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Bridging the gap between teaching and research: a case study for engineering & applied science

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ABSTRACT

Higher education systems need to rethink the way teaching content is delivered to face the evolution of education and breakthroughs in educational online services. One way in which systems can innovate is by allowing students to apply their knowledge to real research problems. The benefits are dual: the students work on highly innovative topics and real examples; and for teaching staffs, there is a seamless integration of their research into their teaching. We present a case study in the form of an observational analysis of an Engineering & Applied Science undergraduate lecture taught in the UK at master level and teaching skills in electronic and rapid prototyping. We present the rationale chosen to better integrate research aspects in the unit and the results of an observational study: we used thematic analysis to expose eight guidelines for better integration of research in teaching as well as consideration for higher education curriculums.

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Introduction

The format of lectures in educational systems has been relatively stable through centuries with students engaging with one teacher, generally facing them and delivering the material. Such traditional format has many advantages for online teaching: it scales well with large classes; the students learn when they want which fits to different types of learners or students with disabilities; the content can be tailored to each individual, e.g. it allows learners to choose (or skip) content on-demand, which can increase motivation to learn (Oliver, 1999).

However, with such a democratisation of education material, we can wonder what the place of higher education systems is and if, in the future, we will still need physical educational platforms such as Universities. On the other end, there are obvious advantages to meet physically: (1) embodiment, i.e. being able to physically meet others (teachers and students) and link socially with them (Johnson, Aragon, & Shaik, 2000); (2) access to state-of-the-art equipment and facilities (McIntyre & Watson, 2011). For example, there have been attempts to create online laboratories, but it is still limited in term of possible actions and requires substantial investments in setting up experiments; and (3) access and collaboration with experts in specific fields of research (Zamorski, 2002). In fact, we believe that the last point is the most important. Teaching staffs are
renowned researchers, sometimes working with highly innovative material, hardware devices or software artefacts. There is thus a substantial opportunity here to exploit the expertise of researchers to enhance the quality of the teaching material, as well as to give a unique opportunity for students to collaborate with them.

The idea of bringing research into teaching is not new and researchers have already pointed out the benefits of such practice (Brew, 2006; Clark, 1997), with the particular emphasis on the creation of inclusive scholarly knowledge-building community. There are also evidences that separating teaching and research does not result in better teaching (Baker & McLean, 2004). However, it is currently unclear how teaching curriculums can, in practice, embed more research aspects, and we are not aware of literature focusing on the specific area of Engineering and Applied Science teaching.

To better understand how such a curriculum could be implemented we present a case study in the form of an observational analysis of an Engineering & Applied Science undergraduate lecture entitled Designing Interactive Devices. In this module, we deliberately mixed students and research staffs for three months of group projects aimed at producing innovative digital technologies. The final students’ assessments were then sent to a scientific venue focusing on innovative technologies. In this paper, we first present the context of this unit, we explain the set up created to enhance collaboration between students and researchers, and we present an observational analysis performed during the unit. We learn from this analysis by drawing a list of eight guidelines for better integrating research into teaching.

Our works show that designing a unit in such a way that it integrates research and teaching can enhance student learning and engagement via innovative and real-world projects. We believe this could be of major interest in the fields of science focusing on teaching innovative technologies. In fact, the ACM SIGCHI Executive Committee has sponsored a project to investigate the present and future of Human-Computer Interaction (Human-Computer Interaction) education (Churchill, Bowser, & Preece, 2013). A theme that emerged from this project was the desire to create a community of practice that could share and develop course outlines, curricula, and teaching material, known as a living curriculum (Churchill, Bowser, & Preece, 2016). Our work contributes to this direction and provides new insights about teaching practices for the Human-Computer Interaction and Design community.

**Literature review and research question**

**Research-led teaching: benefits and challenges**

Research-led teaching involves exploiting the teacher’s own research to benefit student learning and outcomes (Trowler & Wareham, 2008). Many authors have already highlighted the benefits of such practise, e.g. (Baker & McLean, 2004; Brew, 2006; Clark, 1997; Healey, 2005): it enables a deep understanding of the teaching material; it allows students to develop their intellectual capabilities by experiencing independent and/or collaborative research and by letting them become creative and critical thinker; it increases students’ engagement in their studies and help them become independent learner. Additionally, exposing them to real problems enhances their skills for employment and shape their future interests. As reported by researchers (Kuh & Bridges,
it is important to realize that students are not only expected to acquire knowledge, but they should also learn skills such as critical thinking and intellectual flexibility. New forms open technologies are becoming more common in higher education, and it becomes crucial to also enable flexible pedagogies to promote learner agency, autonomy, and self-regulation (Evans, Mujis, & Tomlinson, 2015; Katrakoski, Littlejohn, & Hood, 2017).

Despite such benefits, research and teaching activities are still secluded and experienced by academic staffs as distinctive (Schapper & Mayson, 2010). The issue first originates in higher education systems that often separate teaching and learning activities (Brew, 2012). It becomes therefore a myth for academics that both of these activities can be intertwined. Institutions, and particularly the ones who are research intensive, prioritize research over teaching because allowing staffs to innovate in teaching requires incentives such as professional development to support the use of new pedagogies and technologies (Fung & Gordon, 2016). The problem also comes from that there are limited studies that empirically demonstrate a correlation between teaching and research (Brennan, Cusack, Delahunt, Kuznesof, & Donnelly, 2017; Hattie & Marsh, 1996). Additionally, the link between research and teaching is shaped by different disciplinary contexts because each discipline of science have different views about research as well as different methodologies that impact how the teaching and researching materials are delivered (Healey, 2005).

Another issue is the lack of guidelines, for academics, on how to embed research within teaching in a concrete way. For instance, the most tangible guidelines currently available are centred on geoscience research (Jenkins, 2014). We can wonder how these guidelines apply to different disciplines. Indeed, Breen et al. pointed out that ‘there are important disciplinary variations in teaching–research relations that need to be valued’ (Breen, Brew, Jenkins, & Lindsay, 2003). They further added that “a central way to develop effective practice is to share case studies of discipline-based practice and department policies (Breen et al., 2003). This resonates with Hattie and Marsh (Hattie & Marsh, 1996) who also argue that efforts should be made ‘to increase the circumstances in which teaching, and research have the occasion to meet’. In a more recent article, Tight (Tight, 2016) highlights the lack of concrete guidelines to implement the research-led despite the numerous amounts of research on the topic. This motivates our work to study how research-led teaching could apply to the context of Engineering & Applied Science.

Note that we use the term research-led, but we can find other terms in the literature such as research-informed, research-integrated, research-intensive or research-oriented which are now ubiquitous within the landscapes of higher education institutions (Griffiths, 2004). All these terms are derived from a more general term, the research-teaching nexus, which invites researchers to think about higher education as having two major functions: teaching and research. As reported by Tight (2016) we should assume that ‘teaching and research have a strong relationship forming the foundation stone of the higher education endeavour’. And in the last three decades, this research-teaching nexus has been applied to higher education and has proved to be not only resilient but also popular.
Research question

Our goal is to better understand how to embed research within an applied engineering teaching unit and to offer concrete guidelines and examples for academics in this area. We particularly used several strategies within a teaching unit (see context section). Through qualitative observations of the students and the teaching staffs, we aim to answer the following questions:

How efficient are the research-led strategies used in this work to enhance students learning?

How to better integrate research-led strategies in unit to enhance student engagement?

Context of the case study

To understand the context of this work we present the details of the applied engineering teaching unit that is used as our case study.

Overview of the unit

The Designing Interactive Devices unit aims at teaching students an iterative design process to build innovative digital technologies. The unit is a 12 weeks undergraduate unit taught at Master level from September to December at the University of Bristol UK in the Computer Science department. The students are in groups of 4–6 people. The teaching crew is made of one-unit director and an additional 6–8 teaching assistants who are PhD students or research assistants in related research fields (Human-Computer Interaction, Robotic or other fields of Computer Science). The number of teaching assistants varies depending on years to accommodate the number of students but also depends on the availability of research staffs.

The unit is divided into three lectures of 2 hours, nine workshops of 2 hours (two of which where the students work independently). The schedule is shown in Figure 1. The intended learning outcomes of this unit are:

- Identify the different phases of the User Centre Design (UCD) process typically used for designing interactive products (Abras, Maloney-Krichmar, & Preece, 2004).
- Implement them through a group exercise where students design and build an interactive device of their choice.
- Compare the produced device with concurrent or prior systems through a study to demonstrate a benefit to end-users.
- Explain the design of the device and analyse the result of the study.

The students receive an individual grade and a group grade. The individual grade is based on an individual work submitted in week 12. The individual work consists of reviewing a scientific paper. The group grade is divided into 15% for completing a wiki every week and 85% for the project, i.e. quality of the final demonstration and report.

The students are told that a working demonstration will make them pass the unit (50%). Extra points are given for the complexity of the devices, the quality of the work and report. The students are told that more ambitious and innovative projects, although
not completely implemented, will be graded higher than simpler but fully implemented projects. Obviously grading such projects is hard and is similar to reviewing a scientific paper for a scientific venue.

**Research-led strategies used in the unit**

Below are the six strategies we have used to integrate research into this unit. These strategies are derived from a set of general guidelines used in geoscience research (Jenkins, 2014). We particularly choose these guidelines because, as said earlier, we are not aware of related work offering concrete guidelines (Tight, 2016). The strategies are the following: 1) Develop students’ understanding of the role of research in the discipline; 2) Develop students’ abilities to carry out research; 3) Progressively develop students’ understanding; 4) Support students think to beyond disciplinary research silos; and 5) Manage student experience of faculty research. We particularly focussed on implementing strategies for the three first guidelines. We did not look into supporting student thinking to beyond disciplinary because it was too much for the short duration of the unit. However, we wondered how the strategies would impact on the fifth guidelines, i.e. the student experience of research.

**S1. researchers embedded in the students’ groups**

The unit benefits from a large number of teaching staffs. The reason is that two staffs (including the main teacher) are embedded in the student groups and become members of this group. The staff members are told to help their groups with (1) findings relevant related work; (2) improving and helping the student populating their wiki; (3) help with the technical implementation of the interactive device. Not all the teaching staff has the same expertise and thus staffs are likely to be requested by other teams, in a similar way as consultants (e.g. on technical aspects, to help design a study or help with related work). The main emphasis is to make students understand that we can achieve more by combining skills and that they need to reach out for staffs with the expertise they lack within their own group.
S2. final report sent to a conference
We are clear from the beginning that the final reports will be sent to the best conference in Human-Computer Interaction, CHI the conference in Human Factors. We send the paper to the Late-Breaking-work category that has an acceptance rate of ~40%. For this reason, the students are told to write their report following the ACM SIGCHI proceedings format. The benefits of this strategy are the following: (1) they know from the beginning of the unit that they will have the opportunity to work on highly innovative research projects; (2) they will themselves be able to have an impact on a research field; (3) if their paper is accepted they will go to the conference to present their work. We believe this increases the student’s motivations. In addition, they also (4) familiarise with research work by working on real-world problems, which should increase deep learning over surface learning (Weigel, 2002). Note that the students are told that the grade will be independent of an acceptance of their paper. This is important because, although it is exciting for the research staffs to publish exciting projects, the main goal of this unit is still to teach. In addition, publishing a piece of work is also prone to other factors that do not correlate systematically with the quality of a research work.

S3. open thematic projects
The students choose their own projects between week 2 and week 5 through different sessions of brainstorming and refinements of ideas. Through previous iterations of this unit we observed that it is better to give a theme to help students focus on concrete applications. This could be technology for museum, healthcare, mobility or campus life. In 2016–2017 we choose the theme healthcare and well-being technology. The students are free to pick a topic within this theme. The teaching staffs work intensively during the initial weeks to help the students find an idea that is innovative. We believe that letting the students choose their project gives them a sense of ownership and motivate them all along the unit.

S4. individual reviews to cover related work
By week 7 each student submits a review of a scientific paper that is related to their project. This is an individual work. The students are told they can pick any paper but are highly encouraged to discuss with other group members in order to pick different paper in order to cover the related work needed to motivate their idea. They are given the same review guidelines than for a scientific paper, which put them in a real-world scenario. Note that in week 1 and week 2 the students are also given an overview of the major advances in interactive technologies to support ideation.

S5. progressive wiki to help them writing a paper
Every week the students must fill in a wiki page to report their advances (Figure 3). The wiki page is following a template in order to help the students structuring their thoughts. For example, as soon as they have chosen their idea they are asked to write an abstract (week 5). They are asked to create a list of related work by week 7, i.e. after the individual assignment. By the end of the unit, if the students have filled in their wiki correctly, they have already written most of the content for the sections of their final paper (Abstract, Introduction, Related work, Design, Study and Conclusion), which, in principle, minimise their workload. They receive feedback from the teaching staffs every week to help improving their writing.
**S6. public demonstration of the prototypes**

The last week of the unit is dedicated to public demonstrations of the final prototypes. This is done during an open day at the university. This event gathers academic staffs as well as general public. The goal of the demonstration is to help students improving their communication skills as well as to get feedback on their prototypes. We specifically ask the students to prepare a study to compare their prototypes with concurrent systems. The main benefit of this event is to put the students in a real-world practice where their prototypes will be seen publicly. It also helps them to gather participants for their study. Such an event also helps to raise institutional awareness about research-led teaching by showing to other academics the benefit of such practise on students and their creations.

**Methodology**

To understand how efficient the research-led strategies used in this work are to enhance students learning and engagement, we performed an observational study. The goal of the case study was to understand the complexity of a specific case in the most complete way possible, and for this reason, case study research often involves the use of multiple methods for collecting data (Berg & Lune, 2004). We particularly used semi-structured qualitative study that typically involves interviews and observations, that have some explicit structure, in terms of theory or method, but are not completely structured. Such studies typically involve systematic, iterative coding of verbal data, often supplemented by data in other modalities (Mann, Soegaard, & Dam, 2012). Qualitative methods play an essential role in understanding user needs and behaviours and are essential tools, as important as more formally seen tools such as quantitative studies (Mann et al., 2012). Previous studies investigating research-led teaching have also relied on quantitative and qualitative methods such as questionnaire or focus group (Jenkins, Blackman, Lindsay, & Paton-Saltzberg, 1998; Willis & Harper, 2000).

**Participants**

The unit was taught in 2016–2017 with 33 students at Master level organized in six groups (between 20 and 26 years old, 6 females), as well as 8 teaching staffs (between 25 and 34, 2 females) remunerated for their work on the unit.

**Data collection**

We used the principle of triangulation by gathering data through cross verification from three sources. This helped to ensure that the data collected was consistent across different sources and help strengthen our analysis. The data gathering process was ethically approved by the university.

1. During the unit, the lead teacher wrote a weekly journal. This was chosen in order to summarise problems encountered in the lectures and general observations.
2. At the end of the unit, we used online surveys to gather students’ feedback. They gave a grade to the unit and to the main teacher as it is usual practise in UK.
They were also given the possibility to give textual comments. We did not use the grades in this analysis because they did not provide a relevant metric to answer our research questions. Instead we focused on qualitative feedback using the additional comments given by the students in the survey, which reflected their engagement with the lecture.

(3) A month after the end of the unit, we organised a group interview with the teaching staffs and some students to discuss the current benefits and drawbacks of the unit. We used semi-structured interviews in which we prepared several questions and used them to facilitate discussions: ‘What is your overall feeling about the unit?'; ‘Did you feel motivated to achieve the work necessary for this unit?'; ‘How was the collaboration between students, between staffs and between groups?'; ‘Did you provided work outside of the curriculum, how did you feel supported?'; ‘How did you choose your project topic and were you satisfied with it?'; “What did you think about writing a scientific paper as part of the assessment?”; “How useful was the demonstration day”; ’What did you think about the use of the wiki”. We ended the session by asking the participants ideas for improving the unit in the following years.

Data analysis

We used thematic analysis (Braun & Clarke, 2006) to analyse the collected data. We used the original framework proposed by Braun et Clarke. to perform our analysis and, as highlighted by the authors, the process of data analysis can be used in inductively or deductively way. We choose an inductive approach in which the coding occurred without trying to fit the data into a pre-existing model. We first combined the observations from the observation logs, the textual comments from students’ surveys and the comments gathered in the group interviews. The data was collated in the form of a list of texts that were then attributed to codes. One initial coder labelled the data with initial codes around the question of ‘how to improve this unit, in particular regarding the research-led aspect’. We conducted peer validation throughout the coding process, i.e. meeting with another coder (teaching staff) to review and clarify coding and grouping decisions and at the end of coding, we regrouped the codes in themes. Our final scheme had eight final main themes.

To give an idea of the process we give an example of data and codes associated with one theme (G1. Helping students to understand research outputs). We can particularly observe that similar data appeared in the different sources we used.

- From the survey ‘for the main project, objectives were not clear, and we ended up just guessing everything’. Code [unclear objectives].
- From the survey ‘it was strange to write the abstract at the beginning of the project rather than at the end which makes more sense’. Code [research practises are different than traditional assessments] (we also used another code which was used for another theme [writing skills]).
- From the observation logs ‘students compared their work with the other groups or with previous wiki pages from past years in order to make sure their project was
The research output was scientifically valid. Code [need of template/model to understand research output]. (we also used another code which was used for another theme [use of wiki]).

- From the observation logs, ‘students used google doc to write their report and used the fact that staffs could edit their text to learn how to form a scientific argumentation’. Code [using staff’s skills to learn] (we also used another code which was used for another theme [use of technology]).
- From the group interviews, a student said, ‘I really like the fact that the lecture output was different from the other units and that we worked on real projects’. Code [this unit is different from typical units].
- From the group interview, a staff said, ‘students told us they would like a marking scheme to help them understand what is the most important in the report’. Code [adding a marking scheme to help understanding writing].

**Findings and implications**

We present a summary of the observations gathered, including the presentation of the final artefacts produced by the students and the overall feedback from the unit. We then present the results of our data analysis by presenting the eight themes extracted from our data and which present the lessons learned for future iterations of the lecture or application to other units.

**Final artefacts**

Six projects were achieved (Figure 2). Below are the summaries written by the students and improved by the teaching staffs.

1. Inflashoe: A Shape Changing Shoe to Control Underfoot Pressure. The group presented Inflashoe, an interactive shoe that uses a pneumatic system to change the inflation level within the sole. The shoe adapts its shape to different surfaces and users’ foot morphology, or to alter users’ gait. Inflashoe can not only change the overall inflation, but also individually control the inflation of the back and front of the insole, creating different levels of elevation across the shoe when needed.

2. Drinking Buddy: An Interactive Cup that Regulates Daily Water Intake. The group focused on the problem of water consumption and the fact that a lot of people tend to ignore/fail to receive their daily amount of recommended water intake. The lack of proper hydration can lead to negative physical and health issues such as headaches and loss of concentration. The group proposed Drinking buddy – a device that constantly monitors the amount of water taken by the user and gives a corresponsive feedback, this feedback promotes regular water consumption by the use of red flashing light.

3. GYME: A Gamified Weight-Changing Weightlifting Device. The group focused on a weight-changing input device used to enrich the user experience and encourage physical activity whilst playing interactive games. Whilst the user’s arm movements control the game character, water is pumped into the device increasing the weight, which adds to the physical difficulty. This allows for fun physical exercising and encourages healthy competition between friends. Their
work aligns with the concept of exertion interfaces and is the first to investigate weight-changing weights in the context of a game.

(4) LUMY: a workspace lamp with customisable projections and embedded task scheduler. The group focused on sedentary behaviour problems. Various ‘stand up’ reminders have been developed to encourage people to take breaks from desk-based work in order to reduce the time spent sitting. However, they often require on-screen interactions, interrupting users’ work and causing annoyance, which leads to the abandonment of these technologies. They proposed Lumy, a prototype of a desk lamp that displays messages to help users take short breaks.

(5) StressLess: Improving Stress Relief through Stress Ball Usage Tracking. The group presented StressLess, an interactive device designed to improve the standard stress ball. Standard stress balls can be effective at reducing stress, but they lack the ability to adapt to the user and track stress over time. The StressLess prototype incorporates pressure sensors and wireless connectivity to enable the inference of user stress levels and interact with the user’s environment to more effectively calm the user.

(6) VibraSight: Obstacle Detection and Feedback Device for the Visually Impaired. The group presented VibraSight, a non-invasive feedback system for the visually impaired. Current navigation solutions for the visually impaired can often be obtrusive and many current solutions are not hand-free, rely on predefined paths or other people and offer disruptive and public feedback such as audio. Their solution combines ultrasonic sensors and vibration feedback to create a precise approach to real-time obstacle navigation of an immediate environment.
Project page template

the following is given as template but feel free to add more content if you want

WEEK 2 - group picture
upload here a picture of your group

| member name | member name | member name | member name | member name |
|-------------|-------------|-------------|-------------|-------------|
| member email | member email | member email | member email | member email |

WEEK 3 - the best 3 ideas
upload here three pictures of the best ideas you had during the class (hand drawing totally ok)
you can also add a short (2 sentences) description

| idea 1 | idea 2 | idea 3 |
|--------|--------|--------|

WEEK 4 - the best 2 ideas / or best 2 designs
upload here two pictures of the best ideas you have (hand drawings totally ok)
be free to change ideas if you had better than last week
you can also add a short (2 sentences) description

| idea 1 | idea 2 |
|--------|--------|

WEEK 5 - the best idea
upload here a picture of your final idea (hand drawing ok)
find a title for your idea
write an abstract of your idea (started in class)

| title | abstract | picture |
|-------|----------|---------|

WEEK 6 - related work
put here a list of related work
for each, say in what it is different from your idea (in a few words)

WEEK 7 - storyboard
upload here a scenario describing a user using your system, in images (sketches totally ok).

WEEK 8 - write user study setup
in particular write:

1. goal: what are you trying to find out
2. participants: how many do you plan
3. task: what are you gonna make them doing, give details for reproducibility
4. data: explain what data you will collect and how (time, error, subjective answer from survey, interviews etc.)

WEEK 9 - start writing the paper
you can use this space to write sections such as the one below
everything you put here will be read and commented to help you improve but it won’t be graded at this point so use this opportunity!

4. design
5. implementation
6. study

WEEK 10-11-12-13 - upload final paper and additional material
upload here your final paper and additional material you have (e.g. videos, data).

Figure 3. Template used for the wiki pages.
Lessons learned

Overall the unit was a success. Not only all the students were able to write a scientific paper of good quality and present a working demonstration of their prototypes but also one group had their paper accepted as a 6 pages Late-Breaking-Work paper at ACM CHI (Baousi et al., 2017). The unit gathered exceptionally high feedback from the students. Example students’ feedbacks include ‘really enjoyable unit’; ‘one of the best I have taken in the degree’; ‘Very much enjoyed the freedom of being able to experiment and build whatever device we liked’. ‘Probably the best teaching staffs in any unit I’ve taken’. Many students engaged with the research nature of this unit as it was reported a few months after the unit had ended ‘it is the first time a unit allowed us to do something that matters and that is concrete’. Although the feedbacks seem to support the strategies we put in place and demonstrate the they enhanced student’s engagement, we also gathered problems and areas of improvement. Below we present the data analysis highlighting eight themes for improving the unit and embed research within teaching in a more efficient manner.

G1. helping students to understand research outputs

We observed two types of students: the ones who embraced the research aspect of this unit, i.e. who were not afraid of innovating and taking risks, and the ones who were uncomfortable with the unconventionality of the unit. This may stem from the fact that, contrary to traditional lectures, it is hard to give clear guidelines to students on how they will be graded, which some students thrive for. For example, one student said, ‘for the main project, objectives were not clear, and we ended up just guessing everything’. The students were told to have a working demonstration and to write a report to pass this unit (at least 50%), and extra points are given for the complexity of the devices, the quality of the work and report. These two last points are however hard to comprehend for certain students. In fact, even for researchers there are no clear guidelines on what the rest of the community will consider to be a great research work. A good researcher might have an ‘intuition’ only. Some solutions to this problem could involve:

- Give examples of previous years projects to help students develop an ‘intuition’ for a good project.
- Give a grading scheme for their report to, e.g. 10% for the abstract, 10% for the figures, 10% for the introduction, 20% if the related work coverage, 20% for the design section and 20% for the study, 10% for the conclusion.
- Warn in the 1st lecture of the unit that the grading will be different from traditional units because of the research-led aspect behind the unit.

G2. helping student to provide independent work

We observed a large disparity between groups ability to work independently. Certain groups worked extra (requested) hours to finish their project while some other did not. This also correlates with groups that struggled to envision how they will be graded (previous point). Addressing G1 might thus help with this problem. A consensus
reached during the group interviews was that week 9 to week 11 sessions should be supervised rather than independent, i.e. the teaching staff should be present. This should encourage the students to work on their projects during the two last weeks. This also corroborate students’ feedback, e.g. ‘I also wished there was more dedicated lab sessions with the teaching staffs towards the end of the unit.’

**G3. helping students to choose a good project**

We observed that some groups had no issues in finding an interesting research idea while some others struggled and iterated for several weeks before choosing a topic, almost by default. During the group interviews, we discussed a lot about how long the students should have to select their ideas. We concluded that a solution would be to help them ideate and to do this we could: (1) have a repository of topics pre-chosen by the teaching staffs before the beginning of the unit; (2) add the students’ ideas generated in h5 and h6 to this repository; (3) let the student choose a topic by a certain given date (either their own or one from the repository), up to which, if they haven’t chosen (or have a topic that is not considered innovative enough), they will have to take a topic from the repository. If we had applied this strategy, only two groups over six would have had a better topic as the rest of the group did managed to find interesting and relevant ideas.

**G4. helping students appropriate their projects**

The students had to report their weekly advances in a wiki, which should have help them with writing the different sections of their scientific paper. Although the students liked the idea of spreading the final writing through a weekly task, not all of them were convinced by the wiki format, which allowed little room for customisation and appropriation. During the group interview, the solution of replacing the wiki by a blog was proposed. The students could have to create their own blog via their own means. This could allow each group to make their own personal website and create a more personal atmosphere around their project. Because a blog is public the students might also be more tempted to take nice pictures of their prototypes (which was one aspect lacking in the current unit).

**G5. helping students to understand scientific writing**

The students were asked to produce an abstract early on, which seems to correlate with better quality of paper. However certain students were not convinced by this idea: ‘you can’t write the abstract before you’ve done it’. It is currently unclear how to help students with this aspect. In fact, even in the scientific community, it is known but yet unproven, that writing earlier lead to better quality papers. This could be explored further. Beyond this particular point, the students liked the idea of writing early on and in particular the fact that teaching staffs could comment their wiki every week and improve the texts. In fact, one of the groups that used the wiki intensively produced one of the best final paper compared to the ones who did not.
**G6. Helping teaching staff to be more involved**

Although the teaching staffs have been well involved in each project and both the students and researchers appreciate this collaboration, we believe that there are still ways to improve this aspect. First of all, the researchers could be more involved if the students work on a project related to their own research. To make this possible the idea of the repository of idea would work well (G3). Another point is to assign the staffs to one group at the beginning of the unit. In such way, they can be involved in the brainstorming phase. Finally, some concerns were raised about the way to communicate with the students. The wiki was not the ideal solution and most people suggested to use a shared Google doc for the final report. This would allow tracking changes and ease communicating between members. Another difficult question relates to the distribution of staffs in groups. Because the teaching staffs have different expertise, it is unfair to have them only associated to one group only (e.g. someone with a technical background will substantially help the group while other groups won’t have this advantage). However, we do believe that having the staff embedded inside the groups helped creating this atmosphere of team work. Here again there is a trade-off between embedding the staffs in groups vs. letting them help all the groups.

**G7. Free-formed vs. controlled groups**

The students were allowed to choose their groups on their own. However, this does not help mixing the expertise within the groups. For example, we noted a lot of differences in programming skills. A solution for that would be to use the end of h4 to form groups in the class and make sure there are at least one programmer and one student familiar with basic electronics in each group. Of course, controlling the formation of the groups also have drawbacks as the students don’t pair with ‘their friends’ or people who have similar schedule. This could lead to difficulty in coordinating the project and communication with each other. Both strategies (free-formed or controlled) have advantages and drawbacks and further investigations need to be conducted to understand which format better fits this type of unit.

**G8. Giving additional research skills in the curriculum**

We observed, across all the projects, that the overall qualities of the studies were low. We believe this is due to two factors presented next. First, the students were asked to conduct their study during the demonstration event, but this may not be an appropriate idea. The rationale to coordinate the study and the demonstration was to use the open day to attract people and make it easier for students to find participants for their studies. We think the studies would be better if not coupled to the demonstration event in order to help the students focus on the quality of one or another. This could be done, e.g. one week before the demonstration event. Secondly, the students had no knowledge in how to conduct an evaluation. This is due to the fact that teaching evaluations is not part of the curriculum of this unit. However, there are a large number of evaluation methods, in particular in the area of Human Computer Interaction, and introducing just the most prominent one, e.g. a controlled experiment, would require more than a couple of hours.
of teaching, which is not feasible in the current 12 weeks curriculum. We suggest this needs to take place outside of the unit and that we need to discuss, at institutional level, for the need of a core unit (e.g. in 1st of 2nd year) that would teach students basic scientific skills such as evaluations, statistics and scientific writing.

**Limitations**

Our case study sheds some light on how to apply research-led teaching in an engineering teaching context. We hope that our list of guidelines can be directly applied by academics wishing to introduce research-led elements in their lectures. However, the reader may keep in mind that our results could be dependant from the context in which we operated, and which may have impacted the outcomes. First the University of Bristol is one of the best in the UK and the students are known to be particularly hard working. A different population of students may react differently to the strategies used. Additionally, our students had access to facilities and equipment (e.g. 3D printer and laser cutter with trained technicians), and this may have enhanced their engagement throughout the different activities. Secondly the skills of the teaching staffs (main teacher and teaching assistants) certainly impacted the outcomes of the unit. However, quantify the impact of the teaching staffs vs. the curriculum design would need further studies, e.g. comparing different iterations of the unit could give us some initial clues. Finally, the author of this paper was involved in the research and this may have affected the outcomes presented here, as the author’s background may have affected the topic of investigation, the grouping of codes during the analysis and more generally the methods used.

**Conclusion**

We presented a case study of research-led unit. Through an observational analysis we presented different strategies and guidelines to better embed research into teaching curriculum, in particular for the case of Engineering and Applied Science teaching. Our main findings are that research-led teaching is enhanced by adding research staffs within student teams and by empowering students with the possibility to work on innovative projects that they can publish in scientific venues. However, using research-led teaching is difficult because certain concepts are hard to quantify, e.g. how good a research project is. In fact, even within the research community it is sometime hard to access such a question. The challenge of ‘how to transmit to student’ the uncertainty of scientific outcomes is still arduous, or maybe we just need to profoundly change the nature of teaching in higher education and allow uncertainly to be part of the game. We have provided guidance to help further this direction, i.e. concrete guidelines that academics can use in practice, and we hope to inspire other academics into using research-led methods as we believe this could be the direction that higher education institutions need to take to renew the teaching material and compete with on-line platforms.

**Notes**

1. For example, the Stanford’s Crowd Research lab investigates mixing teaching and research online ([http://crowdresearch.stanford.edu](http://crowdresearch.stanford.edu)).
2. Human Computer Interaction is a field of research focusing on understanding human and using this knowledge to better design interactive systems for them.
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