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Facilitating Independent Learning: Student Perspectives on the Value of Student-Led Maker Spaces in Engineering Education*

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Embedding and effectively managing independent learning within engineering curricula can be somewhat challenging. This work examines the development of a student-led maker space to facilitate independent learning and explores the value that these spaces can add to engineering curricula from a student perspective. Student-led maker spaces as used here, refer to learning environments created and developed solely by students, generally outside of the university setting and with minimal faculty support, to explore concepts related to their studies. We examine the experiences of two undergraduate engineering students involved in creating a student-led maker space to develop and produce a working prototype of a 3D printed modular separation column. The results show that these spaces can provide rewarding independent learning situations that encourage entrepreneurship, promote life-long learning, build project management skills, increase self-efficacy and motivation and allow the freedom to work in accessible spaces that are not confined or controlled by the university. Effectively managing student-led maker spaces however requires both students and staff to carefully reflect on the balance between independent learning activities and other work commitments as well as the availability of departmental support in particular areas relating to the academic and technical staff access and laboratory scheduling. Managing a small number of student-led maker spaces within academic programmes is potentially easy and feasible; larger numbers however may require a careful consideration of resources which, for some departments are already constrained during their normal academic year activities.

Keywords: student-led maker spaces; independent learning; interdisciplinary collaboration

1. Introduction

Over the past few decades, embedding independent or self-directed learning within higher education (HE) curricula has grown considerably [1]. This is often regarded as a consequence of a changing global workforce, who require a distinctive set of skills and attitudes compared to past generations [2]. These skills and attitudes involve not only acquiring new knowledge and learning how to apply it but also the increasingly important development of critical thinking, entrepreneurship and life-long learning skills [3].

Independent learning (IL) can broadly be defined as learners acquiring knowledge through their own efforts. Although IL has been linked to an increased academic achievement [4, 5] and enhanced student experiences [6], establishing and effectively managing IL within curricula can be somewhat challenging. This is partly due to the uncertainty as to how IL activities can best be included within academic programmes and the difficulty to manage these activities when they are included [7].

Accounting for the provision of IL within academic programmes however has become progressively more important given the recent HE changes within the European Union (EU) over the past few years. One such change is the adoption of the Bologna Process which involves the inter-governmental cooperation of 48 European countries to guide the collective effort of improving the internationalisation and standardisation of higher education across the EU [8]. The Bologna educational reforms include recommendations on the standard workload of students who are undertaking full-time academic programmes and specifies that this workload should range between 1,500 and 1,800 hours per academic year [9]. This implies that most academic curricula will tend to have a non-contact (non-teaching) time which lies in an excess of 1,000+ hours.

It therefore becomes important to closely examine the ways that these 1,000+ hours are allocated across the academic year and explore how this allocation can best serve the independent learning needs of students. These ideas form the rationale of this work and our paper examines the development of a small-group student-led maker space (SLMS) as means of

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informing the shape and structure of allocated IL hours within engineering academic programmes.

We look specifically at the experiences of two second-year undergraduate students at Imperial College London (ICL) who have created a SLMS, based on interdisciplinary collaboration, to develop and produce a working prototype of a 3D printed modular separation column. These students lived within the same hall of residence which allowed a common accessible space in which to share project ideas and then to create a physical maker space away from the main university.

The students independently undertook their initial column design without any prompting or guidance from departmental staff. It is important to note that this project did not carry any credit weighting (or could not be used for any future credit award) and was not tied to any assessment within the students' degree programmes; the project had been conceived entirely by the students to supplement their own learning. Staff were only consulted and made aware that the project had been on-going for 6 weeks after the project's conceptualisation.

This consultation, along with our desire to better understand the role of student-led initiatives to facilitate IL, led us to study several selected experiences of these two students as they worked through their project tasks with the hope that this could inform our practice. Our research questions included:

1. Why are students motivated to undertake student-initiated and led projects?
2. How do students perceive their motivation, project management skill gain, knowledge gain and the need for departmental involvement across the project?
3. What are the perceived benefits and challenges of undertaking these types of projects?

We believed that the above questions could help us assess the value and ways of embedding such student-led initiatives within our curriculum as well as help identify the risks and challenges that arise during the process which could impede the student experience.

The repeatable and progressive inclusion of student-initiated activities within engineering curricula is heavily dependent upon the continued willingness of students to undertake these activities. Students are the drivers of student-led projects and so must be motivated to first initiate and then sustain these kinds of projects. It therefore became important for us to understand what led these particular students to undertake this type of project (Research Question 1) so that we could better understand possible linkages to their motivations and intrinsic characteristics. We were also interested in the progression of the SLMS in terms of its overall development including the use of project management tools, what led students to narrow design choices, how these choices were informed by taught content and what kinds of support were needed throughout the project to produce the final design.

Assessing the students' perceptions of their knowledge gain and the building of their transferable skills was also an important part of this study especially as these took place in the context of a group project. Team-working and collaboration have been shown to be key opportunities for knowledge facilitation during which students construct knowledge together and learn with and from each other [7]. The success of this experience can, however, be impacted by the low motivation which exists or ensues as part of the process [8, 9] and as a result, understanding student motivation throughout the project was also particularly important to us given that students are the driving force behind student-led activities. Exploring how students perceived the role of our department during the project was also a key motivator of this study as we believed that this could inform future departmental support mechanisms and resource planning initiatives (Research Question 2).

Finally, it was important for us to understand what students considered to be the major benefits and challenges associated with the project and how these manifested themselves at key project stages (Research Question 3). This information could help mitigate the risks and uncertainties of future endeavours arising during the process that impede the student experience.

This study and the responses to our research questions are particularly valuable and timely given that the MEng Chemical Engineering programme at Imperial College London (ICL) is currently undergoing a review of its curriculum during which we have an opportunity to restructure our IL provisions. We believe that partnering with students and using student-led activities to guide and direct our future IL efforts can lead to higher levels of "student engagement in learning, increased staff enthusiasm for teaching, and a curriculum that meets students' needs" [10, p. 499]. Co-designing the curriculum in this way can serve to introduce new learning opportunities for both students and staff which could transform the way we teach and learn in our department.

2. Students as Agents of Change and the Move towards Small-Scale Student-Led Maker Spaces

We focus on the student voice to inform our IL activities in this paper given that students often have their own ideas of what contributes to an effective learning experience. They are the co-creators of their own learning [11] and we believe that understanding their perspectives of IL (during which they acquire knowledge through their own efforts) and using this to co-design student-led activities can lead to profound educational transformative experiences.

Although there is some uncertainty as to how IL activities can best be included within academic programmes [7], IL is often embedded and reflected in the design of many learning approaches, such as problem-based learning [12, 13], project-based learning [14], online learning [15] and flipped classrooms [6].

Based on the variety of approaches which exist, we use the work of Cukurova et al. [1] to simplify IL into the broad forms of guided and unguided IL. Guided IL generally refers to the guidance or involvement of others to shape the student's learning situation, which can include individual study and homework [16] as well as the IL associated with several instructional approaches, such as problem-based learning and flipped classrooms [6, 12, 13]. Unguided IL describes learning situations where the learner pursues or acquires knowledge without direct or implicit instruction; a good example is when students undertake further studies or pursue personal projects that are aligned with the curriculum but are not rooted in their assessment.

The use of maker spaces as a tool to promote independent learning and undertake personal projects is well-established in the literature [17–19]. There are many types of university maker spaces [20] and these can range from existing teaching labs to newly created spaces dedicated to interdisciplinary activities. These maker spaces serve diverse audiences and this often results in numerous ways to define the maker space. Within an engineering education context, we use the definition proposed by Oliver [18] who describes a maker space as a learning environment in which students pursue projects (often of personal interest) using advanced technologies while collaborating with peers in a community of makers.

Farritor [20] contends that these spaces serve as an important source of intrinsic motivation in which behaviour is driven by internal rewards. This type of motivation has been shown to strongly contribute towards the uptake of independent learning activities [21] which explains why students tend to participate in maker spaces of their own accord [20], are inclined to undertake self-directed activities within these spaces and wish to have more responsibility for their design and management.

The involvement of students to design and manage maker spaces within engineering universities is not new. Barrett et al. [22] provides a comprehensive review of 40 US-based university maker spaces which shows that the purpose, nature, resource-input and student autonomy within these spaces can vary widely. In terms of autonomy and supervision, the management of these spaces ranges from being entirely faculty-run to being wholly student-led.

Several examples exist in the literature which detail the collaborative development of maker spaces within universities as a joint effort between students and departments and where these spaces often managed exclusively by students [20, 23, 24].

Shelley et al. [23] describe a small-group project, initially carried out by a team of four students, to develop and design a physical maker space at the University of Alabama at Birmingham in collaboration with faculty members and other students. This can be considered to be a relatively high-resource endeavour (requiring buy-in from the University's management to grant the use of relevant building space), aimed at allowing students to take more control of their learning experiences and managed entirely by the student team.

Another similar undertaking is the iForge makerspace designed and developed in 2017 by a group of seven students and two staff members at the University of Sheffield [24]. The iForge is run wholly by students but is partly supported by university staff who provide advice and guidance regarding operational as well as health and safety issues. Student representatives, who have undergone the necessary training, supervise other student users in 3-hour shifts.

These examples show that the scale of student-led makerspaces can be sizeable, serving a large population of students (who must physically attend maker space facilities hosted at their universities) requiring significant university infrastructure and other associated resources. Many of these spaces also start off as a collaboration between staff and students to support a mix of university-based and personal projects.

We build on these ideas by using the term student-led maker space (SLMS) in this paper to denote maker spaces created, developed and managed solely by students at a relatively low-cost with minimal faculty support, which are generally located outside of the university setting to explore concepts related to their studies. We contend that the prevalence of affordable and user-friendly 3D printers (and associated technologies and software) has meant that engineering students are no longer physically constrained by university workshops and laboratories to pursue personally- and academically-related projects. This has reduced the need for departmental involvement from an operational and cost perspective and we believe that this freedom has allowed students to autonomously move maker spaces further away from university classrooms and other traditional spaces into homes, halls of residence, virtual spaces and beyond.

Within this context, SLMS are good examples of the unguided IL type of activity described above where students choose to undertake projects which they develop themselves that are aligned with the curriculum but are not rooted in their assessment. The strength of this approach lies in allowing students to make the relevant decisions to meet their own learning needs [25]; this can lead to the development of 'criticality' or the capability to manage knowledge in ways that will equip them for life [26].

3. Research Design

In this paper, we explore the concept of students developing and managing their own maker space by looking specifically at the experiences of two second-year undergraduate students at ICL who have created a SLMS, based on interdisciplinary collaboration, to develop and produce a working prototype of a 3D printed modular separation column. These two students came from the Chemical Engineering Department (Student A) and Mechanical Engineering Department (Student B) at ICL.

Students often have their own ideas of what contributes to an effective learning experience and understanding their perspective has been shown to influence and enhance reflection-on-action practices [27]; this can allow practitioners to reflect and review past practice with the purpose of improving future scholarship. For this reason, we focussed primarily on the students' perceptions of their experiences during their SLMS and based our research questions on understanding why students choose to undertake these kinds of projects and how their perceived motivation, project management skill gain, knowledge gain and need for departmental involvement varies across the project. We felt that assessing these particular variables could provide an initial measure of both the value and the ways of embedding similar student-led initiatives within our curriculum.

To examine these experiences, we used an explanatory case study approach which allowed us to focus on 'how' or 'why' a phenomenon or event happens or has happened [28]. Case studies are a detailed investigation of the development of a single event, situation or individual over a period of time [29]. Yin [28] goes on to classify case studies as being either explanatory, exploratory or descriptive in nature. Generally, exploratory case studies are used when there are no clear outcomes and can be regarded as initial research that attempts to identify patterns in the data. Descriptive case studies generally probe deeper than, and build upon, their exploratory counterparts as they focus on a pattern or feature in the data. Explanatory case studies have the narrowest focus and attempts to explain 'presumed causal links in real life interventions' [28, p. 15].

The presumed causal links here refer to the assumption that the project is dependent to some degree on sustaining student motivation, that the project builds both knowledge and project management skills and that there is a need for departmental involvement during the project. We were however mindful that any information obtained from our case study approach would be limited as it could not be used to make generalisations [30]. The approach however was considered very useful for generating hypotheses [30] and it is on this basis that we use the information obtained during this study as a starting point for further investigation into the wider use of SLMS within our curriculum.

Explanatory case studies also offer an opportunity to use a wide range of data collection methods including questionnaires, focus groups and life histories [29]. To examine our research questions, we asked the students to rank their perceived motivation, project management skill gain, knowledge gain and need for departmental involvement at key project stages on a scale of 0 (no or low) to 4 (very high) over the 6-month long project. We also conducted individual and joint interviews with the two students using a range of open-ended questions to not only assess the above variables but also to understand their motivation for wanting to undertake this project and to identify what they perceived as the risks, challenges and benefits arising during the process.

4. Why this type of Project? Facilitating Independent Learning through the Development of a SLMS

The rationale of the project came about by these students "*wanting to learn how the theory they had been taught could be transformed practically*" (Student A). In the first-year of the MEng Chemical Engineering degree at ICL, students are taught the theoretical aspects of the design of separation columns. This includes the related theory governing separation types (distillation, adsorption and stripping) as well as column types (plate, random and structured packing), along with the tools needed to design the columns. However, these students do not physically design their own (scaled-down) columns.

> "A lot of the reasons I wanted to embark on this project is, in most of our courses, we are taught the concepts and technical details of building something like a distillation column but rarely do we get to actually implement it." (Student A)

Similarly, in the first-year of the MEng Mechanical Engineering degree at ICL, students are taught elementary computer design and undertake a theoretical project to apply the key principles taught, but these often include very limited opportunities to manufacture, 3D print or transition from computer models to real life objects.

These gaps served as the motivation for these students to independently design and manufacture a working prototype of a 3D printed modular separation column which they felt would continue their IL by:

> "allowing us to acquire additional knowledge not taught in our respective curricula and gain experience which would be invaluable to engineers in industry." (Student A)

The tendency for students to proactively pursue IL activities as a means of expanding their knowledge base and making meaningful connections with the world outside the classroom, is often a result of possessing a deep approach to learning in which students have an intrinsic interest in the subject matter and wish to comprehensively understand and relate it to their personal experience or prior knowledge [31–33]. This is in contrast to a surface approach to learning in which students tend to be passive learners who are inclined to view learning tasks as enforced work, reproduce learning material and focus on test-oriented strategies.

The two students involved in this project displayed the characteristics of having a deep approach to learning being motivated by an intrinsic interest to obtain a greater understanding of the material they had been taught and the opportunity to apply these concepts practically. The involvement of student learners possessing a deep approach to learning with student-led activities is not entirely unexpected given that students must initiate and sustain these kinds of projects.

We are however mindful that not all students will have the same approach to learning; some may be entirely surface learners and some may use both deep and surface approaches to achieve their goals depending on what is required and the conditions under which they are learning [33]. This is referred to as a strategic approach. Embedding student-initiated and led projects within engineering curricula as means of facilitating IL therefore requires a careful consideration of the learning characteristics of affected students as well as the inclusivity of the experience. Not all students will want these kinds of projects or feel that they can do well at them. These become important considerations influencing the continual interest and uptake of embedded student-initiated projects.

5. The Development and Project Stages of the SLMS

After a review of the associated literature, the students embarked on their SLMS at the start of the 2018/19 academic year. Their initial project design was based on a similar research project undertaken by Mardani et al. [34] which involved the design of a 3D printed distillation column. This however involved the use of a column design that they had not been introduced to as well as the use of a relatively expensive 3D printer. To overcome these limitations, the students focussed on the design and construction of a plastic 3D printed distillation column based on their existing knowledge which could then be manufactured at a hobbyist-level budget.

Fig. 1 provides a timeline and the associated SLMS project activities. It is important to note here that upon reflection, the students felt that at this point in the project a more careful consideration of the project goals and its deliverables could have led to a greater success. Although they had not initially considered a firm project end date, Fig. 1 shows that the project lasted for roughly 6 months and that future work to make their designs more robust is ongoing.

> "We had not put a great deal of thought into what exactly we were building the column for or how we would evaluate it. In addition, as it was end of summer and classes hadn't started, very little care was put into how we would manage our time during this project." (Student B)

Being a student-led activity, the initial design and project conceptualisation were also completed without the guidance of departmental staff. In retrospection, the students felt that seeking academic and technical help from related staff at the start of the project could have mitigated some early project challenges. Several of these challenges led to the overall project having two iterations (shown in Fig. 1) as it became evident to the students during their first testing phase in November 2018 that certain knowledge gaps in both the design and manufacturing of the column existed for which they eventually sought advice from their lecturers.

The following section provides a brief overview of Iterations 1 and 2 which are shown in Fig. 1.

5.1 Iteration 1: Design, Production and Testing

The goal at the start of the project was to design a packed 3D printed distillation column. Engineering

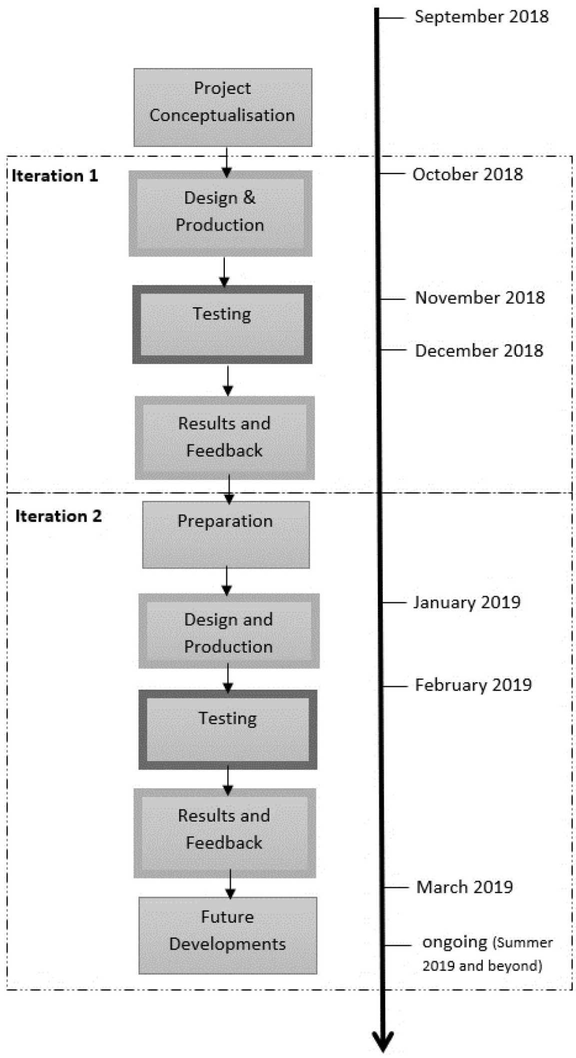

Fig. 1. The SLMS project stages and associated timeline.

drawings were produced (Fig. 2a) and a variety of modular subsections (Fig. 2b) were then 3D printed using polylactic acid (PLA) filament. Minimising production waste during the 3D printing process was a priority for these students and the use of a smaller 3D printer allowed both project costs and waste to be kept low.

After the subsections had been printed and assembled (which took approximately 2 weeks), the students approached academic staff for feedback mainly through corridor and other informal discussions. Several design flaws were then highlighted with the majority of these involving the lack of proper sealing mechanisms, column support, uncertainties as to how the inlet and outlet streams would be connected to the associated pipework and the availability of more effective internal packing material (where the students had decided to 3D print these themselves which proved to be costly and time-inefficient).

As these flaws would cause some concern during the testing phase, the students quickly modified their design by adding O-rings to ensure proper seals, altering the inlet/outlet connections to ensure proper connectivity and adding suitable support mechanisms (Fig. 2c). These small modifications allowed an initial test to be carried out in November 2018 which would not have been possible without the help and support of academic, technical and workshop staff to procure laboratory space and equipment (such as pumps), to ensure adequate health and safety and to provide expertise and supervision during the test.

Although the students attempted to modify their column to account for the above design issues, the column unfortunately experienced significant leaks and flooding during testing and selected portions of the column were susceptible to breaking and cracking due to the thinness of the walls and connections and the brittle nature of PLA material. This limited the amount of testing time and resulted in generally unreliable results which led to the students feeling despondent and frustrated after their first testing phase.

> "After the first failed run, I felt quite demotivated and did not particularly want to continue a project that I felt wouldn't be successful. However, I still felt like the process had taught me a lot, not only about engineering, but about time management and budgeting." (Student A)

> "The first test of the first column was, as I perceived it at the time, a complete failure. I simply did not comprehend that what I made was so faulty and that our organisation as a team was non-existent; at that point I was really tempted to quit, and had there not been my teammate to push me on I probably would have done so." (Student B)

Although initially discouraged, the students undertook further research to bridge knowledge gaps which in-turn motivated them to return to their designs and address several of the design shortcomings they had encountered in their first iteration. At the end of this process, the students decided that it would be more realistic to design an adsorption column instead of a distillation column since the limitations of the PLA material restricted the temperature and pressure that could safely be used during distillation. Based on their lecturer's advice, the students decided that an adsorption column (which does not require heating) should be the focus of the project. This subsequently required several modifications which resulted in a second iteration (Iteration 2) that is described below.

5.2 Iteration 2: Design, Production and Testing

After taking a break from the project towards the end of the first term to concentrate on their exam-

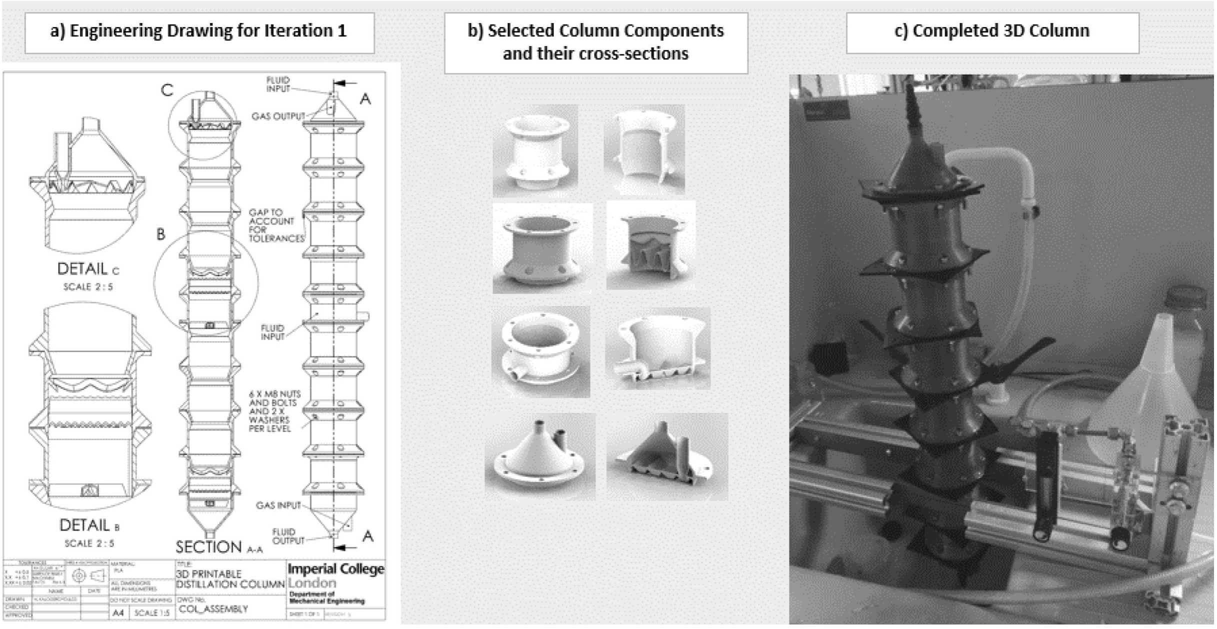

Fig. 2. Design, Production and Testing of Iteration 1.

inations, the students resumed their work on a revised adsorption column in January 2019. This involved developing and fine-tuning a new design (Fig. 3) that included O-ring grooves, an increased wall thickness, stronger inlet and outlet pipe connections, the addition of a gas distributor to avoid flooding the inlet gas stream and heat treating the components prior to assembly to minimise material inconsistencies.

Many of these changes were done with the guidance of related academic staff who attempted to direct the students towards relevant research resources. Academic and technical staff also provided a small design review prior to the assembly and construction of the second iterated column and the students believed that this support led to the second iteration having a smoother and seamless production and assembly than the first column.

Building on their experiential learning, the students also felt that they were able to test the second column much more effectively given that a greater deal of planning had been done prior to the testing

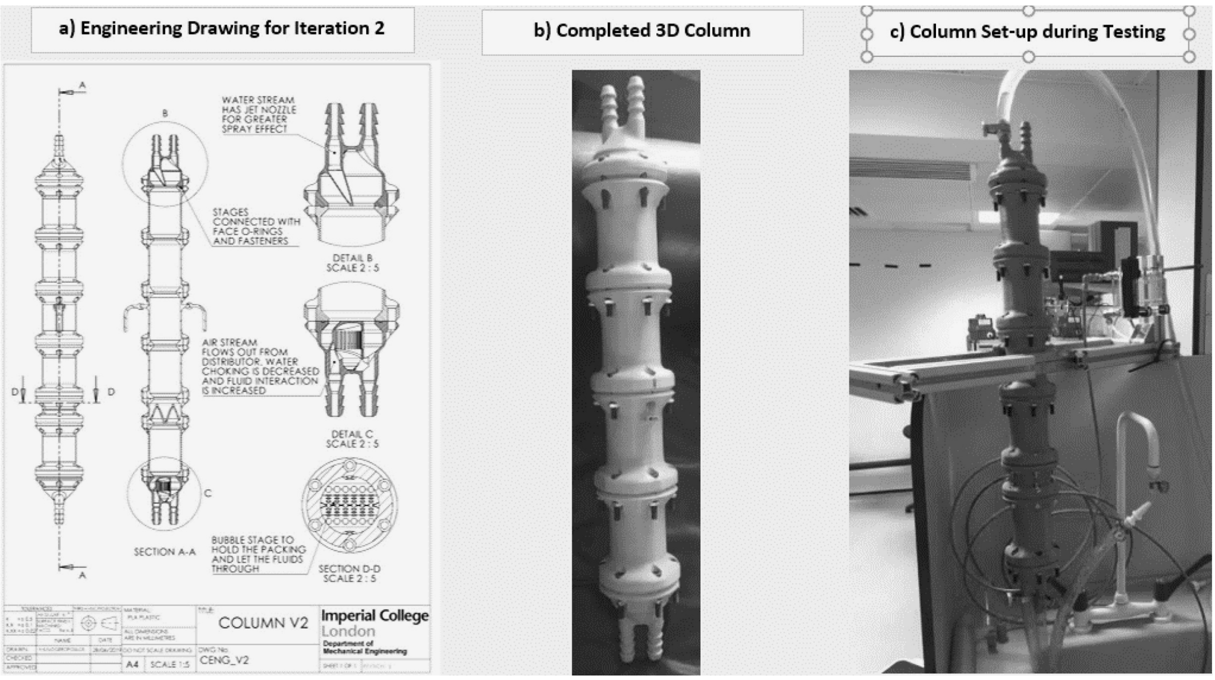

Fig. 3. Design, Production and Testing of Iteration 2.

which allowed the test to be carried out in a more systematic manner. This significantly reduced the need for academic and technical input during the test as fewer leaks were observed and the column remained intact throughout the experiment. This led to more reliable results and a better understanding of column performance which in turn resulted in high levels of self-efficacy and motivation.

> "Having spent more time designing and planning the second iteration, the actual test felt a lot more structured and I felt a lot more confident in what we had produced. Although this could have been because of the feedback we had been given from academic staff, I really felt that we had produced something that we could be proud of and that demonstrated the knowledge we acquired during the project." (Student B)

6. Mapping Student Perceptions of their Motivation, Project Management, the need for Departmental Involvement and Perceived Knowledge Gain across the SLMS

The above section highlights some important issues that the students faced during the development of their SLMS particularly in the areas related to motivation, project management and the need for departmental support throughout the process which is the focus of Research Question 2.

To further examine these issues, we interviewed the two students using a range of open-ended questions and asked them to rank the following specific variables on a scale of 0 (no or low) to 4 (very high) over the 6-month long project. These were:

- motivation,
- project planning and management skills,
- the need for departmental involvement,
- the perceived gain in knowledge and new information.

The results are shown in Fig. 4.

Given that students are the driving force behind student-led activities, it was not surprising to see from Fig. 4 that the students involved in this project were often highly motivated during their SLMS. The only major exception to this was directly after the first testing phase (November 2018) when the students felt despondent and frustrated due to a lack of column failure and poor data results.

Generally, however we found that the tendency for these students to display high levels of motivation and be involved in student-led initiatives were due to their deep approach to learning and enhanced achievement goal orientations which was fuelled by the students wanting to develop and display competence (in whatever form it is conceptualised by them) [35].

> "The idea of running our own project where we were fully in control gave me a great sense of excitement and desire to really push myself. . . Thus I wanted to show myself that, not only did I know the things that I had

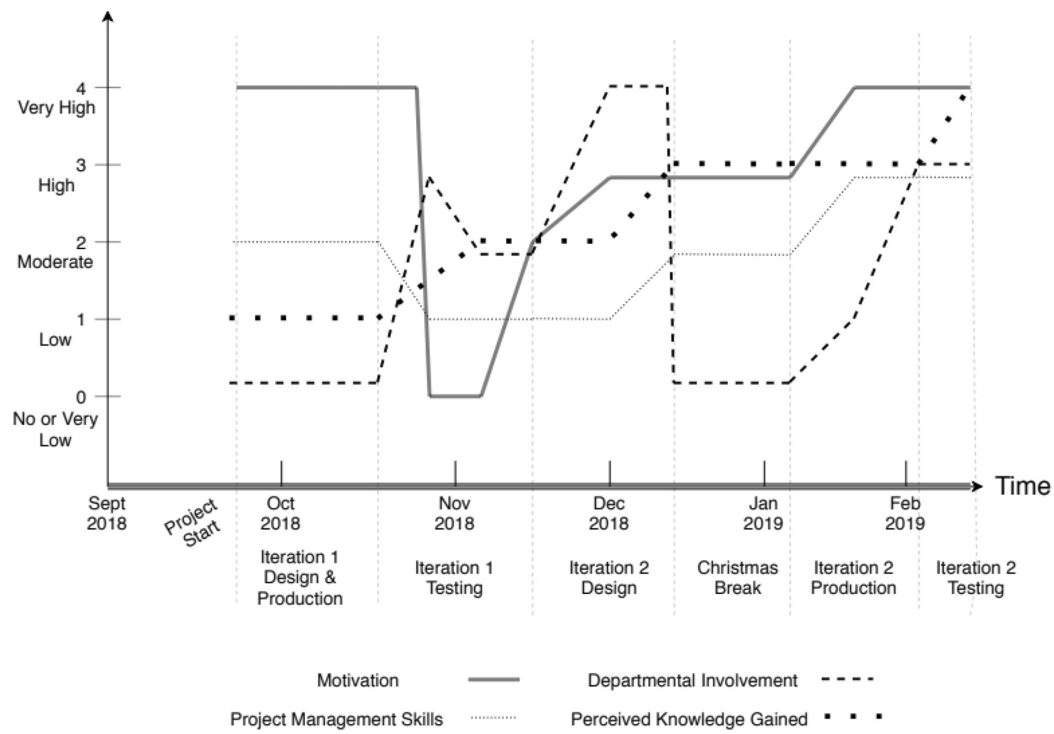

Fig. 4. Mapping Student Perceptions of Motivation, Project Management, Departmental Involvement and Perceived Knowledge Gain across the 6-month SLMS.

> been taught, but I actually knew how to implement as that is, after all, the essence of engineering.'' (Student A)

In terms of departmental support, although we propose in this paper that a SLMS is created, developed and managed solely by students with minimal faculty support, the students felt that an increased academic presence or consultation particularly during the early stages of the SLMS could have mitigated several early design flaws and led to an earlier project success. This introduces the idea, and risk, of students having a limited expertise of selected engineering concepts to design realistic and robust project goals and deliverables. This can severely reduce SLMS success and motivation particularly when students are in the initial years of their programme.

> ''The difference between a student-led and department run activity became apparent when we actually starting to run the column as our lack of foresight and planning meant that many potential flaws had not been considered and the experiment did not run as smoothly than most other academic projects do. . .
>
> This might have blinded us to the actual intricacies of what it takes to actually run such a project and gave a false sense of easiness.'' (Student B)

The students were however mindful that an increased departmental involvement especially in the early stages of the project could reduce their own experiential learning as:

> ''. . . each mistake made gave me an opportunity to learn a new concept (such as industrial standard components, the importance of time management, good experimental behaviour) which I might not have learnt in any other environment.'' (Student A)

In terms of the level of perceived knowledge gain, the students felt that this rose and continued to grow throughout the project, culminating to a very high level at the end of the project. The changes in perceived knowledge gain as well as project management skills were found to be strongly tied to each specific project stage and Table 1 also provides more information of how these varied across the project stages.

7. Exploring the Benefits and Challenges of the SLMS

Understanding the particular risks and benefits that students perceived throughout their project was also a significant part of this study since we believed that this would allow us to better understand the ways that these SLMS could be embedded within our programmes as well as mitigate any challenges that might arise throughout the process.

Table 1 provides a synopsis of the key benefits and challenges that the students experienced throughout their SLMS. It also explores several additional themes that are not represented in Fig. 4 which include:

- the freedom to work in accessible spaces (not confined or controlled by the university),
- the possible limited availability and access to academic staff and other university resources and
- the need to carefully balance their IL activities with their other work commitments.

In terms of a physical flexible workspace away from the university, the students found that it was somewhat easier to work from home since they were not restricted to laboratory opening hours and the need to have their activities supervised by academic and technical staff who would usually work regularly set hours (9am–5pm). However, this experience was somewhat limited by a lack of support when it came to trouble-shooting and assistance. The need for departmental support and resources during the testing phases also required students to work in laboratories and this reduced some of the freedoms associated with the SLMS.

> ''Working at home made it so much easier for us to work at this project. We were not restricted by a timetable, we had full control over what we could make and when we could make it. We could reduce parts overnight or during weekend, thus we had more time to iterate designs and troubleshoot problems. Only difference we experienced from other workspaces was that there was no one else to ask for help or to ask for advice, so we had to ask the academic staff for their expertise.'' (Student A)
>
> ''The only times we were able to perform the experiment within the department's premises was when staff was there to supervise which would either be during teaching hours or after classes had finished (requiring them to stay longer).'' (Student B)

The students also felt that while the availability and access to academic staff contributed significantly to the project's success, they were mindful that this support was potentially limited due to staff workload and other commitments as:

> ''. . . the academic staff themselves could not allocate much time towards this project as they had their own projects and modules to take care of first.'' (Student B)

In addition to staff workload and commitments, the students found that there was the need to carefully balance their own university work and SLMS commitments especially as the SLMS was not assessed as part of their course. This sometimes meant that the SLMS was given a lower priority particularly during the busier times. However, as the students were highly motivated to complete their SLMS objectives, this led to the development of stronger project management skills and personal responsibility as they began to allocate specific times

Table 1. Summarising the key benefits and challenges of developing the SLMS at each project stage

		Benefits	Challenges
Iteration 1	**Project Conceptualisation**	• No deadlines or time pressure. • Students can think specifically about the knowledge gaps. • Allows students to think outside the box.	• Limited expertise of subject matter. • Poor project management. • Poor time and resource budgeting. • Poor development of project goals and deliverables.
	Design and Production	• Freedom to work in an accessible space, not confined to university hours or spaces. • Interdisciplinary learning. • Testing and broadening existing knowledge base.	• No gain of new knowledge. • No sense of budget.
	Testing	• Experience in lab setup, monitoring and data logging.	• No or poor laboratory planning. • Assigned a set number of supervised hours in the lab which results in rushed experiments and unreliable data.
	Results and Feedback	• New knowledge ways learned. • Results showed the gaps in knowledge that needed filling.	• Negative results demotivated the students. • Danger of neglecting project entirely.
Iteration 2	**Preparation**	• Previous feedback resulted in enhanced design parameters for next stage. • Budget and timeline firmly established.	• Too big a gap between new and old iteration. • Many more departmental resources required and used.
	Design and Production	• Gained knowledge of standards and appropriate design methods. • Worked under budget. • Designed new parts.	• Needed to make bespoke parts which required a learning curve. • Christmas break broke the workflow.
	Testing	• Lab properly planned and set-up beforehand. • Proper lab preparation and data gathering methods established.	• New equipment used. • Preparations did not fit new parts.
	Results and Feedback	• Prior efforts and testing made it easy to know what to look for.	• Reduced knowledge gain.

for the project around their existing workload and to produce detailed Gantt charts to match project objectives with realistic timescales.

8. The Value and Implications of SLMS for Departments

Although we focus on the student perspectives of their SLMS experiences throughout this paper, their responses have led us to question the role of SLMS within our engineering curriculum and the ways that our department can support such initiatives. Based on discussions with the selected academic staff who supported this SLMS, we believe that the SLMS satisfies selected desirable criteria where it is educationally valuable, fosters interdisciplinary collaborative learning, encourages entrepreneurship and promotes independent and life-long learning.

Building and continuing the successes of SLMS however requires particular kinds of departmental support specifically relating to the access and availability of academic staff and laboratory scheduling which is echoed in the student responses. We believe that assigning an academic mentor would be extremely beneficial for most students embarking on SLMS-type projects, but we are mindful that for some departments, staff resources and workloads may already be constrained during routine academic year activities.

During this work, we found it relatively easy and manageable to devote adequate resources towards a single project like the 3D printed modular separation column described above. This will become progressively difficult if both the number of enrolling students and SLMS projects were to increase. Special consideration must therefore be given to the introduction of SLMS within engineering curricula and the ways that these can be supported in order to integrate and enhance individual student experiences.

Although assigning an academic mentor can help mitigate design issues earlier, this has the potential to reduce the innovation, experiential learning and independent learning which are key facets of the SLMS. In addition, the inclusion and possible mandatory undertaking of SLMS-type projects within engineering departments might also prove to reduce some student experiences as not all students will want to work on these kinds of projects (perhaps due to varying achievement goal orientations) or feel they can perform adequately when compared to traditional staff-influenced projects.

There is also the risk of students having a limited expertise to design realistic and time-effective project objectives particularly if they are in the earlier years of their programmes. Embedding SLMS-type projects therefore requires a careful consideration of these risks as well as of the inclusivity of a range of learning orientations and styles.

9. Discussion

Concerns related to student satisfaction, expectations, engagement and attrition have led higher education institutions to transform their educational approaches and adopt contemporary ways of delivering course material [36]. In this paper, we explore the use of SLMS projects as one such contemporary way to inform the shape and structure of allocated IL hours within engineering academic programmes.

Student-affiliated maker spaces within universities are becoming increasingly prevalent [20, 22–24]. The scale of these endeavours can vary widely but they typically tend to be sizeable, serving a large population of students who must physically attend maker space facilities hosted at their universities. This often requires significant university infrastructure and associated resources. Many of these spaces also start off as a collaboration between staff and students to support a mix of university-assessed and personal projects.

The prevalence of affordable and user-friendly 3D printers (and associated technologies) has meant that engineering students are no longer physically constrained by university workshops and laboratories to pursue personal and academically-related projects. This can reduce the need for university and departmental involvement from an operational and cost perspective and provides an impetus for students to autonomously move maker spaces further away from university classrooms and other traditional spaces.

We build on these ideas in this paper by denoting SLMS as maker spaces created, developed and managed solely by students at a relatively low-cost with minimal faculty support, which are generally located outside of the university setting to explore concepts related to their studies. These may also be used to supplement IL rather than wholly form part of an assessment. Understanding what motivates students to develop these spaces, how their projects progress and how these spaces grow over the project can help universities and departments better support these kinds of activities which in turn can influence the shape and structure of allocated IL hours within engineering academic programmes.

Our research design centres upon using an explanatory case study approach to examine the development and progression of an inter-disciplinary SLMS created by two second-year undergraduate students at ICL. Our research questions focussed specifically on the student experience to better understand the motivating factors involved in student-initiated projects (leading to the development of a SLMS), the perceptions of knowledge and skill gain during the projects, the perceived need for departmental involvement as well as the perceived benefits and challenges of undertaking these types of projects. We were mindful that any information obtained from our case study approach could not be used to make generalisations but could generate hypotheses which could then be used as a starting point for further investigation into the wider use of SLMS within our practice.

Initial findings show that a key motivator of the SLMS was the intrinsic interest that the students had to shape their IL by applying the theoretical concepts they had been taught in class in order to build a more comprehensive knowledge base. This is characteristic of students who exhibit a deep approach to learning [31–33] which tends to stimulate and drive student-led activities. This becomes an important consideration affecting the continual interest and uptake of embedded student-initiated projects within engineering curricula as not all students will display the same range of approaches to learning needed to initiate and sustain student-led activities. Equally importantly is that not all students will want these kinds of projects or feel that they can do well at them leading to a further examination of the inclusivity of the experience.

Sustaining motivation throughout the SLMS is also particularly important given that students are the drivers of the SLMS and therefore have an ultimate responsibility for its success and completion. Fig. 4 shows that although motivation levels varied throughout the SLMS (which were lowest during column failure or when students obtained poor data), the students involved in this project were often highly motivated to complete their project deliverables and rework project stages accordingly. This was attributed to their deep approach to learning and enhanced achievement goal orientations.

Although we propose in this paper that a SLMS is created, developed and managed solely by students with minimal faculty support, the students felt that several early design flaws could have been reduced by consulting with academic staff earlier. They also indicated that this early intervention could have possibly better helped them design more realistic and efficient project objectives.

This introduced the risk and challenge of students having a limited expertise of selected engineering concepts to design realistic and robust project goals and deliverables during student-initiated activities which in turn could tend to reduce SLMS success and motivation particularly when students were in the initial years of their programme. The early appointment of an academic mentor or consultant was seen as a possible means of reducing these challenges by bridging knowledge gaps and mitigating the design of unrealistic project objectives. This also indicated that perhaps the level of student autonomy in SLMS activities could best be undertaken progressively, with more guidance being provided to students in their earlier years gradually leading to a greater responsibility for project design and deliverables for students in the later years of their programmes. The students however were mindful that this had the potential to reduce the innovation, experiential learning and IL of the SLMS experience.

The perspectives of staff and departments were also equally important towards understanding the value and challenges associated with using SLMS. Several academic staff involved with this study indicated that the effective management of departmental resources throughout the SLMS, particularly the recommendation of a dedicated SLMS mentor, could be a potential challenge in light of increasing student numbers and staff workload. Managing a small number of SLMS was considered to be potentially easy and feasible but larger numbers would require a careful consideration of resources, which for some departments might already be constrained during their routine academic year activities. Special consideration must therefore be given to the introduction of SLMS within engineering curricula and the ways that these can be supported in order to integrate and enhance individual student experiences.

10. Conclusions

This paper examines the development of a small-group SLMS and seeks to better understand from a student perspective the motivating factors which underpin student-initiated projects, the perceptions of knowledge and skill gain during student-led projects, the perceived need for departmental involvement as well as the perceived benefits and challenges of undertaking these types of projects.

An explanatory case study was used to look specifically at the experiences of two second-year engineering undergraduate students. This research design and the small number of research participants meant that no generalisations from this study could be made; however it was felt that a deeper and rich understanding of how SLMS develop and progress could be obtained by exploring the students' experiences. This information could then be used to guide both the delivery of other types of student-led activities as well as the wider use of SLMS within our practice.

Key findings showed that a deep approach to learning and enhanced achievement goal orientations were important factors pushing students to participate in their SLMS activities. Although more work in this area is required, these initial findings have implications for inclusivity and for the continual uptake of embedded student-initiated projects as not all students will display this same range of learning characteristics needed to initiate and sustain student-led activities. The students also felt that their knowledge gain and project management skills increased throughout the project, culminating to a very high level at the end of the project.

Managing student motivation throughout the SLMS was also found to be tied to the early involvement of an academic mentor, particularly when the students were faced with the challenges of designing realistic project objectives, recovering from project failures and dealing with uncertainties and gaps in their knowledge bases.

Despite these challenges, the students in this study perceived that the benefits of SLMS included a rewarding and collaborative IL situation which was educationally valuable, built project management skills and allowed the freedom to work in accessible spaces that were not confined or controlled by the university. These are key findings which add to the existing literature and help inform the ways that SLMS and other types of student-led activities can be embedded within engineering curricula to shape and structure IL.

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