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The Role of Project Based Learning at the Core of Curriculum Development

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Abstract

This paper will present the argument that while Problem Based Learning (PBL) (or its variant Project Based Learning, PjBL) provides significant benefits and advantages to student learning in of itself, the full benefit of PBL is only completely realised as part of an "integrated" curriculum that provides a variety of learning opportunities and instructional support. We propose that PBL should be more widely considered and used as the key integrative feature within a curriculum to enable programmes to connect theory, practice, societal context, values and skills as well as to break the mentality that comes with modularisation. To do this, we suggest that a coherent thread of PBL should be enacted that is stratified to progress students through increasingly open problems and projects, each connected to other aspects of the taught curriculum while enabling skills development and the formation of professional and responsible attitudes and attributes. We provide some examples from our own experience in Engineering but advocate that this approach is much more widely applicable within higher education.

Keywords: Problem Based Learning (PBL), Curriculum Design, Curriculum Development, Integrated Curricula.

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Introduction

Higher education has evolved significantly over the last decade, responding to external pressures as well as further rehearsing its on-going debate of the role of higher education in civilised society as espoused historically by Humboldt (Anderson 2004), Newman (1996) and more recently by the likes of Barnett (2011) and Marginson (2016). The emerging and complex landscape in which degree programmes are conceptualised include increased emphasis on quality assurance mechanisms, opportunities for blended and hybrid learning, as well as a reimagining of the disciplines and boundaries of disciplinary knowledge. Emerging topics such as AI and big data, as well as our necessary response to climate change and the climate emergency, cast a long shadow over the fundamental topics traditionally taught and are increasingly demanding a response from educators.

Perhaps most notably, in subjects such as science and engineering, the concept that learning should no longer be primarily based on the imparting of propositional knowledge but instead that such knowledge should sit within a much wider general context that is socially constructed and developed in a student-led environment (Goldberg & Somerville, 2023) has gained momentum. This has led to the development of curriculum frameworks, such as the Connected Curriculum (Fung, 2017) which aim to provide an outline of how relationships can be formed within the design of a curriculum to connect students with research, with the public, with the workplace and with each other across disciplines. Unfortunately, these desires for interconnectivity at times run counter to other developments in higher education, most notably that of modularisation. While neatly defined boxes of knowledge or educational activity, self-contained in terms of delivery and assessment, are convenient for university processes and accreditation bodies, they encourage compartmentalised thinking in both students and staff. All disciplines like to think of themselves as being hierarchical rather than encyclopaedic in terms of their knowledge structures, however, in STEM subjects this is often made starker with clear progressions of modules in a single subject spanning across years – for example in engineering, Thermodynamics I and II or Structures I and II or Electronic Circuits I and II, are all common disciplinary threads.

Set against this landscape we argue that a form of curriculum design is needed that is pragmatic, but also creates vehicles for flexibility and substantial change as new opportunities or requirements present themselves. Problem-Based Learning (PBL) has become a widely accepted pedagogy within many disciplines and particularly vocational disciplines such as engineering (Chen, Kolmos & Du, 2021) and medicine (Barrows, 1996). Alongside this, significant research has gone into evaluating the effectiveness of PBL as an instructional tool at a variety of levels, from its implementation in schools (Dole, Bloom & Doss, 2017) to higher education (Guo et al., 2020). In this paper we are going to argue that a central core of problem (or project) based learning pervading all years within a degree program and structured as a progression of skills and technical depth is an ideal mechanism to create connections between elements of the curriculum and create a structure greater than the sum of its parts. We will draw on our experience in engineering, however, we suggest that for many disciplines a key curriculum design consideration should be to ensure that PBL experiences are structured with stages and not a series of unconnected activities. We propose that this approach is an ideal framework for revision of existing curricula – recognising the fact that the exact nature of the revision, for example the size of the PBL components, will be heavily dependent on the local context and legacy frameworks and that no single implementation could be prescribed. Instead, we suggest curriculum designers use our conceptualisation of a PBL core as an inspiration for their own models, acknowledging that the reuse of a considerable amount of the existing teaching activity will very often be necessary.

The authors are both engineering educators and educational researchers with leadership and Professorial positions in the UCL Faculty of Engineering Science, a research-intensive university in London, UK. Both have been involved in developing integrated programmes, most notably, UCL's Integrated Engineering Programme (IEP) (Mitchell, Nyamapfene, Roach & Tilley, 2021), where technical and transferable skills are combined within a curriculum centred around a core of Project Based Learning. They advise universities worldwide on strategies to review and adapt their curricula to incorporate active learning and to refocus their educational approaches to produce highly employable graduates for the modern workforce. This paper draws on these experiences of curriculum design and support of curriculum development in different contexts.

We will start by clarifying some definitions and describing the theoretical frameworks in which we propose our curriculum design.

What is the Curriculum and Curriculum Development?

It is common to consider the curriculum as having four elements (Bernstein, 2000) which involve different, although sometimes intersecting, groups within a university. Firstly, there is the *planned curriculum*, that which is designed, developed and ultimately validated through bureaucratic university processes. Secondly, there is the *delivered curriculum*, the manifestation of the designed curriculum when put into practice. Thirdly, there is the *received or perceived* *curriculum*, acknowledging that the curriculum received by students may differ from that proposed or delivered by staff. Finally, and perhaps most crucially, but most often ignored, is the *hidden curriculum*, that which is not formally specified but tacitly transmitted thought the processes and cultures that are inherent in the educational organisation. For new programmes, the first element is typically driven by a programme lead or a visionary tasked with developing a new curriculum, perhaps supported by a small team. Once established, there may be periodic review by senior members staff, for example a Director of Studies. The remaining three elements are the sum of the inputs of many different actors who form the teaching 'team' that are responsible for all the separate elements of the programme. The coherency of this team and the extent to which there is a shared vision and understanding of the programme will contribute significantly to how and how far these elements diverge from the planned curriculum.

Typically, within each of these curriculum lenses discussions take place about what should be specified. The most common approaches have tended to focus on the content of the curriculum – the 'what' of the curriculum. For many years, documentation from accrediting bodies or government ministries specified, sometimes to minute detail, the specific knowledge a graduate engineer should acquire during their studies. Most recently an outcomes-based approach has been adopted in many parts of the world, reframing the requirement to be the knowledge and skills acquired by students by the completion of their studies. This has led to other aspects of professional practice to encroach and take priority in the act of curriculum design. This has been within the context of the shift to learning outcomes as the starting point of the development, which encourages the recognition of the importance of skill and competencies in graduates in addition to fundamental knowledge. We have also seen discussion of organisation processes, such programme level assessment and synoptic projects or synoptic assessment methods (synoptic - an element outside the modular structure that covers students' understanding of the links between the different elements of a subject). Although in many cases there is significant contextual constraints to making these changes, they demonstrate potentially significant shifts in pedagogy and assessment practices (Blackmore & Kandiko, 2012) that might be considered.

Despite engineering degrees often being considered as vocational, fitting with Short's (2000) definition of a 'practical' or 'mission-orientated' subject, the typical engineering curriculum, especially at top-ranking, research-intensive universities often has much in common with the 'Disciplinary Knowledge' model that Short would ascribe to philosophy or the sciences. In reality, this emphasis on knowledge over practice means that curriculum design becomes heavy on theory, with a focus on mathematics and science as the core, that leads to engineering science theory and application of theory in later years – the math-science death march as characterised by Goldberg and Somerville (2014). A shift from this situation has been the centre of the majority of the curriculum development activities in recent years and in emerging calls for reshaping of engineering education (Habbal et al., 2024).

Although often implicit and highly contextualised, institutional structures, including ways of working and culture, are rarely articulated clearly, thus we deem interrogation of the organisation processes of the curriculum an important starting point to any design. Most faculty assume they work within a set of organisational constraints that are 'normal' (i.e. the same everywhere) despite huge variation occurring between countries and even between institutions within the same country. For example, in the UK and Canada, as well as many Nordic countries, the concept of a curriculum can take on a fairly rigid structure, with precisely described modules in a predefined order certainly not uncommon in the first two years if not further into the programme, especially in Science and Engineering. In contrast, in the USA, Egypt, and certain parts of Europe the curriculum is often far less structured, with credit-hour systems that allow considerable free choice in the modules taken (as long as the subject hours add up), when they are taken and in some cases even in the order in which they are taken (although pre-requisites exist). The differences in these fundamental structures mean that the level of curriculum 'design' that is possible can be very different depending on the context. In the Integrated Engineering Programme (IEP) at UCL, all bar one module of the first two years is pre-determined in both content and order for each discipline allowing the possibility of a programme level curriculum design to a high-level of detail creating a complex web of interconnections to be formed between modules and interconnecting activities (Mitchell et al., 2021). In contrast, the New Engineering Education Transformation (NEET) at MIT had to introduce far more structure than typical to provide coherent threads of modules within their degree programmes (Crawley & Hosoi, 2019).

Taking this concept of the curriculum, one which considers the knowledge and skills but also the academic process, pedagogy and assessment, we define curriculum design as: *the systematic process that defines what will be taught, who are the teachers, who will be taught, and how they will be taught within an engineering education.* We define curriculum development as: *involving the planned, purposeful, progressive, and holistic process to create positive improvements in an education system so that graduates are best prepared to maximise their future*. As such both draw together threads of knowledge and transferable skills and pedagogic approaches to create an amalgamated set of learning experiences to meet the intended programme level outcomes.

The desire to have Programme level outcomes stems from a shift in thinking towards Outcome-based education (OBE) (Premalatha, 2019) which (in engineering at least) has, in part, been led by accreditation as well as by other quality assurance mechanisms within the academy, included a recent emphasis on the skills and employability of graduates. OBE "means clearly focusing and organizing everything in an educational system around what is essential for all students to be able to do successfully at the end of their learning experiences." (Spady, 1994, p11). This is a central conceptualisation of our approach to curriculum design, where the elements within the curriculum are all intended, in one way or another, to progress the student towards the ultimate programme level goals (Premalatha, 2019). It is highly likely that these stages themselves will also be expressed as having goals – often expressed as module level learning outcomes, but the key consideration is that they do not occur in isolation but as stages in a longer journey towards successful degree completion. It is also important to note that there is a multiplicity of programme level outcomes and although many may interrelate and support each other this is not always necessary.

Perhaps the most common example of this can be seen in accreditation documents that specify the graduate attributes and competencies. For example, in the UK Engineering Accreditation documentation one such outcome is "Analyse broadly-defined problems reaching substantiated conclusions using first principles of mathematics, statistics, natural science and engineering principles." (Engineering Council, 2020, p28). This demonstrates how outcomes may provide overarching coverage of skills – in this case analytical skills – with knowledge – mathematics, statistics, natural science and engineering principles. A key feature is that they are the product of multiple, interconnected learning elements within the curriculum rather than one single class, module or activity. Such statements can be seen in many disciplines, for example, Law "The ability to demonstrate knowledge and understanding of a wide range of legal concepts, values, principles and rules of English law and to explain the relationship between them in a number of particular areas" (SRA, 2014, Appendix A) or Medicine "recognise the complex medical needs, goals and priorities of patients, the factors that can affect a patient's health and wellbeing and how these interact. These include psychological and sociological considerations that can also affect patients' health" (GMC, 2018, p11).

What these definitions of curriculum development and design seek to highlight is that the curriculum is the drawing together of threads, some relating to technical content, some relating to transferable skills and purposely proposes to connect them in the students' understanding of the discipline within the context of the institutional vision, values and strengths. In our conceptualisation of this prevalent curriculum model, which exists within many higher education institutions, it is then Problem (or Project) Based Learning that then becomes the central mechanism around which the rest of the curriculum is structured. It becomes the vehicle for skills to be developed and the place where core technical content is applied. It is where connections are made, and an opportunity presented for all these elements to be integrated through authentic experiences. However, it can also be the place where new knowledge is created. All open-ended projects offer that opportunity, and while not all students will achieve this it is paramount that intellectual space is available for new areas to be explored. It should, however, also be noted that preparation is needed. Isolated PBL without providing students with support or basic training in the skills required for success in that environment can be counterproductive. Any design should consider how students build and development communications skills, teamwork skills and critical thinking skills both inside and outside the PBL environment so they are prepared to get maximum value out of the project experience.

Problem and Project Based Learning

We have placed PBL at the heart of our curriculum, but why? Well firstly we should include our definition of PBL as it is quite evident from the literature that PBL covers a vast array of student-centred activities and forms. PBL is generally characterised as a constructivist, active learning technique built on the use of ill-structured problems (Savery & Duffy, 1995; Barrows, 1996) which form the core stimulus for the learning process (Savin-Baden & Major, 2004). It is typically undertaken within groups or teams. We further define Project Based Learning in a broad category that can be encapsulated after Hanney and Savin-Baden (2013, p8) as:

> "A time-bounded activity which is directed by the project participants or team, who determine the course of the project and the final output in response to a brief of some description."

For many years, the argument has raged (although this is perhaps putting it too strongly) as to where particular instructional models sit in the taxonomy landscape that surrounds PBL - this was even before the new entrances of Challenge-Based Learning (CBL) (Gallagher & Savage, 2023), Design-Based Learning (DBL) (Davis, 1998), Team-Based Learning (TBL) (Hrynchak & Batty, 2012) etc. where invented and created an even more confusing alphabet soup. We take the stance that in the evolutionary tree of these approaches, PBL is the central ancestor and most fundamental description of the genre. Although we also note that there are many lists of characteristics that are subscribed to PBL. For example, Savery (2015, p7) in *Essential Readings in Problem-based Learning* described PBL as "an instruction (and curricular) learner-centred approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skill to develop a viable solution to a defined problem. Critical to the success of the approach is the selection of ill-defined problems (often interdisciplinary) and a tutor who guides the learning process and conducts a thorough debriefing at the conclusion of the learning experience".

This definition covers many of the elements typically attributed to PBL. There is, however, an important omission here, often present in other definitions. That is for the need of the problems to be authentic to the discipline or interdisciplinary context in which the problem exists. We suggest that this is critical to the success of PjBL activities and to the engagement of students (Roach, Tilley, & Mitchell, 2018). It is because of this that we believe in many subjects the difference between PBL and PjBL is at best blurred and in practice, in engineering at least, it is almost non-existent as projects are recognised as a unit of work associated with the profession and thus inherently align with our authentic learning argument (Lahiff et al., 2019). Hence, in our experience of engineering education, we have most commonly implemented what we would consider to be Project Based Learning. While we will typically use the PBL nomenclature in the rest of this paper, there is no reason that in an appropriate context, the other approaches mentioned above could not replace anything discussed here.

It should be noted that Boud and Felettir (1997) caution against confusing PBL as an approach to curriculum design with the teaching of problem solving. This is something with which we strongly agree – PBL is educational tool that can be called upon within a curriculum design – not a starting point (e.g. we must have 50% PBL) around which a design should be based. While we are strongly advocating for the inclusion of a significant element of PBL, it is precisely because of its features of authenticity, its ability to encourage students to integrate theory and practice, and its appropriateness as a vehicle to allow students to apply skills within context, rather than any predetermined institutional ideology concerning its role as a transformative or reforming pedagogy. For example, in our own curriculum design experience, PBL as an active learning philosophy (Christie & de Graaff, 2017) was used as a central theme connecting the curriculum, rather than as an all-encompassing ideology. However, it is not uncommon that PBL and its variants are the centrepiece of a redefined curriculum when an institution is championing significant educational change where they are looking for what Kolmos (2017, p2) described as a 'mode 1' academic university where the emphasis is on theoretical learning, to 'mode 3', a hybrid institution with greater focus on social progress.

Creating a Spine of PBL in an Integrated Curriculum

Far too often curriculum development and revision is framed as a battleground. On the one side, the traditionalist clinging onto the methods of the past – the (large) lecture or prescriptive laboratory, while the other side is characterised as the evangelists of active learning, espousing student-centred approaches such as PBL as the only effective method of instruction. Of course, this polarised scenario poorly reflects the true landscape. As engineers, unsurprisingly, we have taken a very pragmatic, somewhat 'engineering' approach to our curriculum design – that of selecting the right tool for the job. Curriculum design at a programme level allows for the consideration of the wide variety of different learning outcomes that are to be achieved and the stages that students must progress through to eventually achieve those outcomes. Of course, it is surprising to see the lecture chosen as the predominantly form of instruction as traditionally may have been the case, but it would be equally surprising to have PBL as the only alternative. Controlled variety is key, with lectures as well as supporting tutorials, interactive workshops and inspiring seminars, explorative laboratories and project-based learning activities that interconnect and build into a coherent and connected learning journey for the students.

There are many different approaches to the implementation of PBL within the curriculum. Kolmos, De Graff and Du (2009) expertly dissect the differences between these models and draw on the five models of PBL developed by Savin-Baden (2000). The models provide a useful characterisation against which to evaluate each PBL approach and while we will make use of them here, we apply a slightly different framing to that explicitly adopted by Savin-Baden and implicitly by Kolmos, De Graff and Du. That is, rather than seeing them as a spectrum of approaches based on the quality of PBL that range from minimal engagement with PBL in 'model I' to the self-confessed utopia of 'model V', we see them in the context of a student journey – from a highly structured and broadly familiar approach strongly rooted in their disciplinary knowledge in 'model I' to wicked and open problems in 'model V'. As Savin-Baden describes it, a model where knowledge is "contingent, contextual and constructed" (2000, p127).

This framing leads us to the view of a curriculum that builds and develops and is often referred to as a spiral curriculum (Harden & Stamper, 1999), where there is an opportunity for iteration and the revisiting of important elements of learning – for example, key skills, throughout the curriculum. Originally conceived by Bruner (1960), it encourages reinforcement and integration of knowledge through an aligned process of building new learning that is connected to previous learning. In our curriculum model, we propose that PBL is the core mechanism of that spiral which provides the continuity – as shown pictorially in Figure 1. Despite being central, it is important to note that it also needs to be fed and supported by the other elements and aspects of the curriculum creating a symbiotic relationship between the theory, skills and practice. These are shown as the parallel threads, with the spiral indicating the building nature of the curriculum as student connect these threads together via the PBL core.

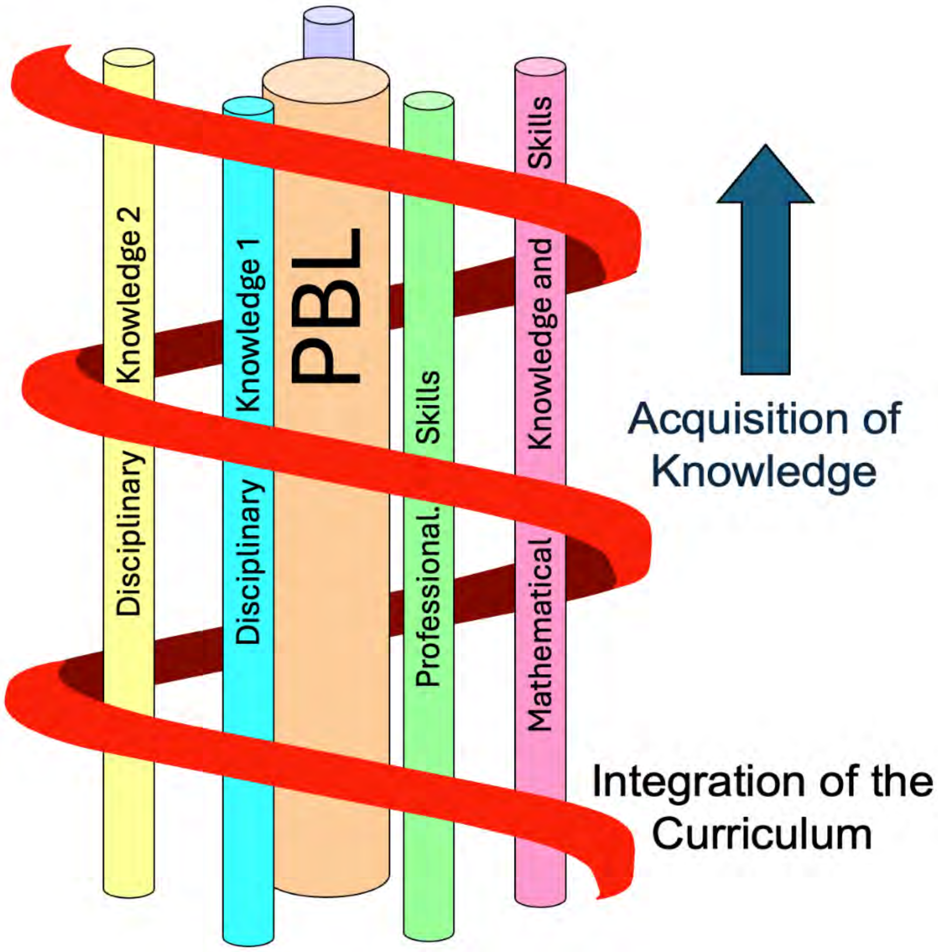

Figure 1. Example of PBL at the heart of a spiral curriculum.

In practice, we understand that this will take many forms and be dependent on the subject as well as the local context. However, what is critical is the integration and the interconnections that are formed between the central elements and the knowledge development in the outer threads, connected together via the spiral. This requires a multi-dimensional approach to curriculum design, considering the hierarchy of discipline specific knowledge as well as the points of interconnection to the PBL core and how the projects can be used a vehicle to develop skills and practice. This approach provides many advantages, one critical element being the future-proofing that these context rich experiences provide for the programme and the opportunity they present to enable continued innovation and rapid curriculum development. For example, a recent change in the accreditation requirements for engineering programmes in the UK has brought an increased emphasis on contextual topics. In a more traditional curriculum, such changes might require a new compulsory module or significant change to existing modules. In the curriculum we describe here, there is ample opportunity with this PBL core to embed sustainability into the authenticity of the projects, or bring ethics into the student's learning including coverage of wider social and global responsibilities central to the modern profession.

Such an approach is not without risks. Most notably, it can create a separation of the curriculum and scourge of 'someone else's problem' where key non-technical elements of the curriculum are segregated, forming ghettos of instruction, where everything outside of the traditional fundamentals of the discipline are dumped. Drawing on our experience of engineering education development in different disciplinary and institutional contexts, we have seen that in response to pressure from accrediting bodies to increase the teaching of design in the engineering curriculum in the early 2000's, it was not uncommon for traditional engineering programmes to introduce a design thread, often a series of design modules across the years where project-based design activities are undertaken. On paper, this might appear to look exactly like the sort of PBL thread that we are advocating here. And in many cases, they are. However, this is not always the case. If implemented solely out of pressure from accreditation without holistic curriculum design, they can become their own silo; separated and distinct from the rest of the curriculum. This approach creates projects/problems disconnected from the content of the programme, which risks this representation of the profession distracting students from what they perceive as their core learning. While they achieve many good things regardless of their segregation, valuable opportunities for greater integrative learning are missed and they can also become the sole repository for all 'non-technical' elements of the curriculum, reinforcing in students minds the separation between the mathematics, the science and the technical engineering and considerations of design, sustainability, ethics, user requirements etc.

While it might initially seem that such an approach requires wholesale curriculum revision which is hugely disruptive and likely to be met with significant resistance from staff, in fact, we suggest that it can be implemented in a far more pragmatic fashion. In such an approach, all elements of the curriculum should be reviewed but although some space is needed to be fashioned in the core, the vast majority of the programme can remain, with relatively minor disruption. This approach, while leveraging many advantages, also allows for continuous regeneration of the curriculum rather than a momentous revolution to suit the constraints of traditional universities. In our experience of the Integrated Engineering Programme at UCL (Mitchell et al., 2021), approximately 20% of the entire curriculum saw major revision, while the rest experienced much more modest refinement to fit within the new approach. Ten years on, we see that this programme has continued to evolve. In some cases, this was driven by the leadership team consciously developing the planned curriculum, but in others it is driven by the teaching team evolving the delivered curriculum by both further developing the new content, but also expanding their reach further across the programme. While some have rightly questioned diffusion models of innovation in higher education (Smith, 2012), it seems that if a critical mass of innovation is achieved, the resulting culture change promotes further developments.

What is important if such an approach is adopted, is that consideration is given not only to the planned curriculum but also to the perceived curriculum. The critical question is "How do students see the curriculum?". Do they still see the compartmentalised progression of technical modules as the main instructional element of the curriculum or do they now see the projects/problems as core, with the theoretical learning supporting these experiences. This shift in mindset is critical. In designing and evaluating such a programme, we must remember the mode in which students experience the curriculum. As educators we often take a bird's eye view of the curriculum – looking down on it as it is laid out across the years. Students, of course, rarely share this perspective. They approach the curriculum in a linear fashion from start to finish and hence it is an understanding of this journey through the educational landscape and the combination of the delivered curriculum and the hidden curriculum that is fundamental to how the curriculum is perceived. Approaches such as modelling the student journey can provide hugely valuable insight into the impact of any reform.

One advantage of adopting such an approach centred on PBL is that we can maintain the strong disciplinary presence that will be, in the majority of cases, the most recognisable feature of the existing degree, but augment and connect it through a core of PBL with associated supporting instruction. This forms a discipline specific programme that draws on interdisciplinary learning to provide the breadth of experience that students and employers are calling for. There are many ways these connections, which emphasise the relationship between disciplines, can be formed. The project core can contain separate projects, mapped to build and progress or may contain vertically integrated projects (Coyle, Allebach & Krueger, 2006) – a single long-term project that spans multiple year groups. Figure 2 shows an example of the sort of connections that might be developed with such a curriculum, with a central spine of project activities that build skills and provide a vehicle for practice and integration of learning, supported by not only the discipline specific material but also by a thread of instruction to ensure that student have the necessary skills to perform well within this project element.

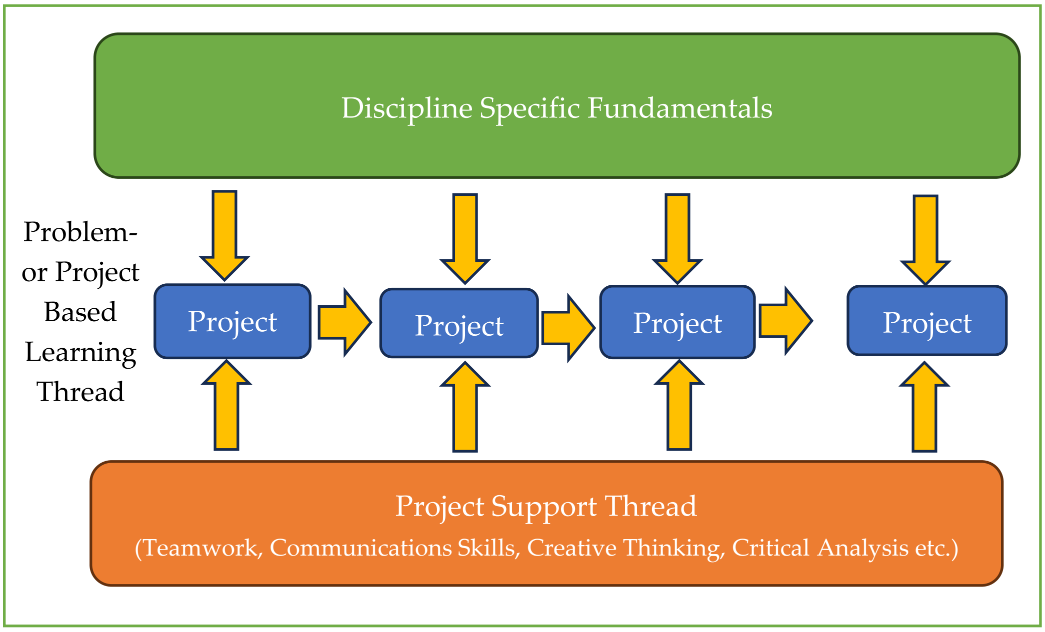

Figure 2. Example of the connections between elements of the curriculum.

This final area is one which is often missing, borne out of the mistaken assumption, for example, that putting students in teams will naturally teach teamwork through some form of self-discovery or osmosis.

Conclusions

In this position paper we argue for a model of curriculum development that uses problem- or project-based learning as its core to promote connections between all other elements of the curriculum. We suggest that a model of curriculum design that actively encourages the interconnection to modules and learning threads within the programme via a problem/project-based learning core is an excellent approach to curriculum development that can be undertaken as part of a curriculum reform within an established programme to create a significant shift in the emphasis of the educational experience that students perceive without the pain that is often considered to be associated with wholescale curriculum revision. We advocate for a revised programme structure, promoting skills development and authentic practice within students, that pragmatically overcomes some of the key disadvantages of modularisation and addresses the calls for an increased emphasis on developing rounded graduates, with a high-level of social awareness and considerable practice in key employability skills.

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