Disciplinary learning in project-based undergraduate engineering education: the case for new knowledge

Ann Lahiff
University College London, Institute of Education, London, UK
ann.lahiff@ucl.ac.uk

Emanuela Tilley
University College London, London, UK
e.tilley@ucl.ac.uk

Janet Broad
University College London, Institute of Education, London, UK
j.broad@ucl.ac.uk

Kate Roach
University College London, London, UK
katherine.roach@ucl.ac.uk

Andrea Detmer
University College London, Institute of Education, London, UK
andreadetmer@gmail.com

Abstract: *Project-based Learning (PjBL) utilises a series of authentic projects which reflect the 'unit of work' as experienced in the engineering workplace; is understood to be closer to professional realities and involves the collaborative application of knowledge, understanding and skills. Moreover, it offers curriculum designers a pedagogical approach which moves away from a more didactic, knowledge-led curriculum to a more active, student-centred approach to learning. However, it is often suggested that PjBL in engineering education is more directed to the application of knowledge as opposed to the acquisition of knowledge. This is seen to limit both the learning outcomes of PjBL and the likelihood of students developing both generic skills alongside disciplinary knowledge and technical skills. Drawing on qualitative data collected through observations of PjBL activities and interviews with undergraduate engineering students in situ, we show how students develop their disciplinary understanding through collaborative learning and engagement.*

Introduction

Over the last twenty years, Higher Education (HE) institutions involved in engineering education have reflected on their curriculum offer in response to the worldwide call for graduate engineers who have achieved "…the right balance between scientific and technical understanding and their practical application to problem solving" (RAE, 2010:ii). The 21st century engineer is expected to be able to identify as well as solve problems and work across multiple boundaries with people whose specialist and/or cultural frameworks differ from their own (Jesiek et al. 2018; Tilley and Roach, 2018; Graham, 2018). Skills and attributes such as communication with peers, collaboration, team working and problem solving/solution-finding – variously described as 'soft' or 'generic' skills - have therefore become central aspirational outcomes of engineering curricula alongside the development of disciplinary and technical knowledge (Passow and Passow, 2017). Common features of various curriculum reforms have therefore included more problem/inquiry-led learning using group projects and tasks, with a shift in pedagogy away from a more didactic, knowledge-led curriculum to a more active, student-centred approach to learning. In such learning environments, opportunities to engage with and evaluate knowledge, rather than memorize factual information, are central (Damsa and Nerland, 2016).

Nevertheless, achieving a balance between the development of critical problem-solving skills and collaborative working whilst also ensuring the development of technical knowledge and understanding remains challenging. To respond to this challenge, HE institutions have had to address at least three troublesome issues. First: the issue of 'transferability' in relation to 'generic skills'. Introducing generic skills and attributes into a revised curriculum does not necessarily mean that once students graduate and enter the workplace they will become 'better' communicators, problem-solvers and collaborators. This is because, as Tynjälä et.al (2000) have shown, 'generic skills' are highly context-dependent. Second: the development of more student-centred pedagogies to address the disciplinary and technical knowledge requirements of engineering. Third: the pedagogic development of engineering academics in changing curriculum contexts. For many engineering curriculum designers, including the one at the centre of the research presented in this paper, a project-based learning (PjBL) pedagogic approach provides a response to the first two issues.

The rationale for the adoption of a PjBL approach is multifarious. While there are parallels with other inquiry-led learning innovations – particularly problem-based learning (PBL) – the use of the term 'project' in PjBL is particularly significant in relation to engineering. This is because project-working has become part of the working life of many, including IT, media and engineering professionals (Hanney, 2018; Guile and Lahiff, 2017). In an engineering context, as elsewhere, the concept of the project team informs the division of labour. Working practice is therefore organised around time-bound projects and teams, which are composed of various multi-disciplinary engineering professionals (and often external non-engineering professionals), focus on problem-solving and solution finding in addressing a given brief (see Guile and Wilde, 2018 for fuller discussion). Hanney (2018:770) also points out that in conceptualising a project team, attention should not solely be directed to the tools, procedures and techniques involved, but also to the recognition that project-working is "… a practice born of a particular set of historical, social and cultural factors."

Project-based learning can be understood as a pedagogical innovation which is consistent with a social constructivist approach to learning (Felder, 2012) where students work in discipline-specific and/or multi-disciplinary collaborative groups towards a solution to a problem and/or query. This learning context provides students with the opportunity to construct their own understanding through interaction with others, as Duffey et al (2013) have shown in their review of a PjBL module in Electrical Engineering. PjBL aims to offer the opportunity to integrate theory and practice by way of organising learning around a 'real-life' and, therefore, authentic, time-bound working issue or problem. In such situations, as Thomas (2000:3) has shown, PjBL not only involves students in constructive investigation, but also enables much more "student autonomy, choice, unsupervised work time, and responsibility". However, it is often suggested that PjBL in engineering education is more directed to the *application* of knowledge as opposed to the *acquisition* of knowledge (see, inter alia, Hall et al 2012; Perrenet et al. 2000) and that this, in turn, limits the learning outcomes of PjBL. It is therefore seen as *less likely* to offer a learning environment which achieves a balance between the development of generic skills vis-à-vis the development of technical/disciplinary knowledge and skills.

Drawing on data from a collaborate research project: *Fitness for purpose: developing the pedagogy of project-based collaborative learning* (2017-18), this paper examines the nature of student learning and engagement in discipline-specific project-based learning activities. It questions the positioning of PjBL as more suited to the *application* of knowledge (described above) and addresses the following questions: a) How do students describe *what* they are learning? and, b) H*ow* does learning takes place in disciplinary-based PjBL activities?

This paper is organised in five sections. Following this introduction, a brief overview of the learning context will be provided. An account of the research design and methodology underpinning the research is then followed by a discussion of the findings. The paper concludes with some implications for practitioners.

Context

At University College London (UCL) Faculty of Engineering, PjBL has been an integral feature of the undergraduate curriculum since the introduction of an Integrated Engineering Programme (IEP) in 2014. In her global review of undergraduate engineering education Graham (2018) features UCL's programme and summarises the educational approach taken as having two main components:

- "a common curriculum structure, adopted by all undergraduate programs across UCL Engineering, that is built around a series of authentic engineering projects;
- shared multidisciplinary team projects and Minors, bringing students together from across UCL Engineering." (2018:91)

We focus here on the first component. In their first and second years at UCL, students experience six discipline-specific PjBL scenarios which often draw on external partnerships and the knowledge and experience of academic staff (faculty) in specific engineering contexts. The 'series of authentic projects' are called 'scenarios' and take place in one week, full-time, across all engineering departments. They are, initially, designed to contextualise prior learning – requiring students to solve problems and/or develop design solutions to specific issues. The final two scenarios generally reverse this format, exploring the theories and principles that underpin the scenario after its completion (Graham, 2018). The scenarios therefore become increasingly complex and open-ended for students as they progress through the programme. Students also experience two interdisciplinary PjBL experiences in their first year which run over a five-week period across all departments and a further two-week block challenge (*How To Change the World*) at the end of their second year. In terms of scale, it should be noted that the *How to Change the World* experience involves 750+ students, 65 partners, 5 cohorts, and a 50+ teaching team (for further discussion see Tilley and Roach, 2018; Graham, 2018).

The PjBL scenarios have evolved over the years of the IEP, are varied and reflect both the numbers of students in the cohort and their respective disciplinary roots. In terms of student numbers, the UCL Engineering programme with the largest student population is Mechanical Engineering, which … "has seen its undergraduate intake rise from 45 in the early 2000s to 150 today. The smallest intake cohort, of 25 students, is to the Biomedical Engineering Programme within the department of Medical Physics and Biomedical Engineering" (Graham, 2018:93). The PjBL scenarios range from 'designing and building an article of smart clothing for an athlete' in Biomedical Engineering, to 'formulating a bioethanol production strategy for the UK capable of satisfying 5% of road transport fuel demand using a given feedstock', in Biochemical Engineering.

Irrespective of this diversity, the projects can be seen to embed central features of PjBL outlined above. For instance, students are normally given a query or a problem at the start of their activity; the projects are strictly time-bound with interim and final deadlines for feedback opportunities; they require collaborative group work managed by the students with varying amounts of guidance and instruction from staff. Most importantly, *student learning* lies of the heart of the PjBL scenarios. This is central to the PjBL experience because, as Hanney & Savin-Baden (2013) have argued, if learning is de-centred from the experience, then students are simply engaging in 'project work' – not project-based *learning*. In the case of the former (project work), the outcome (the product; the artefact; the concept) may become the driving factor rather than the learning gains throughout the process.

Theoretical framework

The research design was generally informed by insights from socio-cultural theories of learning and, in particular, the work of Brown et al. (1989) who challenge the ways in which teaching and learning (in all phases of education) has traditionally separated what is learned from the context and use of learning. In developing the concept of 'situated cognition', they argue that over reliance on methods of didactic education has led to a separation of knowing and doing, where knowledge is treated as "…an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used" (1989:32). In contrast, socio-cultural theories of learning present an understanding of knowledge which accepts that rather than being wholly given, knowledge should be construed as dynamic and emergent in practice. This means that the deployment of knowledge and skills is highly dependent on situational factors. One consequence of accepting the situational nature of knowledge use and development would be that we would be *less likely* to have students who can, "…manipulate algorithms, routines, and definitions they have acquired with apparent competence, but have no idea what to do with them in a 'real life' situation" (1989:34). This approach aligns with the insights offered earlier by Tynjälä et.al (2000) in relation to the highly context-dependent nature of generic skills. Additionally, we draw on insights from broader theories of workplace and work-based learning, including pedagogical approaches to skill development and the nature of knowledge. In these approaches, the opportunity to construct understanding through interaction with others in a social setting is a fundamental aspect of learning (Lave and Wenger, 1991).

Research Questions

The overall aim of the research project reported in this paper was to develop knowledge and understanding of how engineering students learn in the IEP PjBL context. Two research questions framed the research reported in this paper: a) How do students describe *what* they are learning? and, b) H*ow* does learning takes place in disciplinary-based PjBL activities? The questions were addressed through qualitative, collaborative, multi-disciplinary practitioner research (outlined below). In this research, the aim was to generate data from as many instances of PjBL as the research constraints allowed, whilst reflecting the diversity of engineering disciplines in the faculty. The research activities centred on first- and second-year students between October 2017 and March 2018.

Methodology

To achieve an understanding of the ways in which students learn in a PjBL context, qualitative data was collected through observations of PjBL scenarios and interviews with undergraduate engineering students *in situ.* Observation, informed by the principles of ethnography, enables data to be collected in 'live' settings. Data is collected on the ground, in real time, as it happens. Adopting an "unobtrusive observer" role (Robson, 2002:309), the researcher can generate descriptive narratives of the observation setting. Interviews elicit perceptions of feelings and views which cannot be gained by observation alone. Crucially, conducted *in situ,* they offer opportunities for participants to discuss practices that are being observed. Semi-structured interview questions provided a prompt to researchers for what was envisaged to be a more conversational interview approach. This is because where interviews take a less structured format, they act to make public what Burns (2000:424), describes as the "… private interpretations of reality". This rationale helped the approach taken to the interviews conducted *in situ*. Students were engaged in PjBL in groups, and discussions were therefore held with group members – individually and collectively. Following students' agreement, discussions were recorded and later transcribed. Four of the research team were engaged in gathering data as observers and interviewers. Each of us also led a small group (of two or three) Post Graduate Teaching Assistants (PGTAs) who were recruited from the Faculty of Engineering Sciences. Six PGTAs were recruited from the pool of PGTAs who facilitate learning across all engineering departments. A research methodology training event was provided prior to data collection.

Table 1, below, provides an overview of the disciplinary scenarios that were observed and the interviews that took place *in situ.* Although not reported on in this paper, in the time frame of the research, one interdisciplinary challenge was observed over a five-week period between November and December 2017.

Table One: **Disciplinary challenges observed**

Year One	Year Two
Civil Engineering	Biomedical Engineering
Electrical and Electronic Engineering (EEE)	Biochemical Engineering
Mechanical Engineering (Part 1)	Chemical Engineering
Mechanical Engineering (Part 2)	Computer Science

As is the case in any qualitative approach to collecting data by observation and through interview, all the descriptive items were compressed and made manageable through the identification of categories, "analytic schema" (Fielding, 1993:167) or themes. Findings from the research project were initially organized around four key themes. These themes were identified from the outcomes most often associated with innovative engineering curricula. That is, the extent to which students developed skills associated with *non-technical aspects of engineering solutions*; the extent to which students are able *to turn theoretical work into real solutions*; the ability *to start with the minimum* and *to identify problems as well as problem-solve* (see Lahiff et al. 2018)**.** To address the aims of this paper and, specifically, to shed light on the development of students' technical /disciplinary knowledge in PjBL, we have focused on findings from the second theme: *Turning theoretical work into real solutions.*

Findings and discussion

Three main themes associated with the development of disciplinary/technical knowledge and understanding were identified. These themes are: putting knowledge to use in new contexts; learning something 'new'; and developing knowledge through collaboration. But, as reported elsewhere (Lahiff et al. 2018; Detmer et al. 2018), common learning points identified by students in discussions were related to the development of 'generic skills' under the theme of *'non-technical aspects of engineering solutions*'. Communication and team working were most frequently referred to although, for some students, budgeting and working within limited resources also featured in their responses. The following responses from Biomedical Engineering students are illustrative:

> "*I think definitely communication, because it's OK that everyone does anything but if they're not communicating what they're doing it's hard for you to know what they're doing […]. It's also difficult to know what they're thinking."*
>
> *"In terms of soft skills… I think we've definitely worked on communication and different methods of keeping everyone up to date and in the loop, including like using Google Drive, setting an action plan each day…"*
>
> *"We looked at what we were given [budget/resources] because we needed to do something that was viable […] We'd used flex sensors and pressure sensors in previous labs so we knew how they worked, so they wouldn't be wasted [if we spent some of our budget on them]..."*

However, what also emerged from the data in relation to the development of generic skills was the importance of the *disciplinary context* to both the development of communication skills and team working. In single discipline scenarios, students explained that they thought that they '*spoke the same language'* with disciplinary group members because they not only shared technical knowledge but also a discourse and understanding of the ways of working in the discipline. Their learning was, therefore, consistently framed by the disciplinary context.

Putting Knowledge to Use in New Contexts

Turning attention to the development of disciplinary/technical knowledge per se, students spoke specifically about the ways in which the PjBL scenarios provided opportunities for the application of knowledge to practice. Across the disciplinary groups, students talked about the ways in which the PjBL scenarios provided a way to contextualize their disciplinary learning. This is unsurprising of course; some scenarios were developed specifically to provide this opportunity (see context, above). Nevertheless, the data offers an insight into the ways in which disciplinary learning develops, *as it is being developed,* and *how,* when faced with a real-life problem, students develop their knowledge and understanding. To illustrate, when asked what technical knowledge they brought to the scenario being observed, a Biochemical student reflected:

> *"I guess it's familiarisation with the material that we learn in class. Because I guess in lectures you kind of absorb it but when you actually apply it and you kind of think of all the assumptions [….] it's better than like sitting in a room, a lecture room, listening to pure theory things. Because you work through it and you learn better..."*

Similarly, an Electrical and Electronic Engineering student reflected:

> *"Yeah, I mean I'm learning a lot. I know things that I didn't know and I feel like I'm really understanding the equations we're using. The thing is that [because] we are applying these in real life, we have to figure out what we are measuring [when using equations] … like when we did the problems [in lectures]..we just take like what they tell us, but here …. I'm really understanding what we are doing, and it's good."*

Across all the scenarios, irrespective of the relative complexity of the scenarios and the disciplinary context, the value of the PjBL approach to the development of understanding is acknowledged. The following response from a first year Electronic and Electrical Engineering student is illustrative:

> *We learn more because the lecturer doesn't tell you how to make an electromagnetic force; they just tell you some theory. And the scenario kind of helps us to put it into practice and to measure some parameters by ourselves. So, I think it's more important than the lectures.*

However, there was also evidence of disciplinary learning which moved beyond theory and into developing understanding of the practice of engineering. For example, Mechanical Engineering students experience two linked scenario weeks in their first year. During the first week they focus on a design process which is followed five weeks later by a 'build' scenario. As with other students, they fully appreciated the value of the PjBL experience but they also identified the contribution the PjBL scenarios made to their sense of 'becoming' a Mechanical Engineer as the following quotations illustrate:

> *Because like it's about using what we've learned so far and the planning process and everything about the design process to actually make something that we can feel and touch and that actually works…*

> *[In this second] scenario, like we actually build something! So, like to me, it felt like I was doing engineering, it didn't feel like I'm doing an actual science degree!*

Learning something 'new'.

Across the disciplinary scenarios, some students were asked whether they were learning '*anything new*' and left to define what that meant for themselves. What is reported here is a selection of the various ways students described 'new learning' in relation to technical knowledge and skill. For second year Computer Science students, for instance, there was a consensus that a lot of the technical skill development was 'new' and similarly for Biomedical students who had been told they needed to use a new coding system. The first student quotation is from computer science, and the second from Biomedical

> *"Well…a lot of the stuff that we're doing is new, so it's connecting to new systems that we haven't seen before and providing sort of features that we haven't tried before. So, both in own areas of expertise and in other areas we've sort of learnt new things."*
>
> *"This is Arduino [coding] and we're just given it! [Its] daunting to have to learn it, but we actually learn a lot because we make mistakes…."*

Being aware of learning 'something new' in the PjBL scenario was also the case for some Chemical Engineering students who were asked whether they were applying what they had learned before to a practical context. The first response is unequivocal, while the second takes up the notion of 'newness' given differing contextual conditions:

> *"No, Not really. I think it's quite new, like the materials that we're doing you know it's not really like what we've done last year. Because last year we did a lot about pharmaceuticals […] But this year it's really more about working through with like this new area…."*
>
> *.. "a lot of the stuff is new and you're putting that into a newer context too, so you need to do research on that to make everything work."*

Finally, in Civil Engineering, some students who were interviewed whilst they were completing some mathematical calculations required for the scenario were asked whether they were learning anything new. One student responded directly:

> *'From knowing nothing to finding a way to figure out all this, then you must learn something!'*

Developing knowledge through collaboration

One of the assumptions of a social constructivist approach to learning is that through engagement with others knowledge is developed both singularly and collectively. This is also the case in the workplace: the key to successful project-working is often seen to be successful collaboration. In the PjBL scenarios student groups, depending on size, often shared out areas in need of investigation and came together throughout the week to combine their efforts. In the following illustration a student from Civil Engineering describes the 'knowledge gains' in the division of tasks:

> *"If people are working on like let's say, geo-technics they are getting knowledge of that part. But if you're doing tunnel structures you're getting knowledge of that part, you know. Also standards, what sort of materials you want and so on"…*

When asked whether individuals then came together and shared their developing knowledge, the overwhelming response was: "*Yeah we do*." There was a similar response from students in Computer Science. When asked whether sharing of knowledge occurred, one group member responded:

> *"Yes…especially in the integration part, because you cannot just integrate with the others, you have to understand what he has done. You have to understand everything. You cannot just integrate some part without understanding the work".*

The recognition of the importance of sharing learning was common across most of the scenarios. In part, this might be explained by the way in which some academic staff have ensured that group members share their knowledge gains through the promotion of more collaborative rather than simply co-operative group membership. This has been achieved through structured activities and assessment practices. For example, if students are being assessed on presentations, any member of the group can be called upon to explain the content of the presentation. This was seen as particularly important for groups of more than four.

Other insights into developing knowledge through collaboration highlighted the value of collective problem-solving. There were a number of instances of this. The first illustration is from Mechanical Engineering and the second from Biomedical Engineering, where various sensors were being tested.

> *"With the design process we found there's been an ongoing [problem] situation for us because every time we thought we'd completed a design we had another flaw came in our way. And yeah just multiple problems that came up and together we just had to find a way of solving them."*
>
> *"It was sort of a trial and error scenario where we found that it wasn't working as well as we'd hoped it would be. We brainstormed, we came together as a team and talked about how we might improve the functioning of the device and once again we tested them and we found that this one worked the best".*

In summary and without underestimating the challenges faced in collaborative working, students across disciplinary scenarios discussed the benefits of collaborative engagement and were also able to identify the utility of collaboration for future working practice.

Conclusions and implications.

This paper has drawn on our research into engineering students' learning in PjBL contexts. By interviewing students *in situ* as they worked through their respective scenarios, we have seen not only how students develop their generic skills in a disciplinary context, but also how PjBL can provide a learning environment in which disciplinary knowledge and technical skills flourish. Our argument is that by introducing PjBL, it is possible to achieve a balance between the development of generic skills and the development of technical/disciplinary knowledge and skills. However, it is important to state some caveats – both theoretical and practical. The first of these relates to understanding knowledge.

Socio-cultural theories of learning understand knowledge as dynamic and emergent in practice, with deployment of knowledge and skills dependent on situational factors. Separating knowledge *acquisition* from *application* therefore creates a spurious and unhelpful dichotomy – not only for engineering educationalists but also for students. As we have shown here, students continue to/develop their understanding of key concepts and disciplinary practices as they 'put their knowledge to use' in new situations through collaboration with others. Secondly, the learning potential of PjBL activities can only be maximized if it is understood as being a pedagogic tool. In other words, students are not 'doing projects'; they are engaged in project-based learning activities. These activities are simply framed as projects due to the ubiquitous nature of project-based working practice in engineering and the desire to replicate this 'real-life' phenomena in HE. Thirdly, through the discussions with students *in situ* reported here and from our knowledge of the IEP scenarios and their respective development, students need the opportunity to reflect on their learning experience and record their own development. These reflections can be built into the experience and, indeed, become part of individual assessment, if desired. Fourthly, the PjBL scenarios reported here are actively mediated and assessed informally and formally in various ways by academic staff and PGTAs in engineering. Ensuring that staff who mediate learning in PjBL contexts are sufficiently confident in doing so requires appropriate professional development opportunities. This does not necessarily mean the development of formal continuous professional development (CPD) opportunities. Rather, our starting point is to engage with IEP staff to share their experiences of the development of expertise in this area. Finally, whilst of necessity a selection, we have been able to share some engineering students' experiences of learning in PjBL contexts *in their own words* whilst they were engaged in PjBL activities by adopting a qualitative approach to research. The value of adopting this approach has been enormous. We would encourage others within engineering education to do so.

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