P109

Making projects work: a review of transferable best practice approaches to engineering project-based learning in the UK

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***Abstract**: In line with international trends, project-based learning is increasingly being viewed as an important feature of engineering education in the UK. The paper presents findings from a snapshot review of current approaches. Undertaken in 2009, the review was informed by consultations with UK and international experts and practitioners in engineering education, project-based learning and problem-based learning. It forms part of a wider programme of work at the Bernard M. Gordon-MIT Engineering Leadership Program at MIT to promote leadership and project-based learning in the engineering curriculum.*

The findings suggest that project-based activities are often developed by faculty operating as lone 'champions' with limited time, resources and support. Given these structural constraints, approaches which have been 'tried and tested' elsewhere could provide robust models, particularly initiatives which are well-regarded by the engineering education community. However, evidence from the review indicates that many well-known approaches to project-based learning do not offer readily transferable models, either through catering to low student numbers on relatively high per capita budgets, or through relying on specialist in-house expertise or equipment.

Against this background, the paper discusses the key features of successful engineering project-based learning experiences in the UK. A selection of transferable best practice examples currently in operation is presented, that could, potentially, be adopted 'out-of-the-box' at other institutions. The paper concludes by noting the importance of institutional support for the current and future success of project-based learning in the UK engineering curriculum.

Introduction

The last decade has seen increasing debate about the aims and quality of UK engineering education. High-profile reports (HM Treasury, 2005, 2007; Royal Academy of Engineering, 2007) have been an important catalyst in engaging engineering faculty and departmental senior management in a dialogue about change in UK engineering education.

In recent years, both project- and problem-based learning have been the focus of considerable attention in the international engineering education community (Du et al, 2009; Godfrey and Hadgraft 2009; Beddoes et al, in press). Within the UK, project-based learning (PjBL) has attracted particular interest because of its potential to increase student engagement and improve skill development (Strobel and Barneveld, 2009). Its development has been further facilitated by government investment in University-based *Centres for Excellence in Teaching and Learning* (CETLs), which include a number of Centres with a particular focus on engineering and active-learning (HEFCE, 2009). Established in 2005 with 5-year funding, it is not yet clear how many CETLs will continue to operate beyond 2010.

Informal networks have also helped to connect UK engineering faculty working in PjBL. These include a network linked via the Engineering Subject Centre (www.engsc.ac.uk) and the UK-branch of the international CDIO (Conceive-Design-Implement-Operate) initiative (www.cdio.org). At the same time, new web resources have been developed, for example by the Higher Education Academy Physical Sciences Centre (2005) and by the *Project Based Learning in Engineering* initiative (PBLE, 2003) and targeted conferences have been held (for example the 2009 conference on *Enhancing Project Based*

Learning in Engineering and the 2009 *International Symposium for Research on PBL in Engineering Education* at Loughborough University).

Against this background, a snapshot review of current UK approaches to PjBL in engineering education was conducted in 2009 (Graham, 2010). It forms part of a wider programme of work at the Bernard M. Gordon-MIT Engineering Leadership Program at MIT to promote leadership and PjBL in the engineering curriculum. The starting point for the review was an appreciation that some of the most effective PjBL programmes are often resource-intensive and designed for small class-sizes. They typically rely on high inputs of staff time (both from mainstream faculty and from external stakeholders), specialist facilities and additional equipment, and can be difficult to ‘scale up’ to the large and diverse student groups that typify many schools of engineering. The review therefore focused on the identification of approaches that were both highly regarded and *transferable*.

Recognising that PjBL encompasses a diversity of approaches, the broad definition provided by Prince and Felder (2006) was adopted for the review:

> Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome.

This definition encompasses a range of educational activities using inductive instructional methods – active learning, inquiry-led learning, problem-based learning (PBL) etc. – where they focus on a fixed deliverable.

Methods

Two linked methods were adopted to identify and investigate ‘best practice’ transferable examples of PjBL.

1. *Targeted interviews* were undertaken to capture expert judgment of engineering PjBL in the UK and locate highly regarded examples. The interviewees fell into four broad groups (i) UK and international experts in engineering PjBL and PBL (ii) UK and international experts and/or innovators in engineering education (iii) experts in PjBL and PBL in UK higher-education and (iv) Heads of Department or Directors of Studies in leading UK engineering schools.
2. *Investigation of targeted programmes*: examination of the most highly regarded examples of engineering PjBL identified during the interview phase, to identify those that are both effective and transferable.

Across the two phases of the study, more than 70 experts and practitioners in engineering education, PjBL and PBL were consulted. While extensive, it needs to be emphasised that the review was not designed to provide a comprehensive survey of UK engineering PjBL.

Findings: overarching themes

The review uncovered some overarching themes relating to the *current position* of engineering PjBL in the UK and to the *contextual factors* likely to shape its future development.

Current position

It was widely observed that the UK is characterised by a wider variety of approaches to PjBL and PBL than typically found in other countries, with the engineering faculty less tied to the classic models such as that developed at McMaster University. What one interviewee described as its more ‘maverick’ approach was linked to the way in which PjBL experiences have often been developed: by engineering faculty with no formal training in education and therefore with fewer preconceptions about what an effective PjBL activity ‘should look like’. It is therefore not surprising that the study uncovered a wide range of understandings of both PjBL and PBL, with many engineering departments preferring broader terms like ‘activity-led learning’ to describe their approach.

In particular, the study made clear that the development of engineering PjBL is being driven by faculty ‘champions’. Evidence from the expert interviews and the exemplar programmes indicated that the majority of engineering PjBL is developed and delivered within discrete modules by a small number of committed faculty. Thus, the common feature of the most highly regarded examples is the quality of leadership. The module leaders were recognised to be committed to excellence in education, to benefit from a high level of autonomy in the design and operation of their modules and often to have a background in engineering industry.

However, the expert view was that reliance on champions has important downside. Leaders often work alone and with minimal support from either departmental/school senior management or external bodies. In consequence, modules incorporating PjBL are vulnerable to staff changes, and prove hard to sustain beyond the tenure of the champions. Thus, a large number of the PjBL programmes recommended as ‘best practice’ examples by experts during the first phase of the study were subsequently found to be no longer running because the module leader had either retired or had taken up a post elsewhere. The dependence on a single individual is particularly significant given the time that experts saw as required to hone and fully embed PjBL activity into the curriculum; for example, a UK-based engineering module leader noted that 5-10 years was probably the minimum period.

Contextual factors: drivers and barriers

Operating within a global market, UK engineering education was seen to share many of the challenges confronting engineering education elsewhere. However, some factors were considered to be particularly important in the UK context. These factors included both drivers of and barriers to the development of engineering PjBL.

Among the drivers, many UK interviewees described the strong **calls for change** from government, industry and professional bodies to ensure that engineering graduates were equipped with a broader set of professional skills and greater experience of addressing ‘real’ engineering problems. PjBL was also seen as an ideal mechanism to drive forward a greater emphasis on ethics, sustainability and multi-disciplinarity in the engineering curriculum.

A second and more specific driver related to student **recruitment and retention**. PjBL was seen as important in attracting students in an increasingly competitive market. Interviewees observed how PjBL experiences were often concentrated in the first year of study and/or the wider degree programme was rebranded around active learning, including project-based approaches. At the same time, recent government changes to university funding are increasing the focus on student retention. Because of higher penalties on institutions where undergraduate degree programmes enrol beyond their allocated number of students, departments are seeking to maximize their income for a capped number of places by minimising subsequent drop-out. PjBL was seen as a way of maintaining student engagement. However, a number of interviewees expressed concern that, in the drive to improve recruitment and retention, the resulting curriculum can simply focus on ‘*wow factor’* projects rather than on educational outcomes of long-term benefit to students.

A small number of interviewees also identified ***Bologna compliance*** as a possible driver for future interest in engineering PjBL. It is not yet clear whether the UK will be required to change the structure and duration of its undergraduate programmes in accordance with the *Bologna* agreement. If compliance is required, a number of engineering schools are considering integrating engineering-related vacation activities into the curriculum, to increase the number of credit-bearing modules. If such plans are taken forward, new mechanisms will need to be developed in order to support these mainly project-based activities.

Alongside these contextual drivers, the interviewees identified factors which they regarded as potentially impeding the current and future implementation of engineering PjBL. A recurrent theme was that, unless these barriers were addressed, PjBL may lose ground within the engineering curriculum. Three broad challenges were identified, relating to resources, expertise and efficacy.

Resource constraints were widely cited as holding back the development of PjBL. Many of the well-known and highly-regarded approaches to PjBL were noted to be resource intensive: costing more than standards approaches with respect to faculty time, additional specialist staffing inputs, teaching space, equipment and materials. Such resources are currently under particular pressure, and were anticipated to remain so in the short to medium term.

Interviewees noted how other demands could crowd out the faculty time needed for curriculum innovation, particularly for forms of student learning that require significant investment of staff time at both the development and implementation stages. Here, the conflicting pressures of teaching and research were repeatedly highlighted. Research performance is closely monitored and assessed by the UK’s higher education funding councils, in particular through the process of periodic peer-led review: the *Research Assessment Exercise* (RAE) in 2007 and, in 2013, the *Research Excellence Framework* (REF). Many viewed the intense pressure to maximise research performance (particularly research grant income and publications in high-impact journals) to secure high rankings in the RAE/REF as disincentivising excellence in education. In particular, interviewees identified PjBL as an activity demanding significant amounts of time to design and support, and noted the difficulty of freeing up such time from their own schedule and securing commitment from their colleagues. The review did identify a small number of institutions where coordinated support for such activities was provided at a school or departmental level - most notably, in recent years, at Coventry University and University College London. Interview responses highlighted that such institutional support broadened the scope for the creation of new PjBL activities, had a highly beneficial impact on the cross-curricular integration of experiences and allowed the modules created to be developed and sustained over a longer period.

Faculty time was not the only resource constraint identified however. Interviewees also described how lack of funds for materials, equipment and non-faculty staff worked against the development of PjBL. Cost constraints are likely to increase following the significant cuts to government funding for UK higher education (Secretary of State, 2009). In addition, with government funding to the CETL centres ceasing in 2010, external resources may also be limited.

In addition, a number of UK interviewees identified a lack of appropriate learning spaces as the key barrier to a wider implementation of PjBL within their curriculum. The alternative – splitting the student cohort and accommodating them in a number of inadequately equipped smaller spaces – was seen to have too negative an impact on the learning experience for PjBL to be a viable long-term option. However, following many years of national under-investment in university infrastructures, a number of engineering schools (such as the University of Liverpool, Coventry University and Imperial College London) have recently completed or are planning new or totally refurbished engineering buildings that incorporate new learning spaces. The new builds appear either to have been influenced by or to be triggering shifts towards active learning. Such developments present a significant opportunity for considering new modes of teaching and learning.

Expertise deficits. Harnessing the expertise needed for PjBL was also highlighted as a significant constraint on its development. A number of interviewees commented on the small pool of UK engineering faculty with industry experience, with numbers declining over the past 10-20 years. Many view such experience as an important element in designing and supporting meaningful 'real-world' project-based activities. For example, one interviewee commented that the "*lack of such experience means that staff are reluctant to move outside their relatively narrow research 'comfort zone' where they are confident of their mastery of the relevant facts into an area where they will inevitably be exposed to areas new to them*".

The training of facilitators also appears to be a significant issue. For many PjBL activities, a large number of facilitators is often required to oversee and support the group working process. In many cases, PhD students or post-docs are employed in this task, but many struggle with the concept of facilitating group activities while providing only minimal technical guidance.

Efficacy and assessment. It was widely reported that PjBL was well-received by students, as measured both by informal feedback and the mandatory student satisfaction surveys. However, a number of interviewees noted that very few PjBL activities employ formal module evaluations beyond such standard student feedback mechanisms.. The interviews made clear that, without such information about the efficacy of PjBL when compared to more traditional educational approaches, many departments are reluctant to extend the scope of PjBL within the curriculum. They pointed to scepticism among colleagues that the apparently positive impacts of PjBL may simply be the result of more favourable staff-student ratios that often support it, rather than from its inherent qualities as a mechanism for improving student learning. The paucity of evidence of efficacy was underlined in a recent US study of project-based service learning in engineering (Paterson et al, 2009); it described current program evaluations as "*anecdotal and qualitative*" and, although some program assessments were underway, "…*comprehensive and rigorous outcomes assessment strategies have not yet emerged*".

The study also pointed to a lack of knowledge and/or confidence in the design and implementation of *assessment* procedures for PjBL. Perhaps for this reason, many UK examples of engineering PjBL incorporate significant levels of summative assessment. In addition, approaches are often highly structured, with the overall task broken down into stages that groups must complete and deliver on schedule. While often developed to support 'weaker' students and encourage a transition into independent learning, these more prescriptive forms of assessment were seen by a number of interviewees as "*missing the key energising element*" PjBL through not allowing the students the space to create and explore new ideas.

Findings: examples of transferable 'best practice'

The themes summarised above suggest that engineering PjBL in the UK faces both opportunities and challenges. On the one hand, the case for expanding and integrating PjBL was widely recognized, with increasing demand from government and employers for appropriately-skilled graduate engineers and increasing pressures on universities to maximize student recruitment and retention. On the other, experts pointed to major structural constraints, particularly around resources and expertise. These limited the scope for adopting well-regarded models of PjBL that relied on relatively low student numbers, high per capita budgets and/or specialist expertise and equipment.

The review therefore sought to identify successful approaches to engineering PjBL that could be adopted 'out-of-the-box' at other institutions. The process was informed by the interviews, followed by more detailed analysis of the modules/programmes suggested as exemplars of best practice. Guidelines were developed to aid the identification of transferable examples, based around the challenges of resources, expertise and efficacy highlighted by the experts consulted in the study (Table 1).

Resources	• cater for relatively large cohorts (greater than 50 students pa) • require relatively low set-up and on-going costs (maximum operational costs of £15 per student pa outside faculty/staffing time) and no specialist equipment or learning spaces beyond that typically found within an engineering department • offer a sustainable 'stand alone' module/set of modules – i.e. not be dependant on a curriculum designed around PBL/PjBL or high levels of central support
Expertise	• not require any specialist external contacts or technical expertise beyond those typically found within an engineering department
Efficacy	• evidence that the project task/context is engaging for students and staff • demonstrate the successful achievement of the learning outcomes (if evaluation data available) • emerge as highly-regarded by national and/or international experts during the interview process for the study

Table 1: guidelines for identifying transferable 'best practice' in UK engineering PjBL

Using these guidelines, a range of highly rated examples of UK engineering PjBL was identified. A selection is outlined below.

1. Partnerships with real on-going constructions: final-year civil engineering projects in which student groups work on large-scale design projects that mirror real local developments, with strong input from the construction company involved. Examples include the capstone *Inter-disciplinary Group Project*, Department of Engineering, University of Liverpool.

2. Entrepreneurship and product design: capstone group projects for students to design an innovative product and develop an associated business plan for taking the product to market. In many examples of this approach, students are asked to deliver an 'elevator pitch' of their product idea to an external industry panel. Highly regarded examples of this approach include the *Marketing and Business Planning* module at Queen's University Belfast (web-resource: *An Integrated Approach to Entrepreneurship*, www.engsc.ac.uk/downloads/Entre/belfast.pdf) and the *Technology Strategy and Business Planning* module at the University of Sheffield. To give a flavour of this approach, Table 2 provides further educational and operational information on this module (awards include the *Royal Academy of Engineering, ExxonMobil Award in Excellence of Teaching 2008-2009* and the *HE Academy Engineering Subject Centre Teaching Award 2004-2005*).

The project	To develop solutions to, and an accompanying business plan for, 'real world' problems, particularly product concepts to improve the lives of individuals or groups living locally. The project 'client' works closely with student groups throughout the module (for example, the 2007 'client' was a 7-year old boy with cerebral palsy who encountered a number of practical difficulties in his day-to-day life; the project brief was to 'make life easier').
Assessment	Assessment of each group is conducted by a team of internal faculty, external industry experts and the project client/s and comprises (i) *Business Plan* (40%) (ii) poster (40%) and (iii) a final discretionary mark (10%) allocated only for

	exceptional work. In addition, a £1000 prize is awarded to the highest scoring team from the panel assessments of presentations.
Scale	In 2008-09, 110 final year MEng students from across the engineering school enrolled in the semester-long module, typically working in groups of 3 or 4.
Resourcing	Set-up and operational costs are very low and do not extend beyond the production of the posters presentations and hospitality for invited guests. All external partners are engaged on a voluntary basis. Each year, industry sponsors donate around £1000 as a prize to the winning project.
Staff commitment	One faculty member manages and delivers the full project. Additional internal faculty support requirements are low and include occasional specialist lectures and availability for advice to student groups on request. External participation from industry experts is provided in specialist guest lectures and involvement in the final project delivery/assessment. Involvement from the selected 'client/s' is required throughout the project and in the final delivery/assessment.
Transferability	A stand-alone model catering to relatively large cohort numbers with minimal costs. The constraints, however, lie in the ability of the module leader/s to access the required external industry specialists and to effectively identify and sensitively manage the relationship with the project 'client' each year.
Other issues	The most significant issue surrounding this project is ensuring the ethical management of the relationship the 'client' and ensuring that their expectations are in line with the likely project outcomes.

Table 2: example of entrepreneurship and product design through PjBL (*Technology Strategy and Business Planning* module at the University of Sheffield)

3. Video production and showcasing: introductory modules, requiring student groups to design, produce and showcase a short video providing insight into a technical engineering subject area. For example, during the 2009/10 induction week, 1st and 2nd year students in *Civil Engineering* at Imperial College London produced and showcased short videos on London architecture. An example from Sheffield Hallam University is outlined in Table 3.

The project	To develop learner autonomy through student groups developing and delivering a short video for a professional conference environment focused on the causes and potential solutions to a real engineering problem.
Assessment	Assessment of two elements at end-of-module (i) group presentations at a conference assessed by a faculty panel and external industry partners (ii) individual multiple-choice test, based on knowledge derived during the module and from conference presentations. No peer assessment is employed and no written reports are submitted.
Scale	The module caters for around 60-80 first year students, working in groups of 5.
Resourcing	The major cost is the purchase of the cameras. In the future, one *Flip Video Camcorder* will be purchased for every two teams, at a cost of around £100 each. Student groups utilise the video editing software available as standard on most computers, such as *imovie* and *Windows Movie Maker*. Additional costs include room hire and catering for the final conference.
Staff commitment	Two module leaders designed and manage the activity. Additional support is also engaged for tutoring students in key skills such as project management, presentation skills and conflict resolution. An industry expert presents the keynote lecture at the conference.
Transferability	The model has low staffing requirements and assessment loads. Once cameras have been purchased, set-up and on-going costs are relatively low.
Other issues	Some in-house expertise in film-making and editing is highly-beneficial, although not essential, for the support of the student groups. As a module developed in recent years, the long-term viability and success of this experience has not been proven.

Table 3: example of video production and showcasing through PjBL (*Materials, Manufacturing and Environmental Engineering* module at Sheffield Hallem University)

4. Robot competitions: projects, often in the 2nd year of study, for student groups to design and build robots to compete in a variety of different challenges. Examples include the *Stamp Olympiad* at Loughborough University (Flint et al, 2009) where robots compete in various 'sporting' events and the *Embedded Systems Project* at the University of Manchester (Barnes et al, 2006) where Mechatronics students compete in a line-following robot race. A number of universities base these exercises around *Lego Mindstorm* robots, such as a creative problem-solving first-year module (Adams and Turner, 2008) at the University of Northampton.

5. Artifact analysis: projects that require student groups to each take one element of a more complex engineering product, such as a car, and investigate its properties, function, design and manufacture. An example of this approach is the *Mechanical Dissection* module in Mechanical Engineering at the University of Strathclyde (Barker and McLaren, 2005).

6. Crime scene investigations: a number of institutions have developed project-based crime-scene scenarios, where student groups are asked to identify the cause of an accident/crime. Examples include the newly developed 6-week full-time air accident investigation activity for first-year Aerospace students at Coventry University and the crime scene investigation in the *Materials with Forensics* project at Queen Mary, University of London (outlined in Table 4).

The project	A PBL spine runs across the first two years of the curriculum in the Department of Materials. The *Materials with Forensics* case-study aims to engender an understanding of key experimental techniques, and asks students to provide expert testimony from evidence they collect at a constructed crime scene. Requiring knowledge of techniques such as Scanning/Transmission Electron Microscopy (SEM, TEM), Thermal Analysis (DSC, TGA, DMA), Infrared Spectroscopy (FTIR) and Energy Dispersive X-ray (EDX), the exercise culminates in a 'court case', with faculty members acting as judge, counsel for the prosecution and counsel for the defence. Groups must submit their evidence in writing to the 'court' three days before the trial and identify members to act as expert witnesses.
Assessment	Uses input from the module leader, group tutors and individual students. The groups are assessed on their written 'submission to the court' and oral presentations of evidence for the 'court hearing'. Individual performance is assessed via a peer review process and moderated by the group tutor based on their observations of the individual's participation and performance.
Scale	The total cohort for the module is 60, with students working in groups of 5.
Resourcing	The total annual project cost is £500. It is assumed that no new experimental equipment will need to be purchased for the project.
Staff commitment	One faculty member oversees the project, with additional faculty support for the final 'court case'. Four teaching assistants oversee all group discussions and technician support is typically required during testing processes. Additional input has included advice from London Metropolitan Police.
Transferability	Low cost in both set-up and on-going costs, and will easily cater to relatively high students numbers. It requires some 'creativity' in setting up the crime scene each year and devising evidence to utilise the experimental equipment available.
Other issues	A suitable space is required for the staging the 'crime scene'.

Table 4: example of crime scene investigations (*Materials with Forensics* within the PjBL spine of the engineering curriculum, Queen Mary's College, University of London)

Conclusions

Engineering PjBL in the UK has reached an important crossroad in its development. There are pressures to increase the range and extent of PjBL, both from external stakeholders and from universities seeking to attract and retain engineering students. But there are also significant impediments, including competing demands on faculty time (particularly around research), a sharp decline in student funding and a reliance on individual 'champions' to develop and deliver PjBL modules.

Given these conflicting 'push' and 'pull' factors, the adoption of existing, 'proven' approaches could provide a way forward. However, many initiatives held in high regard by the engineering education community do not offer readily transferable models, because they cater for low student numbers and incur high per capita costs and/or rely on specialist expertise and equipment. The review therefore tapped into expert knowledge of excellence in engineering PjBL to identify examples operating on low budgets and relatively large class sizes, and without reliance on additional expertise, support and equipment. A range of models was identified, a selection of which have been outlined in the paper.

It is important to note that the successful adoption of these 'out-of-the-box' approaches relies on features that have underwritten their development and implementation - most notably the commitment and experience of the module leader. With such champions, however, it is clear that there is a rich array of high-quality and low cost approaches to PjBL available for adoption by engineering programmes in the UK and across the world. The long-term sustainability of PjBL experiences, however, is likely to rely on wider vision and support from the Head of School/Department and university's senior management team. This institutional support is likely to become more, not less, important for the future of engineering PjBL as UK higher education braces itself for a protracted period of retrenchment.

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Acknowledgements

This report was undertaken with financial support from the Gordon-MIT Engineering Leadership Program at MIT. The authors are particularly grateful to the engineering faculty, education professionals and engineering students from the UK and across the world who contributed so generously to the review by giving their time and sharing their knowledge and expertise.

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