A Materials Library Created by Students, for Students: A Valuable Learning Resource

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Abstract
A materials library, like other curated collections, contains valuable reference "materials". It is highly desirable for universities, especially those with strong engineering and materials science programmes like Queen Mary University of London Engineering School (QMES). Access to a materials library allows students to see, touch and experience a wide range of materials first-hand. QMES incorporates the comprehensive materials library project as part of its 2nd year Personal Development Planning module. The original project requires students to research potential materials, select one, and competitively market it to their peers, build a website about the material and finally apply appropriate techniques to prepare a sample for display in the library. In year 3 the project is expanded in another module. Students carry out characterisation experiments on their materials and expand their websites with primary test data. This affords an opportunity for students to integrate additional knowledge they have gained in other modules and to see how it might be used in in real world applications. To test the effectiveness of the project in terms of students' self-assessed skills development, and to enhance the pedagogy of the project, a survey was conducted on the original material library project and the year 3 additional developments. The results showed that skill development was high, which supported transferable and technical skills for young engineers, and factors such as delivery and support need to be considered when developing the project.

Keywords: Materials Library, Materials in Design, Materials Selection, Problem-Based Learning

Introduction

Materials libraries are a valuable reference for engineers to truly understand materials and to provide support when selecting appropriate materials for a specific application (Akin & Pedgley, 2016). In an educational setting, a materials library provides students with the opportunity to see, touch, feel and experience the materials. As a tactile resource, a library can be used to engage all the senses, in a way that virtual or paper-based analogues simply cannot do. A materials library allows students to fully engage with the material, providing a learning opportunity which facilitates immersion and deepens appreciation of the unique character of each material.

Materials selection has components of both art and science. The science part is relatively easy for engineers to internalise. For example, if an engineer needs to select a material for a beam, (Figure 1) students can use well known equations to work out how stiff the material needs to be to support the load. However, it is much more challenging to work out how the beam "feels" and how it will be perceived by the user. These "aesthetic attributes" may be analogous to materials properties in some cases. However, they are often impossible to calculate and very challenging for engineers to visualise. Aesthetic attributes require first-hand experience. A materials library allows the students to experience the materials with their own senses, to develop an appreciation of how the material will behave and be perceived by the user.

Figure 1: Balance beam *(Pixabay, 2020)*

Universities are always looking for ways to engage the students and enhance their learning experience. This becomes increasingly important when academics recognise different learning styles. A popular approach to promote active learning and engagement is to introduce problem-based learning, (Helle, Tynjälä, & Olkinuora, 2006). Problem-based learning (PBL) is an approach that at its core fosters collaboration and communication. The materials division at Queen Mary University of London were early pioneers of PBL and have continued to refine and expand the practice (Bushfield & Peijs, 2003). Crucial aspects of PBL projects involve developing solutions to a problem, they require students to use initiative and they commonly result in an end product (Blumenfeld, Soloway, & Marx, et al., 1991). The problem should be significant in terms of grades, substantial in terms of effort and duration required. They should serve to organise and drive activities that allow exposure to a variety of educational activities.

In PBL teaching staff are involved in an advisory role and should not to provide answers / solutions as the process of working through the problem is an important part

of the learning activities. PBL also supports interdisciplinary competences as the pedagogy encourages collaboration and the flexibility, allowing touch points between modules to be built into the project. PBL enables practical application of learned knowledge into the degree programme which is a vital ingredient as graduates often cannot recall the knowledge or how to use it (Ruhanen, Axelsen & Bowles, 2020). This is especially important if the knowledge is difficult to appreciate through traditional teaching approaches. Together, the experience gained through discipline specific practice enhances capability and ultimately employability of our students. The advantages offered by PBL and the fact that QMES students are well versed in delivering projects, provided an obvious choice to use this approach to deliver the learning objectives required from the materials library component of the module.

Interdisciplinary competence is something which is highly sort after in engineering education. It is part of engineering accreditation requirements (ABET, 2019) and a distinguishing factor embraced by many leading universities. The ability to be a high functioning member of a multidisciplinary team is an essential skill and highly prised by engineering companies.

QMES students are exposed to PBL in a wide range of modules including experimental modules which consist entirely of projects, teaching modules which contain projects that support traditionally delivered content, and, modules which contain a wide range of projects delivered using flipped classroom methodologies. The projects within the PDP module are aligned with the "Project Component" model described by (Morgan, 1983), they are interdisciplinary in nature and have a real-world objective. The project integrates concepts learned in the various PDP modules but also requires students to integrate knowledge from a range of other modules. As the materials library project is linked to the students' core area of expertise and the output of the project will be used by students, it most closely aligns with the "professional motives" category defined by Heitman (1996).

Enhancing students' employability skills is a vital learning outcome of PDP. All too often undergraduate students are concerned only with their academic performance. Skills such as time management, critical thinking, research, employability and presentation skills are often undervalued by students. However, as they are highly prized by engineering companies, students need to be given the opportunity to develop them. Similarly, support for life-learning and professional practice frequently take a back seat to academic grades, but are essential for all engineers. It is also key that students can effectively communicate within their discourse community as students, but also later as engineers. Engineers are required to communicate with a variety of people including stakeholders, customers, suppliers and also other engineers globally, so an ability to code switch is important. Oral communication is so important that employers are very selective when it comes to potential engineering employees (Irdus, Salleh and Abdullah, 2011). STEM graduates are often criticised for their lack of transferable skills (Riemer, 2002), perhaps because students do not realise the value of these transferable skills to their future careers.

This work aims to address three research questions:
1.   How well does the materials library project enhance the (self-evaluated) transferable skills of the student?

2.   How effective is a materials library project in supporting undergraduate engineering programmes?
3.   What are the main factors in developing a pedagogically sound materials library project delivered by PBL?

Materials & Methods

Participants

At QMES, the materials library project was initiated in 2019 with the inaugural second year cohort (240 students) and further developed in 2020 to better meet the academic needs of students. In the third year, the materials library project is used as a basis for a project within the materials characterisation module. The second cohort of students completing the materials library project consisted of 227 students. The main challenges with this year's delivery was associated with the Covid-19 pandemic. This meant the format of the project needed to be adapted to reflect a blended learning approach.

Course structure and design

Year 2 Materials Library Project

The year 2 materials library project runs for 26-hours. The project is divided into four parts:
1.   Completion of a poster (pairs)
2.   A poster competition (pairs)
3.   A recruitment fair (group)
4.   Building a website (group)

Table 1 shows an outline of the project schedule. The two columns on the left-hand side shows the teaching plan of in-class activities and the learning objectives. The two columns on the right-hand side shows students' out of class activities, groupings and the skills students develop at each stage of the project.

Table 1: Project schedule

In-class	Learning objectives	After class	Student grouping and skills developed
Week 1: Introductory lecture	To understand the requirements of the materials library and safety aspects of materials.	Students choose material and make contact with companies.	Pair work Skills: networking and written communication
Weeks 2, 3 and 4: Guided, independent study on posters	To understand the features of a scientific poster. To be able to write an appropriate poster literature	Students work on each section of the poster and add it to the Wiki.	Pair work Skills: academic writing

	review and abstract. To use engineering judgement to decide on poster SDS information.		
Weeks 5 and 6: Tutorials	To be able to improve work based on feedback and discussion.	Students receive feedback and make improvements to posters.	Pair work Skills: academic writing
Week 7: Poster assessment	To be able to assess other's work as a skill for a future manager/mentor.	Students prepare for the recruitment fair	Pair work Skills: interviewing skills
Week 8: Recruitment fair	To practise communication and interview skills to sell yourself.	Students hold a team project management meeting.	Group work (8) Skills: project management, teamwork
Week 9: Lecture on website design	To understand how to build webpages. To think about the importance of design and layout of webpages. To be able to use the 7 step plan during this project.	Students start website creation.	Group work (8) Skills: website design and academic writing
Week 10: Guided, independent study on project and team management	To understand how to manage a larger group of people. To be able to use a project management tool (Gantt chart) to plan a project.	Students hold team meeting to arrange tasks.	Group work (8) Skills: project management and teamwork
Weeks 11 and 12: Tutorials	To be able to improve work based on feedback and discussion.	Students receive feedback and make improvements to websites.	Group work (8) Skills: academic writing
Week 13: Website assessment	To practise oral communication and presentation skills.		Group work (8) Skills: presentation and spoken communication

Students are given the full timetable at the start of the project so they understand the expectations from the beginning. This approach combined with a student-centred delivery supports students' time management, project management and organisational skills as they are entirely responsible for completing the deliverables within the project requirements, according to the defined timeline.

The first deliverable was a poster. Pairs of students researched potential materials and selected their material, and then created a scientific style poster about it. In the poster, students needed to consider technical aspects of the material, health and safety regulations as well as applications. The second deliverable, the poster competition, is highly competitive; the choice of materials, quality of the poster and the students pitch are important elements in the competition. During the learning process, members of each pair provided support both linguistically (they are required to speak English in all sessions) and with technical knowledge, research / transferable skills competence (Ohta, 2001) to their partner.

The poster competition is peer assessed. The posters which gain the most support are the materials which progress to the next stage of the project. Students take part in the poster competition by listening in groups to presentations from each pair before asking questions. At the end of the session each student votes for their favourite posters; this makes them potentially eligible to become part of the team who will take that material to the next stage of the project. The peer evaluation process promotes learner autonomy (Yang, Badger & Yu, 2006) and builds significant buy-in from students.

The 2020's poster presentation had a total of 112 posters across the cohort, with 28 being chosen as the winning posters. In more normal times the presentation is held in a traditional face-to-face setting. This generates a high energy environment with students "selling" their concept and developing transferable skills while doing so. This year as the students were in their family homes, the event was hosted through Tencent/VooV meetings with voting taking place on WeChat. The academic team involved noted that the same energy and degree of interaction was not possible with the online approach. However, more time was available for students to listen to presentations and ask many more questions than during face-to-face delivery.

The winning 28 pairs then held a recruitment fair to select 6 other team members. This gave students the opportunity to practise "selling" themselves by outlining what they could contribute to the team. The event was designed to be reflective of an interview of the students' first engineering job. Students had the opportunity to practise the interview techniques they had learned in earlier PDP projects. The poster competition and subsequent interviews gives students additional opportunities to develop their communication and other transferable skills. A larger groups size than would be typical in QMES was selected to better reflect authentic, interdisciplinary projects. Having a larger group gave students the opportunity to work in smaller, sub-teams which would be required to deliver within the tight timeline. Sub-teams allow more students to take a leadership role. Similarly, all students were able to practise time management and working with diverse actors, an essential workplace skill.

Websites were created through QMUL's customised Moodle deployment. Students all had experience of creating individual webpages pages but had not created multiple

page website and certainly had no experience of contributing to a collective, curated database i.e. the materials library. This meant that design and layout, navigation and access were new areas that needed to be considered to fully exploit the technology. Using a tool that students were familiar with, but enhancing their skills meant that they were able to improve their technological skill set while focusing on the core engineering aspects of the project.

To ensure easy access to the websites, students created a QR code for each display in the materials library. This was linked directly to the specific website for the individual materials which allowed direct access to the websites by scanning the QR code on any mobile device. The sites can also be accessed through the QMES Materials Library landing page[1].

Guided, independent study (GIS) sessions gave information on a specific topic such as how to write an abstract or a literature review for the posters. Topics were introduced in lecture style classes followed by a question and answer session from the students and group work to put what they have learned into practice. This gave the students opportunities to clarify any points, helped the students feel supported and guided throughout the project, as well as to reinforce the learning objectives by applying the concepts.

Additionally, in both the poster and website elements of the project, students received tutorial sessions where they completed work and received feedback before the session. Tutorials helped manage time effectively by clarifying any misunderstood points and asking thoughtful, relevant questions. This helped students develop and improve their work throughout the project, which is important for learner development (Ferguson, 2011).

Throughout all of this, students complete weekly project management forms to track their progress and develop their project management skill sets. Group portfolios were also created to assist in the knowledge transfer between the group and teacher, so group progress could be tracked as well as identifying any potential problems. All of which are essential elements of project management (PMI, 2017).

Year 3 Materials Characterisation Project

The materials characterisation sub-project is a 10-hour project, consisting of three parts: writing a proposal for characterising the material, characterising the material and then adding that information to the material's existing website. The proposal contained 2 or 3 characterisation techniques, no more than a page in length. Each technique needed to include the following points:
- Briefly state the principle on which the technique works.
- How well could you identify the material? How precise and accurate is the method? Does the technique give you quantitative or qualitative information?
- Show some example data that is representative of the type of material and a description of what the data shows (due to COVID it was not possible to actually

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[1] https://hub.qmplus.qmul.ac.uk/view/view.php?homepage=qmes-materials-library-project&page=qmes-materials-library-2020

characterise the materials this year so students were tasked with sourcing appropriate data from relevant journals)

All work was conducted in self-assigned groups of 5 or 6 students. Students were given the option to deviate from their original materials library group which helped groups that had not worked harmoniously or were interested in a different material to explore other avenues. The group was also required to complete project management forms and peer assessment of contributions.

Experiment design and research instruments

For each project, a survey was conducted with each year group of students. The year 2 survey consisted of 9 questions: 3 Likert scale questions, 2 multiple choice questions and 1 ordering question related to the project and its structure, how useful the project was and what skills were developed, and 3 open ended questions relating to favourite/least favourite parts of the project.

Similarly, the year 3 survey consisted of 6 questions: 3 Likert scale questions, 1 rating and 3 open-ended questions, related to the aspects of the characterisation project, favourite/least favourite parts of the project and future use of the materials library.

Results

Year 2 Materials Library Project

168 students answered this survey. Figure 2 shows that 43% of students' favourite stage of the project was working with their material, followed by 26% indicating that working on the poster was their favourite part.

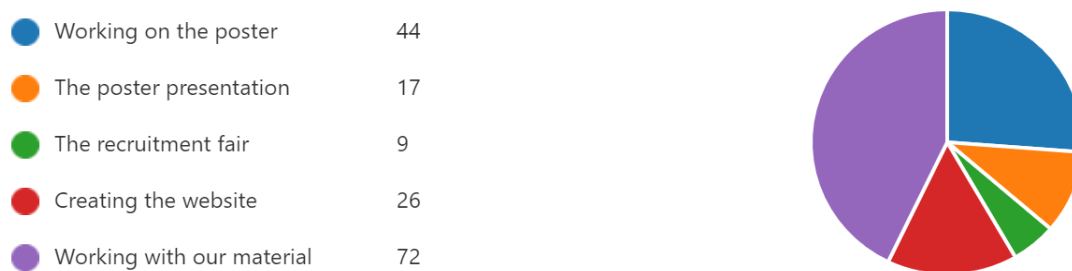| Working on the poster | 44 |
The poster presentation	17
The recruitment fair	9
Creating the website	26
Working with our material	72

Figure 2: Question 1 results- My favourite stage of the project

Students were asked to consider their improvement of skills/abilities and knowledge in question 2, figure 3. In all cases except the 'ability to sell myself', more than 73% of students agreed or strongly agreed. Improvement of written ability and improvement of research ability rated agree or strongly agree for 84.5% and 87.5% respectively. Whilst 67.9% of students agreed or strongly agreed that their ability to sell themselves had improved; this is the only factor that also received a high neutral response (28%).
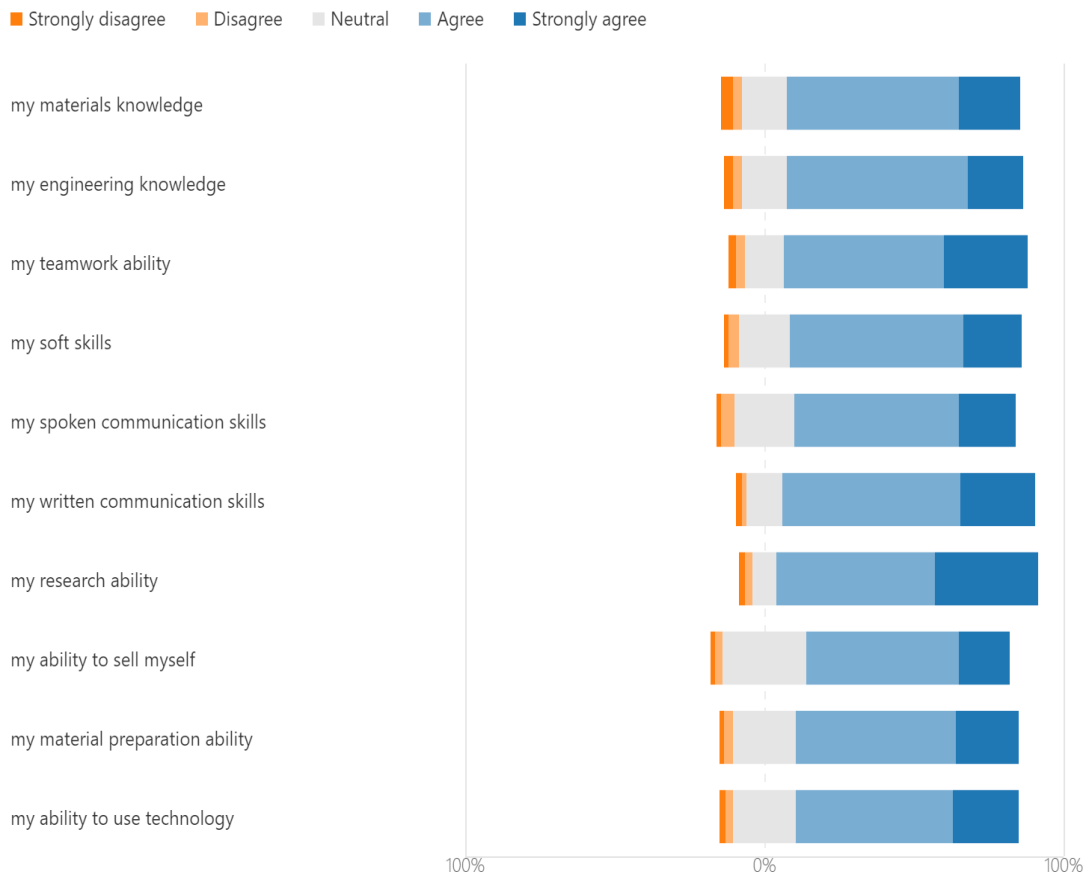
Figure 3: Question 2 results- The project has improved…

Question 3 asked students to rank their skills in order of the level of improvement during the project. Figure 4 shows that students ranked their research ability as the most improved skill, project management second, and written and spoken communication were the least improved. Teamwork ability also featured highly in first and second position and time management featured consistently throughout.
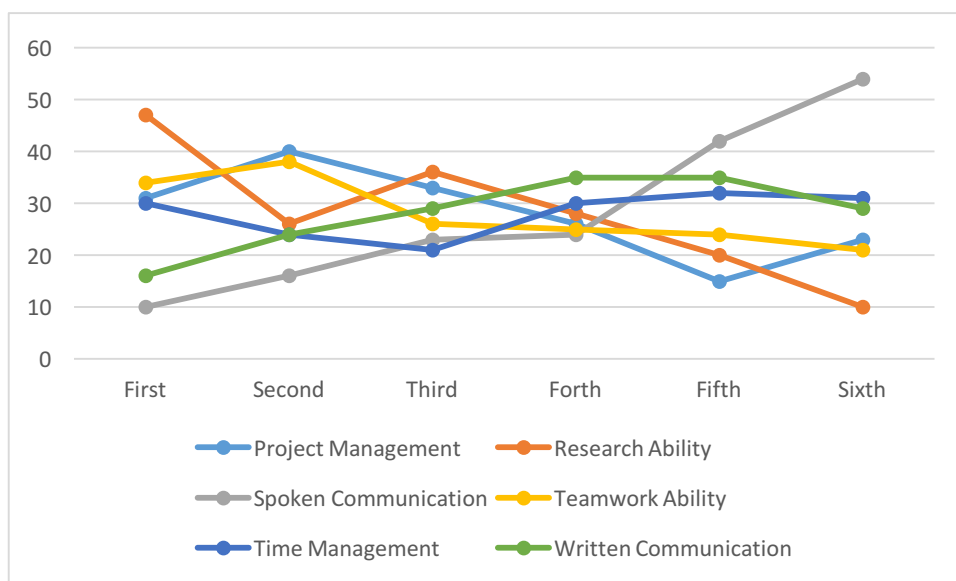

Figure 4: Question 3 results- Skills improvement order

Figure 5 shows that other than 'working in different size teams', the majority of students rated all other structural aspects of the project as either strongly agree or agree, 81.5% or higher. 73.8% of students did agree or strongly agree with working in different size teams, but over a quarter (26.2%) rated it in the lower ranges; more than any other aspect of the project structure.
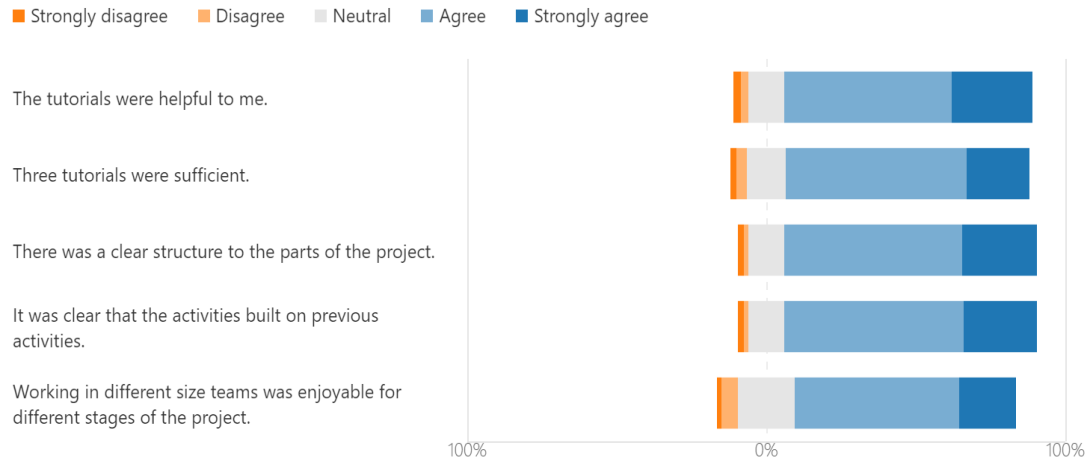

Figure 5: Question 4 results- Structure of the project

Year 3 Materials Characterisation Project

127 students answered this survey. Figure 6 shows that 78% of students agreed or strongly agreed that their development of materials knowledge had developed as a result of this project and 89% agreed or strongly agreed their engineering knowledge developed. Additionally, 71% agreed or strongly agreed that revisiting the materials library showed the students their weaknesses in the original project and 74% agreed or strongly agreed that it gave them an opportunity to improve it.
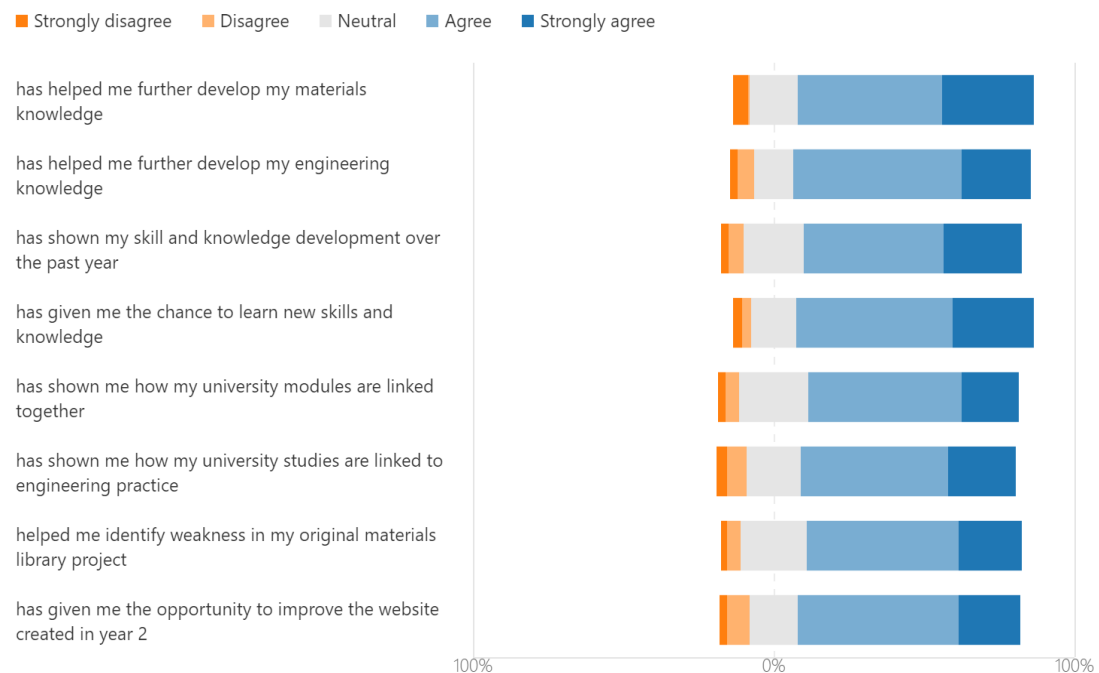

Figure 6: Question 1 results- Adding materials characterisation to the original materials library project…

From question 5, 'tell me how you have used or plan to use the materials library project in other modules and outside QMES', clearly shows the positive impact the materials library project has had on the students in terms of their current studies, future employment, study or in extra-curricular activities, as shown below.

•   "In composite materials and metals I&II, it's a good resource to refer to information and have a practical contact".
•   "It can help me to review the knowledge without carrying a textbook".
•   "I often went to the library in QMES to touch and see the materials. Additionally, my resume is enriched by the material library. During the interview of my master degree, I also mentioned it".
•   "It will be a good way to show others what we learnt in undergraduate degree, which could be a more vivid way compared with describing those courses".
•   "I used to go to the library to see how the material look like actually and touch it. In other modules, we may need to find some materials' data, I went to the website to find useful information. Outside QMES, I will show my material webpages to other people".
•   "The knowledge and methods I learned were applied to the QMES ICTL competition, and our group won third place in the final".

Discussion

From the results section above, the majority of the students found the year 2 materials library project useful. Students were able to improve their skills sets, figures 3 and 4, with research ability being the most improved.

Due to the multiple components in this project, an incremental approach to the completion of this project is important. By taking this approach, students are able to build on the skills they have developed in previous year's PDP modules. It also gives them an opportunity to work with varying numbers of peers which can improve communication skills and help those students who are shy to develop a strong relationship with their partner before moving to a larger group. Chinese students in particular struggle with oral presentation skills (Davey and Higgins, 2005). They lack confidence and cultural sensitivities about 'losing face' often hinders their progress and can affect them in their professional lives (Cardon and Scott, 2003). The method of teach to test (Lu, Goodale and Guo, 2014) also hinders their progress as when given freedom to speak the teacher can often be met with silence due to cultural Confucianism (Sit, 2013). Therefore, giving students the opportunity to progress in communication with smaller to larger number of peers builds confidence and develops rapport within the groups.

However, from figure 4 it can be seen that both spoken and written communication were seen as skills that were the least improved. This is interesting as written and spoken communication feature heavily in this project. One reason that students may feel spoken communication had not improved as much as other skills could be that students feel they already communicate efficiently in English. Another reason could be the use of online communication in this iteration of the project. Students prefer to communicate face-to-face on group projects so may have found online communication more difficult and therefore felt their communication skills did not improve as much as other skills. Finally, it could be that students were

communicating mostly together in Mandarin. This could be because of the distance element or students reverting to Mandarin because of ease and time constraints. Further research would be needed to understand why the students feel this way and this could influence further development of the project.

It is important that students are supported through each part of the project. As the project progresses the tasks become more complex and students also have additional challenges such as working in larger groups and learning to use software in differing ways. Therefore, tutorials were provided for students, so they were able to have their questions answered and feedback explained thoroughly. Students were expected to complete certain sections of the project prior to the tutorial session. Completed work was required to be added to the group's website where the teacher could preview it and prepare feedback before the tutorial. This enabled the students to view the feedback and ask specific questions during the tutorial, meaning the tutorial was used more constructively and was therefore a more valuable resource for the students.

From figure 5 it seems that the structure of the project is sufficient for the students' needs. The project ran extremely well considering it was run online, due to the pandemic. However, one of the students least favourite aspects of this project was presenting of posters online. Informal discussions with students suggest this is due to the difficulty in the audience participation. From observations during this activity, some meeting rooms had little to no audience at some points. It was also difficult for the students to talk to people they could not see (as most students switched their cameras off). This was mostly due to the bandwidth of students in their homes.

Whilst this project can be run online, it is better to run this face-to-face as students have more opportunities to enhance their face-to-face communication skills in the poster presentation and recruitment fair. As the materials library project has been run previously and was highly structured, it was relatively easy to translate it to online delivery.

In the characterisation module students were unable to enter the labs to tests their materials. Consequently, they only gained a theoretical knowledge of the characterisation techniques rather than first-hand experience which is a significant disadvantage of online delivery.

One further point that needs developing is the students' teamwork ability. From teacher observations of this project, students still struggle to complete work in groups, especially large groups, even though they do rate this skill as being improved. This means that more teaching needs to be done on this subject. To try to address this, an additional teamwork lesson has been added to an earlier PDP course in addition to peer evaluation of the group performance to ensure students are fully responsible for themselves and their performance.

Conclusions

As the materials library project has been running for two years, there are now over 75 items on display and a second materials library display is being constructed to reflect the diverse range of materials on offer.

The materials library project and the additional characterisation aspect are valuable and enjoyable activities for students. Students developed their engineering knowledge and transferable skills as well as creating an invaluable resource for the school. This met and even exceeded the aims and objectives of the project.

Revisiting the characterisation addition to the project needs to be reviewed once face-to-face teaching is possible to enhance students' practical skill set. In their final year, students study a module which focuses on materials in design, complete final year project and a number of design related projects. The materials library acts as a valuable resource for students in all these modules. These points show that the materials library is an effective project for developing student engineers and also improves the skills of the students, which makes them more employable.

The research on this project has highlighted that the main factors in developing a pedagogically sound materials library project. These include creating tailor made learning objectives for the students, choose an appropriate approach, teamwork and reflection on the project. It is important to reflect, identify weaknesses and modify the project in order. For example, the research has indicated that the recruitment fair needs some work to fully meet the needs of the students and the students do need that face-to-face interaction of being at university provides, especially in the characterisation aspect.

Overall, the library itself acts as a legacy for the students, it provides a lasting part of their work which will stay in the school long after they have graduated. It is also a focal point for visitors to the school which enhances the image of QMES. The library also supports a number of other modules as students have free access to the library, so, for example, in the module materials in design, students need to select materials for a product, they can go to the library touch and feel the materials to better understand the aesthetic attributes and judge how suitable the material will be for their specific product.

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