there, and their morale was suffering as a result. Having invested a lot of their own time into the iForge, they felt a sense of responsibility for the student outcomes, and wanted students to develop as makers and to leave the University with a positive experience, but felt they should not be shouldering this burden.

Should student-led makerspaces be used to support curricular making?

Student-led makerspaces clearly enhance in-curriculum learning experiences [3] as well as providing reputational benefits for universities, whilst the skills the student Reps acquire to safely supervise the space are of great value in their development. Therefore, on the surface there is a good synergy between the module needs and the skills that the Reps are wanting to acquire. Furthermore, because of the engaging environment created by student-led makerspaces, introducing students to the space to work on a module often leads to them developing a passion for Making and returning to use the space for personal projects, co-curricular activities or for their final year projects.

However, discussions with Rep team leads highlighted the following issues that needed addressing:

- Reps are generally happy to volunteer their time in order to give colleagues improved access to making facilities, and enhancement of students' practical experience through iForge should be encouraged, whether in the curriculum or outside of it, but the iForge is limited in the number of students it can support, and access to Making outside the curriculum should not be excluded because of curricular demand.
- The experience of Reps tends to be more negative when students are in the iForge because "they have to" rather than because they want to. The relationship becomes less collegiate and Reps begin to feel more like unpaid technicians upon whom demands are placed without the associated rewards.
- Reps should not be or feel responsible for the attainment of students on modules should they not be able to get sufficient access to the makerspace – the University therefore has a responsibility to provide a minimum level of supervised access to Making facilities for all students to be able to meet the learning outcomes of taught modules.
- The volunteer model in place in the iForge and other similar makerspaces relies on Reps having extended 'out of hours' access to the space in return for supervising students during 'opening hours'. Reps were aware of pressure from module leaders to increase access for their students and felt that more should be done to protect their autonomy in setting opening hours.

Both Reps and University staff are invested in student success and agreed that Making should be encouraged in the curriculum, but it became clear that the iForge alone could not support the ambitions of the Faculty and provide enough access to allow all students to meet the learning outcomes of all Making modules. It could serve as a supplementary space to allow students to go 'above and beyond', but there would need to be other solutions to support the bulk of in-curriculum Making.

What solutions were implemented to mitigate this problem?

A. *Better communication between the makerspace and module leaders*

An important aspect of the solution was communication with module leaders and management of expectations. Makerspace staff met with academic staff involved with 'design and build' modules to review the situation. The core vision of the iForge was reiterated and the problems that had arisen due to increased demand were highlighted. Best practice was shared in how to spread the Making load across the semester by having regular stage gate reviews in order to avoid a 'last minute rush'. Staff were also encouraged to communicate realistic expectations to students in terms of what could be achieved within the timeframe.

B. *Creation of flexible staff-supervised Making facilities*

Expanding Making facilities requires both staff and space, things which are at a premium in many universities. The proposed solution was to create movable workstations containing a range of hand tools (Fig. 2) that could be deployed in a number of spaces across Engineering (see Appendix A for detailed list of tools). This allowed staff-supervised bookable sessions to be timetabled around lab classes for maximum utilisation and a significantly increased capacity for Making. By making these sessions bookable by students (on a 'first come, first served' basis using an online system) and catering for multiple cohorts, the intention was to reduce the amount of staffing required, since students only booked the facilities when they were needed.

In reality, the moving, setting up and packing down of the workstations required significant staff input and took up considerable time. In addition to this, it was not well utilised by students as it did not offer any benefits over using the

Fig.2 Flexible workstations and contents

Fig.3 Staffed Making sessions using the flexible workstations

iForge and many students were still choosing to join the iForge queue rather than utilise these facilities. Significant barriers to use were that, due to being mobile, only limited equipment could be provided, students would need to bring their own materials and there wasn't any storage.

Whilst this did relieve some of the pressure on the iForge, it did not reflect the amount of staff input or justify the disruption that it caused to other labs. Neither did it result in increased student satisfaction.

Covid provided an opportunity to situate the workstations in a fixed location (Fig. 3) so that we could provide limited manufacturing and prototyping opportunities whilst adhering to government guidelines and University of Sheffield protocols to minimise transmission. These restrictions evolved throughout the pandemic but generally required 2m social distancing and sanitisation of equipment. The use of a fixed location allowed us to address many of the issues that we identified with the mobile stations. They could be now better equipped, provide project storage, and have materials readily available for students to use. The permanent nature of the facility means that there is less demand on staff and other teaching spaces are not disrupted. Having demonstrated the demand through high utilisation, the fixed location has now become a permanent facility. By timetabling specific sessions for each module that requests them, the facilities can provide sufficient access for threshold-level projects so that students can meet learning outcomes without using Reps as "unpaid technicians". In addition to this, open bookable sessions are also timetabled that are available to book for students from all modules.

C. *Service manufacturing*

At the height of Covid restrictions, students were unable to access any manufacturing facilities, and even as restrictions eased, reduced lab capacities necessitated a different approach. In order to complete design-and-build projects for modules a service manufacturing element was introduced. Students would send in CAD designs for components which were manufactured by technical staff. Students could then use the mobile workstations in supervised sessions to assemble their designs. Service-manufacture was primarily available for 3D printing, laser cutting and water jet cutting and required students to follow video tutorials for understanding the submission requirements. These are the most used pieces of equipment in the iForge and often see bottlenecks and long queues. The introduction of service manufacture therefore takes pressure off the makerspace, avoids repetitive tasks for Reps, frees up capacity for more interesting Making and saves students time without much loss in learning. In fact, while this approach was born out of necessity, it does have pedagogical advantages. In addition to "hands on" Making, students learn the importance of communicating their designs effectively, applying their drawing and CAD skills to submit accurate designs to engineering specifications. This is an important skill in industry where manufacturing is often outsourced. Students were also able to request turning and milling. These processes are not currently available in the iForge, so service manufacturing opened up additional design and manufacturing options for the students. For these reasons it continues to be employed despite the lifting of Covid restrictions.

The combination of flexible, bookable workstations and service manufacturing was seen to have filled the gap in provision so that all students had the opportunity to meet the learning outcomes of their module, while still allowing autonomy in how they chose to manufacture – whether in the iForge, in bookable sessions or through service manufacturing.

What were the results?

As the majority of design and build modules manufacture their projects in the Spring semester, results were analysed from the Spring semester of the 2021-22 academic year.

In total, there were 8 modules from 5 different departments where Making was part of the assessment, ranging from 1st year to 3rd year undergraduates. The total number of students on these modules for this academic year was 1,272. All of the design-and-build modules had students working in small teams ranging from four to eight students per group.

The module leaders were effective in staggering their deadlines and implementing stage gate reviews, which enabled sufficient bookable sessions to be timetabled to accommodate a threshold level of manufacturing for all modules. One module leader chose not to timetable flexible workstation sessions and their students did not make use of the open sessions for all modules.

Whilst the flexible workstations were timetabled, they required students to book prior to attendance. Each booking was for 90 minutes and represented three students attending.

The booking statistics are shown in Figs. 4 and 5. Across the seven modules using the flexible workstations, representing 1124 students (ACS231 chose not to use them), the total number of student hours booked was 5130, averaging 4.56 hours per student. This figure varied between modules depending on the complexity of the manufacturing required – in MEC209, students were glueing laser cut parts and only spent an average of 0.9 hours on the workstations, whereas in AER302, students were making complex unmanned aerial vehicles and spent an average of 15 hours each using the workstations.

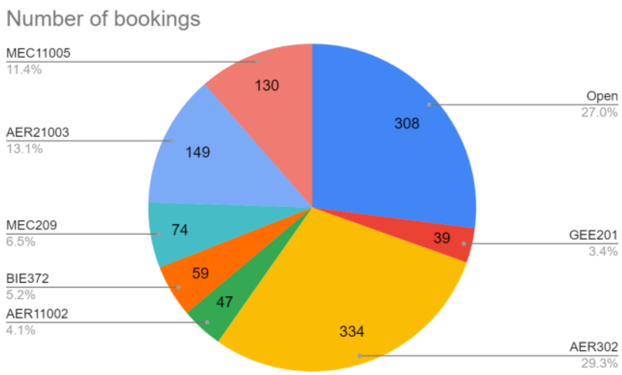

Fig.4 Number of flexible workstation bookings per module

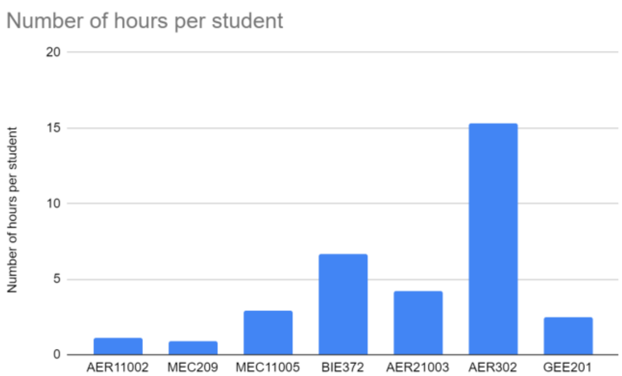

Fig.5 Average number of hours booked on flexible workstations per student for each module

Service manufacture was available throughout the semester. In total, there were 354 requests for manufacture with 278 of these being for 3D printing (with an average print time of ~4 hours), 43 for laser cutting, 21 for waterjet cutting and 11 for milling or turning.

It is evident that these two options were well utilised, but what impact did this have? Did it have the desired effect on reducing the demand on the iForge, improving the iForge Reps' experience, improving module outcomes and improving student satisfaction?

To ascertain this we reviewed the iForge usage data and we conducted a series of interviews with module leaders, Reps and students.

A. *iForge usage data*

When visiting iForge, students have to state the purpose and module code (if for curriculum work). In Fig. 6, the purpose of visits for the 21/22 academic year is broken down into: work for the eight modules, work on other curriculum projects (such as individual research projects) and non-curricular work. Work on modules accounted for almost half of visits. Unfortunately there is no historical data to compare this with in order to determine whether this was reduced by the alternative provision. However, it is interesting to note that by far the largest module use comes from ACS231, which did not make use of the flexible workstations. There were 846 visits for ACS231 (164 students), compared to 354 for all AER modules (447 students) and 407 for all MEC modules (567 students), which had used the flexible workstations extensively.

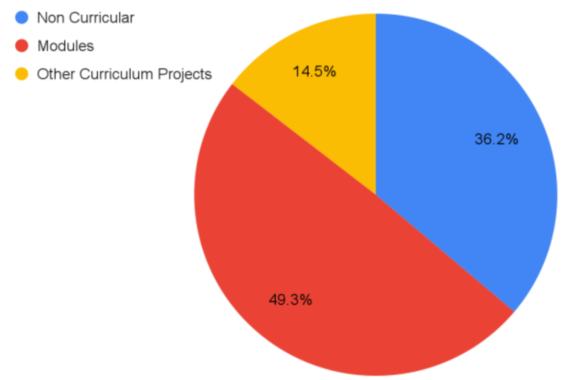

Fig.6 Percentage of visits to iForge in 21/22 academic year by purpose

B. *Interview methodology*

Semi-structured interviews were conducted with 2 module leaders, 4 students who had participated in design and build modules in the 21/22 academic year and 5 current iForge Reps. This study was approved by the University of Sheffield Research Ethics Committee. Thematic analysis of the results was carried out.

C. *Interview results*

Both staff and students felt that the range of facilities available provided enough access to making for students to achieve the module brief and meet the learning outcomes, despite the natural tendency to leave things to the last minute. Students were generally satisfied with provision. Both staff and students liked the ability of students to work independently.

They appreciated the ability of service manufacturing to deliver components for specific deadlines, although some struggled with the planning required and found communicating their intentions frustrating (something that staff felt was a good learning experience), and most students expressed a preference for hands-on Making.

Students generally felt that the tools available in the flexible workstations were sufficient for most tasks, but appreciated access to a wider range of tools in the iForge if required. The main reasons for choosing the flexible workstations were the dedicated access for their module (rather than often having to queue for iForge), and the availability of support and advice from staff.

While the intention of iForge staff and Reps was to direct people towards staffed provision, there was clear variation in the extent to which this was communicated by module leaders, which had a consequent impact on students' choice of method. In most modules, students used the flexible workstations most heavily, and only used iForge when the workstations were unavailable or when specialist equipment was required. However, in one or two modules where this was not communicated, there were significant spikes in iForge demand leading up to deadlines that resulted in a more negative experience for iForge Reps.

In general, Reps viewed supporting module teaching as necessary, realising the benefits in terms of relations with faculty and acting as a gateway to introduce students to Making. However, they showed a clear preference for supporting non-curricular Making due to more interesting projects and a perception of better user attitudes – they often felt poor;y treated by students working on modules, particularly as stress levels increased. Reps generally found it hard to determine what impact the other provisions had on iForge demand, or felt it was not as large as hoped, although there was a general sense that demand had reduced somewhat, and they were positive about the University making efforts to support them. They felt they needed better communication from staff regarding the types of activities and numbers of students that were likely to be using the iForge so they could plan supervision and material supply more effectively.

Discussion and recommendations

Student-led makerspaces are a great asset to universities and create opportunities for improvements in curricular and non-curricular student experience. However, they are a finite resource and must balance the requirements of the different stakeholders in order to remain successful. A key aspect of successful student-led makerspaces is the community of enthusiastic makers that develops around them, and teaching staff should take care that demands placed on resources by course projects do not marginalise this community by restricting access for co-curricular and extracurricular activities. It is particularly important in volunteer-run makerspaces like the iForge that staff communicate to Reps the value of their contribution and are aware of the risk of treating them as unpaid technicians.

There are a number of ways universities can mitigate these issues. A series of interventions at Sheffield have been outlined, along with lessons learned along the way. Interviews with module leaders, Reps and students showed that these interventions were generally well received by staff and students and provided sufficient access for all students to achieve satisfactory outputs and meet learning outcomes, as well as providing opportunities for more capable students to excel.

However, the heavy demand for short periods caused by one or two modules still seemed to have a significant impact on the experience of Reps, despite the reduction in demand from better-organised modules. It is therefore important, if there is to be a significant improvement in the experience of those using the makerspace, that all module leaders: communicate effectively with those responsible for the makerspace; explain the options available to their students, the voluntary nature of the makerspace and potential impact on Reps of poor student behaviour; and manage both their own and their students' expectations of what can be achieved in a given timeframe.

As has been seen in many contexts, some of these interventions were necessitated by Covid-19 but were found to be effective tools and so have been carried forward. Every university context is different, but the authors hope that general principles can be extracted and applied within any local context.

Makerspaces will inevitably lead to more demand for Making, including in the curriculum, which is generally seen as a positive thing by all stakeholders. However, there is a need to balance the ambition of module leaders (and students) with available resources in terms of time, space, equipment and supervision. If an increase in Making within the curriculum is desirable, universities must invest time and money in resource planning and module leaders must be realistic in their project briefs and design learning outcomes and assessments that can be achieved within the available resources.

There is also a need for effective communication between staff, student cohorts and those that run the makerspace in order to ensure that expectations are managed and that conflicting objectives are discussed and compromises agreed. If student satisfaction data is key, then open-ended design briefs can be problematic, with students unclear on how much time they will need to spend manufacturing and how this effort will be reflected in assessment. It is sometimes better to make something simple and finish it in time, whereas students may learn more by pushing themselves to make something ambitious that may not be finished, but may feel their efforts are not recognised or that expectations were not clear.

While makerspaces should certainly continue to support and encourage curricular projects, there are other effective methods of providing valuable learning experiences in design-and-build courses, some of which have been described and analysed here, and academic staff should think carefully in planning such projects in order to provide the best experience for all involved.

References

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Appendix A: List of flexible workstation tools

TOP DRAWER:

Item	Quantity
Toolbox Saw (Wood)	1
Tenon Saw (Wood)	1
Hacksaw (Metal)	1
Junior Hacksaw	1
Stanley Knife (Medium)	1
Craft Knife (Small)	1
Scissors	1

CENTRE DRAWER:

Item	Quantity
Magnetic Vice Soft Jaws 1	1
Magnetic Vice Soft Jaws 2	1
Driver Bits	1
Tape Measure	1
Small Spanner Set 4-10mm	1
File 8" Coarse	1
File 8" Smooth	1
File 8" Round	1
File 8" Half Round	1
Pin Hammer	1
Allen Key Sets, Imperial	1
Allen Key Sets, metric	1
Screwdriver for Bits	1

LOWER DRAWER:

Item	Quantity
Digital Calliper	1
Steel Rule	1
Combination Pliers	1
Cutting Pliers	1
Snipe Nosed Pliers	1
Screwdriver Blade	4
Screwdriver Crosshead	3
Jewellers Screwdriver	10

CUPBOARD SHELF:

Item	Quantity
Multimeter	1
Helping Hand	1
Safety Glasses	4
Masking Tape	1
Clamps (small)	1
Sanding Block	1
Mitre Block	1
Work Light	1
Needle File Set	1