PBL in Engineering Education

International Perspectives on Curriculum Change

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RON ULSETH AND AIDA GUERRA

INTRODUCTION

During 2014–2015, a series of webinars entitled PBL History and Diversity was broadcast from the UNESCO Centre for PBL in engineering science and sustainability at Aalborg University. Following is the description of the series: "In the 1960s and 1970s, a handful of higher education institutions implemented a new and innovate learning approach – Problem Based Learning (PBL). PBL aims to develop a more student centred, close to practice and meaningful learning. For 40 years, PBL did not only survive but it has also grown and evolved due to research, development and implementation in several higher education institutions across the world, resulting in different models and practices. Nevertheless, the different PBL models relate with each other through basic principles around which the learning process is organised. Problem based, team based, self-directed and contextual learning are examples of these principles. This first series of webinars starts with PBL history by presenting its origins and philosophy, followed by seven examples of models PBL developed and practiced around the world" (taken from www.ucpbl.net).

The goals of the webinars were to understand PBL philosophies, models, and practices and further, to relate the models through learning principles and dimensions. This book arises from the webinar series. All of the PBL programs described in the chapters of this book were highlighted in the webinar series.

The intended audience for the book includes higher education institutions as well as researchers and practitioners who aim to implement, or change, their teaching and learning practices to PBL (i.e. problem based, project organized learning). All of the programs highlighted represent engineering education, however the case examples are described taking PBL principles as the point of departure which can make this book an inspiration for other disciplines and areas of educational research.

CONTENT

The book is composed of eight chapters. The first chapter by Anette Kolmos, Chair of the Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability under the auspices of UNESCO, addresses three main strategies of curriculum changes allowing the identification of three types of institutions depending on the type of strategy used. Furthermore, the different strategies underlie different types of drivers/triggers and problems addressed by the change process.

The following chapters present six PBL models from Singapore, Malaysia, Tunisia, Portugal, Spain and the U.S.A.

These models exemplify curriculum change in engineering education and are described based on: (i) objectives and knowledge; (ii) types of problems, projects and lectures; (iii) progression, size and duration; (iv) students' learning; (v) academic staff and facilitation; (vi) space and organization; (vii) assessment and evaluation (Kolmos, de Graaff, & Du, 2009). There is also a focus on a perspective of the time of the change process. Therefore, additional aspects such as drivers, implementation, challenges and perspectives, to the above guidelines are included, providing a holistic understanding of change process. These cases not only exemplify some aspects of the type of change addressed in the first chapter, they are also stories of thriving success which can be an inspiration for those who aim to implement PBL and change their engineering education practices.

The motivation for the book is to bring new theoretical insights to PBL theory and principles, and descriptions of PBL curriculum that thrived through time and from different contexts.

DISCUSSION

Leading off the book, Anette Kolmos defines PBL and provides a historic perspective. She invokes Barnett's (Barnett, 2009; Barnett & Coate, 2004) categorization of knowing, acting, and being to highlight three modes of universities, which are academic, market-driven and community based. Then, further discusses the placement of PBL within the 3 modes. Kolmos and her colleagues (Jamison et al., 2014; Kolmos, Hadgraft, & Holgaard, 2016) created a characterization of curriculum change strategies as being add-on, integration, or rebuilding. She describes the three in detail. As a result of these discussions, Kolmos provides the reader multiple perspectives through which to view the PBL programs that are described in the following chapters, really setting the stage for the characterization of learning and PBL within learning.

Mohd-Yusof describes independent courses that utilize PBL at the Universiti Tecknologi Malaysia (UTM), in "Sustaining Change for PBL at the Course Level" (Chapter 2). The UTM approach is characterized as course-based, cooperative PBL that is instituted using a scholarly approach and highly influenced by the principles from cooperative learning and the medical school PBL cycle.

Lima, Dinis-Carvalho, Sousa, Alves, Moreira, Fernandes, and Mesquita, in "Ten Years of Project Based Learning in Industrial Engineering and Management" (Chapter 3) at the University of Minho (Portugal) describe how PBL is implemented in semesters 1 and 7 in a 10-semester Master's degree program. Characteristics of the Minho program include interdisciplinary project with a dual focus on the development of both technical and transversal competences in the engineering graduates.

In the "Iron Range Engineering (IRE) Model" (Chapter 4), Johnson and Ulseth describe a PBL model in the USA that is in the market-driven mode that was created using a rebuild change process. Vertically integrated project teams, oral exams, and deep development of reflective practices uniquely characterize the IRE model. The semester-length projects sit at the heart of the curriculum. The IRE model is delivered in semesters 5–8 of an 8-semester Bachelor's degree.

"PBL in Engineering Education: Republic Polytechnic's (Singapore) Experience" (Chapter 5) is presented by Wang, Yap, and Goh. In place since 2002, the Republic Polytechnic (RP) program, consisting of 6 semesters and leading to a diploma degree, is characterized by a series of short, "bite-sized" problems lasting from one to several weeks each. Students in their teams start a typical day at RP with a problem-statement, and then proceed to collaborative research and end with the delivery of a solution and reflection of the day's learning. Through this mode of learning, students develop confidence, teamwork skills, and self-directed learning abilities.

At Mondragon University in Spain, Project Based Learning is delivered in every semester in all Bachelor's and Master's programs. Arana-Arexolaleiba and Zubizarreta describe the model in "PBL Experience in Engineering School of Mondragon University" (Chapter 6). The goal of the PBL implementation is to develop graduates with technical and transversal skill capabilities ready for industry. An initial goal of the implementation was to result in the increase in student motivation to learn.

Finally, Bettaieb, in the "Esprit (Tunisia) PBL Case Study" (Chapter 7), describes how the change to PBL was motivated by the disconnect between the capabilities expected of engineering graduates and the capabilities that were demonstrated by graduates of the traditional model. In the PBL model, students complete projects in 7 out of the 10 semester Master's program. Students on teams of 5–6, complete full semester, complex, ill-defined projects. Students are motivated to deeper learning through the application of real scenarios and the opportunities for control over their own learning.

The book, taken as a whole, shows much diversity in the application of PBL as the social construct that it is. From one-day problems to projects which are a part of the curriculum to programs that are defined by full-semester projects in all semesters. The programs have starting dates that range from 2002 to 2012, with most programs already beyond 10 years of implementation.

Common themes emerge from the narratives. Each program is characterized by continuous improvement. Indeed, change appears to be the only constant for most programs through their developments. The development of employability skills was central to the motivations for change and the results of each program. The language varied from professional skills, to transversal skills, to soft skills, but the sharp focus remained the same for each program. In the programs that reported on research done on their graduates, they showed substantial growth in professional skill development and metacognitive/self-directed learning abilities. Further, most programs showed a proclivity towards developing engineers for industry employment often describing strong partnerships during the education phase.

Upon conclusion of the cases, we have included a closing chapter that compares and contrasts the models using the structures from Kolmos' chapter and the structures the authors used to construct their cases, "Perspectives on Engineering Curriculum Change – Final Remarks" (Chapter 8).

In closing this introduction, we hope that the reader is inspired to dig into the PBL stories from the diverse (both globally and through implementation) engineering programs. Our intent is to provide you inspiration as you contemplate implementation of PBL or changes to your own PBL models.

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ANETTE KOLMOS

1. PBL CURRICULUM STRATEGIES

From Course Based PBL to a Systemic PBL Approach

> While all transition involves change, not all change results in transition. Changes can occur within a single historical epoch that do not profoundly affect it in any way.
>
> (Freire, 1973)

INTRODUCTION

These words are formulated by Freire in *Education for critical consciousness*. We could formulate similar hypotheses: while all problem and project based learning (PBL) transitions involve change, not all PBL changes result in more comprehensive transition. If academic staff and students are not critically aware of the transition from a lecture-based curriculum to a problem and project based curriculum, contradictions increase between ways of knowing, acting and being in the traditional curriculum and an emerging curriculum. The transition might be experienced as a tidal wave with glance moments of understanding the new practice but with emotional drawbacks to a safer position in the known curriculum and a stepping back to known practices.

Freire highlights a very important aspect as the conceptual understanding of what changes that are made and under which transition processes will be very different depending on the context of the critical reflection and the creation of new meaning. There might be a change in the curriculum, but the effect of the change will depend on the degree of implementation at course or institutional level, and on the critical reflection on the learning of knowing, acting and being as objectives for the curriculum. Freire refers to the concepts of transition and change – transition in terms of the process of changing fundamental values, change in terms of single actions. In the literature, the concept of transformation also occurs in combination with change. Transformation is often used in studies on higher education to indicate a complete change from macro- to micro level. All the concepts of transition, change and transformation are often used synonymously without defining the concepts theoretically but much more by examples or by overall change strategies (Kotter, 1995; Reidsema, Hadgraft, Cameron, & King, 2013) or how involvement and engagement can be created in a transformation process (Eckel & Kezar, 2003; Kezar, 2013).

An important part of a transition process is to have a conceptual understanding of the university roles and the overall aim of the curricula. Recent research on types of

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university changes has identified three very different university types, see Figure 1 (Jamison, Kolmos, & Holgaard, 2014):

1. A mode 1 academic university with emphasis on theoretical learning and the process of knowing. This is the "traditional" university with a range of parallel courses in a modular system of which some are mandatory and others elective. Basically, the curriculum is aimed at the learning of theory.
2. A mode 2 market driven university focusing much more on relevant knowledge for employers and therefore on action: skills and competencies. How can the knowledge be used? These are typically new process competencies like project management, communication and collaboration. The curriculum expands to integrate projects especially from enterprises.
3. A mode 3 community oriented and hybrid university which focuses on societal needs in general and especially on sustainability, social progress and global awareness. The mode 3 university is driven by a vision for a better and more equal society and it is not a contradiction to ether mode 1 or 2, but it is an integration and development of these two modes combined with social progress and sustainability values emerging as a dominant trend. The UN 17 Sustainable Development Goals will definitely saturate and dominate the mode 3 university and therefore the goals will go far beyond both the traditional academic mode 1, as the problems will drive the learning, and it will be much broader in the scope of its application than the mode 2 market driven university which is basically driven by market concerns – both internally at the university in terms of new management control and externally in a more collaboration with private companies.

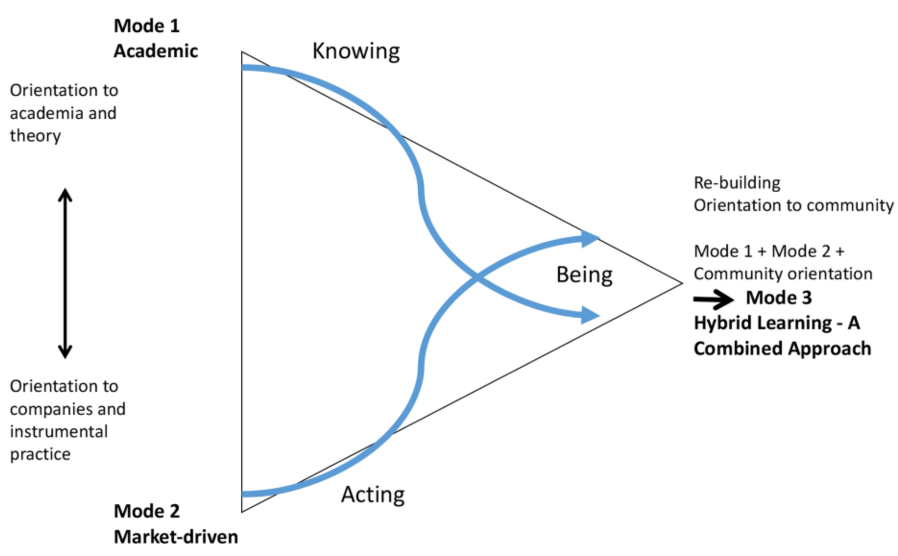

Figure 1. Three university modes (Jamison et al., 2014)

Two Danish universities, Roskilde and Aalborg, originated in the light of a mode 3 vision, with problem oriented project work models. The establishment of Roskilde University in 1972 and Aalborg University in 1974 was part of a critical political discourse. At that time, it was a period with a very strong student movement connected to the left-wing parties and where the values represented in the new pedagogic models reflected these values with strong community orientation and critical thinking. The Danish problem oriented project work models were part of a change in society. In, particular, the universities strove to have a closer relationship with the surrounding society by including societal problems in the students' curriculum and by a critical review of the curriculum especially in the humanities and social sciences. The establishment of the reform universities in Denmark was therefore part of a bigger societal transformation, but it has been embedded and transformed into a much more market oriented agenda in a new technological age.

During the 80s, there was a need for a closer relationship between university research and innovation in companies. New pedagogies like outcome based education started out in the 80s with the emphasis on competencies and skills, and politically this trend was turned into educational policy during the 90s by new accreditation criteria and in Europe by the Bologna process (ABET, 1995; Commision, 2009; EU Commision, 2008; Spady, 1994). Problem and project based learning has been seen as an outcome-based pedagogy as it embraces learning of both knowledge and skills/competencies. Especially within engineering education, the reform pedagogy was applied with the purpose of developing relevant skills and competencies for companies and students started to work on company projects as well as projects with a broader societal aim.

Each of these ideal university modes emphasises different types of curricula. Barnett and Coates (2004) present a new understanding of the curriculum as knowing, acting and being. This approach emphasizes the curriculum as a space for learning processes and that the curriculum should not only address the knowing and acting outcomes, but also the being as a process of identity growth. This approach includes transformative elements where the learner is in the center. The uncertainties and complexities that the graduates will have to deal with the future, will need a much more complex, integrated and deep competence and knowledge understanding which will go beyond the knowledge and skills outcomes which are formulated in today's curricula. Applying Barnett's conceptualisation of curriculum as knowing, acting and being, the mode 1 university will primarily be focused on the learning of knowledge and knowing together with being (Barnett, 2009; Barnett & Coate, 2004). Whereas the mode 2 university will be focused on the learning of action and acting based on knowledge and knowing and, to a lesser degree, be oriented to being and community orientation. However, the mode 2 university will address the relation between academic knowing and context, whereas being will imply a community and value orientation beyond the mode 2 university as being is a much more critical academic approach and it includes citizenship (Christensen, Henriksen, Kolmos et al., 2006).

Problem and project based learning are applied in all three different university types but with very different aims both concerning the type of problems students are working with and in relation to the organisation of the curriculum.

Scope of Problems in the Three Modes

A variety of components defines the PBL philosophy such as: the problem as a starting point, a case or a project organisation, a team aspect, directed participants, contextual and interdisciplinary learning (De Graaff & Kolmos, 2007). The PBL philosophy can be applied in all three ideal university modes and the project organisation, the project management and the team aspect might be similar in the three very different modes. However, the learning of the academic disciplines is approached in very different ways and implicitly the formulation of the problem as the motivational entrance to the discipline will be very different. Therefore, the problem is one of the important components in designing a PBL curriculum.

In the mode 1 university with the emphasis on theoretical and disciplinary learning, the problem will normally be designed by academic staff to suit the disciplinary learning objectives. These will typically be more narrow discipline problems and normally these will be projects only running for shorter periods. In earlier writings, I have called this type of problem the task-problem or the discipline problem. But, I have regretted ever defining a task-problem (Kolmos, 1996). A task-problem means that academic staff have formulated a narrow task for the students to work on. Later writings indicate that this is hardly PBL, but it might be an active learning methodology using teams to solve narrow discipline problems.

In the mode 1 university, there is not so much focus on skills and competencies, whereas there is much more on the learning of general education. Ethics will normally be a discipline which students can choose, although it is not integrated into the other technical disciplines. In the same way, the students might be able to choose service-learning projects, but most often as co-curricular activities, which basically means outside of the formal curriculum.

The mode 2 and 3 universities are characterised by interaction between academic theory and context – although in different variations. The mode 2 university emphasises the collaboration with companies and the learning of skills and competencies. The problems often originate in real companies. However, even if company problems might be much more ill-structured, this mode keeps its focus on the discipline, and in earlier writings this has been called the discipline problem (Kolmos, 1996).

Dealing with authentic problems creates issues in connecting context and academic disciplines. Academic disciplines are developed according to an academic history and not according to real life problems. Introducing real life problems from companies will require more interdisciplinary approaches to the analyses and solving of the problems as well as having a requirement for deeper analysis of the real scope of the problem. e.g. might a problem in the logistics system in a production be seen, on the surface, as a technical problem, whereas an analysis of the problem might point at miscommunication among employees? Thus, the analysis phase of the problem is a necessary step in any PBL project. Unfortunately, this analysis is often carried out superficially and not with the depth it needs. Engineering students are especially keen to jump directly to solution phases and to try out solutions. This might be a very efficient way of testing out solutions, but, if all the solutions address the wrong authentic problem, then the students are not solving the real problem. In a PBL curriculum, it might sometimes be the case that the students will solve "false or fabricated" problems, when the students go out to companies where the problem has to meet the learning outcomes in the curriculum, e.g. in the case of technical logistics versus human interaction and they solve the technical logistics and not the human interaction. But, in this case, it is even more important that the students know that this is not the most important problem in the particular context. It is a minor problem in the context of the logistics as a whole.

In the emerging mode 3 university, there is an emphasis on the societal context whether it is society in broad terms or specific companies. Skills and competencies are also at the core. However, in comparison with the mode 2 university, the skills and competencies are combined with a more general education – or, in the German language, Bildung (Christensen, Henriksen, & Kolmos, 2006). In the Bildung tradition, education is regarded as education to become a citizen with a strong ethical approach – and in the mode 3 university, these ethical dimensions are combined with a competence approach integrated into the disciplines. In the earlier literature, the problems in this mode have been called open problems (Kolmos, 1996). This approach involves deep analysis of what kind of problems are going to be solved as well as a much more flexible interaction among the disciplines and, at the end of the day, in the curriculum. e.g. To analyse and solve sustainability issues – first by analysing the issues, formulating the problems and then pointing out the learning outcomes and disciplines involved – will require a flexible curriculum where the learning of methodologies and application of learned methodologies to new problems should be part of the core curriculum. An example of a mode 3 PBL project could be asking students to make an innovation for homeless people so that the homeless can make a living. The students have to understand the situation of the homeless people – and maybe even live together with them to identify potential innovations which would help the individuals. This is a very open-ended project which will involve various disciplines.

There are no fixed boundaries among these three ideal modes of universities and problem approaches, on the contrary there is overlap. Even the mode 1 university dominated by theory will have elements of the other two and vice versa. But, it is necessary to create ideal types as much of PBL implementation only takes place within a single course. This is a short-sighted strategy for education as a whole, although it is probably a great experience for the students and staff involved. However, to increase student centred and active learning, it is important to keep in main ideal modes of alternative universities and curricula.

Curriculum Strategies

Recent research has identified three strategies for the integration of sustainability at the institutional level and the three strategies can also be used to characterise the integration of PBL into the curriculum (Jamison et al., 2014; Kolmos, Hadgraft, & Holgaard, 2016):

1. an add-on and course strategy change to more active learning within the existing courses,
2. an integration strategy consisting of a merger of existing courses and integration of skills and competencies like project management and collaboration,
3. a re-building strategy which involves re-thinking of the role of the university in society and re-thinking the curriculum towards much more flexibility.

These three strategies can easily be applied in characterising the implementation of PBL in the curriculum.

Course strategy in an add-on curriculum. The add-on and course strategy is the most widespread strategy for PBL. In the literature, there is extensive reporting on PBL applied at a course level all over the world and most of the research reviews on PBL reports actually comes from a single course strategy (Shinde, 2014; Shinde & Kolmos, 2011). As mentioned earlier, the problems that the students are most often working on will be academic problems within the disciplines – and, if there are authentic problems, it will be pre-designed problems representing real world problems.

For the single staff member, this is an easy strategy to use, as it only concerns a course that one might control. From a system point of view, it can be a stepping stone to a bigger change as the individual staff members gain experience from a different teaching and learning practices.

However, there are also a number of disadvantages. The first one is that sometimes the time frame for the PBL activities is so short, that one begins to question if this is PBL or if it is a variation of active learning, which in itself is not necessarily a bad thing. Examples from reported PBL practices count e.g. four hours per week over a period of e.g. six weeks. Of course, with such a timeframe, it is not possible to learn the added value of PBL such as the PBL skills. Most often, formulated PBL skills are not included in the formal curriculum.

The second disadvantage is that an overview of the entire curriculum is often lacking. When students are doing a comprehensive PBL course for the first time, it is important to give the students tools for project management and collaboration and to orchestrate the development of the students' learning of PBL skills by reflection. What further complicates the learning of PBL skills is the fact that, in a modular curriculum system, students can select a set of courses. It might not be possible to create a proper progression in the learning of PBL skills, unless there are PBL components in all the mandatory courses. Therefore, the scaffolding of PBL skills is often lacking at the curriculum level.

The third constraint is that students might encounter PBL in two, or even three, parallel courses at the same time. The issue with this is that students experience an extra workload as they get much more involved and engaged in the learning.

The fourth complication concerns the stability of the academic staff, as the single teacher decides on his or her own course and course pedagogy. There might be a lack of communication among academic staff members and a lack of coordination in the educational program. If the single staff member leaves, there is no continuity to keep a PBL approach in the system.

However, having pointed out some of the disadvantages, the advantage of the course strategy is that academic staff gain experience and trust in doing something new. They experiment with small-scale PBL – or maybe in more correct terms – active learning methodologies. It can be a very important starting point in an institutional transition that academic staff are positive and have some experience.

Integration strategy. Whereas the course strategy can be an individual strategy for the single academic staff member, the two other strategies will require a system approach with a high level of coordination at system level. The integration strategy is very much oriented towards integration of competencies and projects into the curriculum across existing courses, especially company projects which will most often require a cross disciplinary approach.

The integration strategy can be exemplified and found in the Concieve-Design-Implement-Operate (CDIO) community. CDIO contains a long list of standards covering the system level with quality assurance and academic staff development, the integration of skills and competencies into the curriculum and, at a minimum, the integration of real-life projects, mostly company projects, where the students learn to conceive, design, implement and operate (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014; Edström & Kolmos, 2014). Furthermore, there is a set of criteria oriented more to the engineering profession.

Analysing the criteria at the curriculum level, there are many similarities to PBL and many of the standards can be applied directly to a change process to PBL (Edström & Kolmos, 2014). Researchers have formulated roadmaps for how to change the curriculum at the system level encompassing all elements, e.g. mapping the learning outcomes in all the courses and identifying which courses would benefit from combining discipline knowledge with relevant competencies and adequate learning methods.

Figure 2 illustrates such a mapping framework, where specific competencies are integrated into single courses and some of the courses are merged into one course.

There are many ways of re-organising the entire curriculum. Another way is to have a project applying to most of the course disciplines. Figure 3 represents such an approach where existing courses feed knowledge into one common project in a semester.

This structure resembles the capstone project in US engineering education, where the students use the various disciplines in one final project (Dutson, Todd, Magleby,

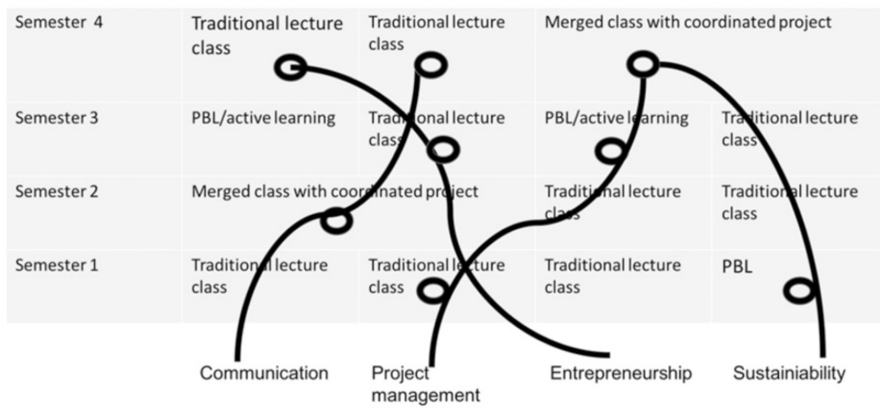

Figure 2. Integration of competencies into the curriculum (Edström & Kolmos, 2014)

& Sorensen, 1997; Todd, Magleby, Sorensen, Swan, & Anthony, 1995). However, there is a huge difference as the capstone project comes at the end of the curriculum, whereas the integration strategy is conceived as a curriculum model which can be used throughout the entire curriculum from the first semester to the final year. Furthermore, it is important that the students try out project several times to learn the PBL skills.

Re-building strategy. Re-building of curricula happens when the entire curriculum is re-structured and/or by building up a new institution or a new program. The re-building strategy emphasises the societal context as the starting point for learning. Students learn to analyse the contextual problems in a critical interdisciplinary academic perspective – and with no given answers, not even from the academic

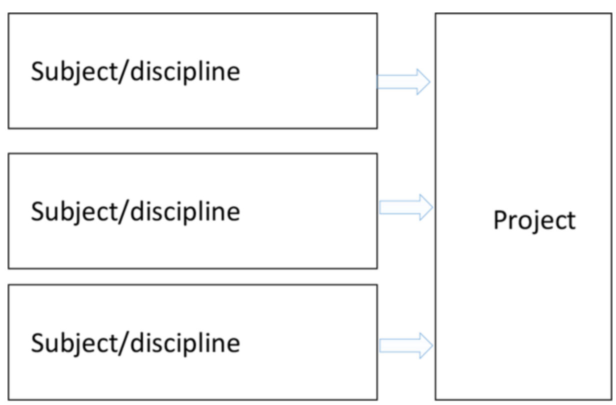

Figure 3. Integration strategy

research societies. The philosophy is to let the students think outside the box to create new ideas for societal development and green innovation. Disciplines do exist; however, these are shaped as a reflection of contemporary issues in society and are presented as societal themes to the students.

An example could be to let the students work on smart technologies in huge cities – e.g. Rio in Brazil where the favelas are intertwined with the rich areas. How can Rio increase sustainability and become a green smart city? This could be the theme – and actually cover most of the programs across all faculties. Then the students should identify problems and issues they would like to work on – and let the taught courses be selected according to the problem and project that the students are working on.

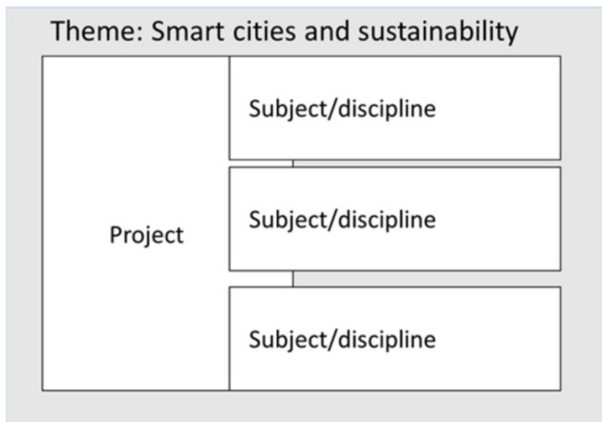

Figure 4. Re-building strategy

In this way, the project will determine the choice of disciplines. Maybe that kind of curriculum is around the corner as the integration of open learning platforms and online courses like MOOCS will allow for a much more flexible blended curriculum, where the just-in-time principles for learning the academic disciplines can be more flexible. Maybe a much more blended and flexible curriculum can also solve the schedule issues, which occur in most PBL implementation as it will be an advantage for students to have coherent time to work on the projects.

Does PBL Make a Transition or a Change?

At a first glance, the three strategies could match the three ideal university modes. Although it might be the most dominant curriculum change strategy, the different university modes will also apply other strategies. However, the mode 1 university will very rarely apply a rebuilding strategy as this will involve a more comprehensive change in merging disciplines and theory and practice. The same counts for the mode 3 university where the add-on strategy can be difficult to apply.

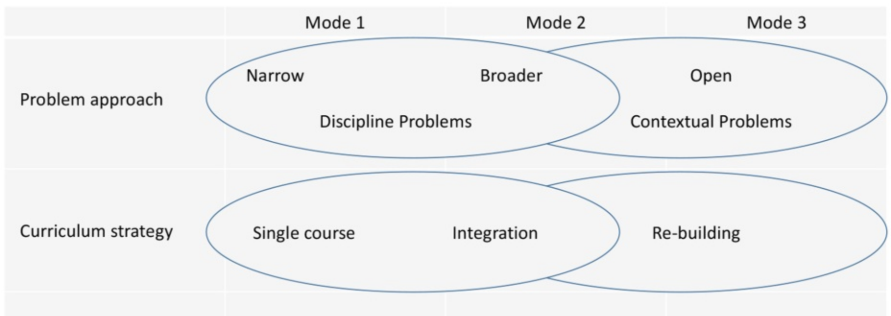

Figure 5. Combining modes, problems and curriculum strategies

In Figure 5, these overlaps are illustrated. What is missing here is that there will also be an overlap between the mode 3 and mode 1 university in the critical academic thinking. Going back to Paolo Freire, his statement on democratic education is important:

> Democracy and democratic education are founded on faith in men, on the belief that they not only can but should discuss the problems of their country, of their continent, their world, their work, the problems of democracy itself. Education is an act of love, and thus an act of courage. It cannot fear the analysis of reality or, under pain of revealing itself as a farce, avoid creative discussion. (Freire, 1973)

Freire emphasise here my point that any implementation of problem- and project based learning might not necessarily be a sign of change or transition. It all depends on the intention of the change process, the extent of the change and the actual practice. But, education should contain a democratic element and, according to Freire, be a place of reflection on society and reflection with society. PBL and democracy are interrelated by the team and contextual aspects when students learn to analyse context from a critical analytical perspective and learn democratic values in teams by academic discussion, negotiation, collaboration, argumentation, disagreement, and agreement. Education is an act of love, engagement and commitment – involving societal values and personal identity in an integrated and hybrid learning process. In Paolo Freire's context, his writing about education was as a space of freedom in relationship to the dictatorship in Brazil at that time, but his thinking reminds all of us that, in general, education should be the space of freedom and critical reflection on society. It is only by allowing freedom and trust in the learners' capability for critical academic thinking and development of competencies for the good of society in general, that education will fulfil the role of being an actor for the future. This is true in terms of critical analysis of the present and the creation of a vision for a more equal and balanced future.

Therefore, the three university modes and the possibilities for practicing student centred curricula are very important. At each institution, there will be elements of modes 1, 2 and 3, however the mode 3 will normally be underrepresented in terms of the integration of contextual issues, the open-ended problem approach and, not least, the interdisciplinary curriculum. Sustainability and community orientation are important in education to prepare students for solving the problems of today and tomorrow.

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2. SUSTAINING CHANGE FOR PBL AT THE COURSE LEVEL

Taking the Scholarly Approach

INTRODUCTION

Problem based learning (PBL) has always been acknowledged as a powerful approach to develop students' learning, professional skills, and positive attitudes (Mohd-Yusof et al., 2016; Duderstadt, 2008; Strobel, 2007; Polanco, Claderon, & Delgado, 2001; Woods et al., 2000; Barrows & Tamblyn, 1980). However, being highly student-centred, it is seen to be more difficult to implement compared to other active learning approaches. The need for proper planning and preparation also renders PBL to be difficult to sustain, especially in the absence of institutional support, acknowledgement, and reward.

PBL is essentially a philosophy that must be adapted to the limitations and conditions of the institution, as well as the desired outcomes and nature of the field that it is applied to. While there are numerous PBL models and definitions, none of them provide a one-size-fits-all approach that can simply be taken from one place and implemented in another. There are different models of PBL implementation throughout the world, varying from the small group medical school model, to the project-organized model, to the one-day-one-problem model (de Graaff & Kolmos, 2003; Tan, 2003; Duch, 2001; Albanese & Mitchell, 1993). Most PBL models, however, can be expensive because they require intensive manpower, infrastructure, and institutional support. Small group implementations typically consist of a maximum of ten students with a dedicated facilitator or supervisor.

The complexity and efforts needed to adapt a suitable model and start implementing PBL usually makes small scale implementation without the proper curricula approach and continuous institutional support challenging. Nevertheless, adaptations where PBL is implemented in isolation (i.e. without a curricula approach) can survive, and even be improved and expanded when a scholarly path is taken. Academics implementing PBL at the grassroots level through a scholarly path with the support of a community of practice can sustain the passion to disseminate, inspire, and mentor others even outside of their own institution at the global level to take up PBL. In addition, small scale course-based PBL implementation is important in convincing other academic staff and institutional management before larger scale adoptions can be made.

A. Guerra et al. (Eds.), PBL in Engineering Education, 13–32.

In this paper, the transformation made on a PBL model designed for a typical classroom setting from its initial course-based implementation in Universiti Teknologi Malaysia (UTM), to an improved generalized framework that can be used to guide others in a similar setting, is described. A scholarly and evidence-based path was taken to systematically adapt the typical PBL cycle to become the current model, called Cooperative Problem-Based Learning (Mohd-Yusof et al., 2011). In this chapter, I have chronicled initial efforts to develop and implement PBL, as well as the transition process until the finalized current CPBL model and the systematic training of higher education academic staff and school teachers to implement student centred learning approaches. Based on the lessons from this journey, my aim is to illustrate the viability of developing and sustaining course-level PBL through a scholarly path, which could grow beyond the four walls of a classroom to make a larger impact on others. I hope that this chapter will assist and inspire other academics to take up the challenge to make changes in their own classes, and to develop themselves and support others in the quest for quality education.

THE MALAYSIAN BACKGROUND

In the 1980's and 1990's, there were not many requirements on engineering programs and graduates in Malaysia, other than the technical knowledge. At that time, there was only a small number of universities in Malaysia, and even a smaller number that offered engineering programs. Students who enrolled in the university were mostly motivated to develop themselves, graduate, and become professionals who can help their families for social mobility as well as the community.

The turn of the century brought about the explosion of the internet, computing power, information boom, communication technology, social media, and many more technological changes. These rapid changes also brought about a different generation of students. At the same time, the number of universities in Malaysia offering engineering programs from both the public and the private sector had rapidly increased. Then in 2003, Universiti Teknologi Malaysia (UTM) started to introduce and hold awareness talks on outcome-based education (OBE), and the Malaysian Engineering Accreditation Council had signed up to be a provisional member of the Washington Accord. All these brought about higher requirements in the quality of engineering education provided that suits the challenges and consequently the needs of the 21st century.

It was not surprising, when in the early 2000's, there were noticeably greater challenges to teach and help students to learn the difficult content in engineering courses. Having read engineering education journals, such as Chemical Engineering Education, and articles while I was a graduate student in the US, made me realise that interesting aspects of chemical engineering education, and engineering education in general, were being written and shared. Faced with the challenge of teaching third-year chemical engineering students in the Process Control and Dynamics course, I realised the need for engaging students through active learning, and getting students to form a learning community through cooperative learning (CL). CL is proven, through numerous studies, to promote cooperation among students resulting in improved learning quality and skills, such as academic achievement, interpersonal skills, and self-esteem (Prince, 2004). Social interaction among learners can create collaboration, leading to a significant positive impact on learning (Jonassen et al., 1995). Without any training, in 2001, I started to experiment by grouping students together. However, there was essentially not much improvement in learning, and there were complaints about non-functioning groups. This caused me to search for articles and read on how to properly apply active learning techniques and improved my implementation. The efforts paid off when students became highly engaged – while students used to be very passive and quiet in class, they became eager to participate in the classroom learning activities. Their efforts were amply rewarded with better results.

INITIAL PBL IMPLEMENTATION

I started reading about Problem-Based Learning (PBL) in 2002, and was appointed to lead the PBL task force in the university. Universiti Teknologi Malaysia (UTM) is a technology-based public university in Malaysia. As part of the university's mission to provide quality education for the masses, in line with the vision of the country, we were given the opportunity by the Centre for Teaching and Learning to bring experts from around Malaysia and Singapore to conduct training in UTM and to observe implementations of PBL within the two countries because of the constraint in budget. A series of trainings were conducted by experts from a medical school and an education faculty, were attended by the core group of approximately thirty academic staff.

After the series of trainings in 2003, plans were made to implement PBL over a period of four weeks with another lecturer who also attended the training and was teaching another class (also known as section) of the Process Control course, from week 8 to week 12 (out of a total of fourteen weeks for learning in a semester). A problem was crafted for students to solve so that they would learn the concepts of feedback control and tuning of feedback controllers when they solve the problem. Before undergoing PBL in the first 8 weeks, students in both classes were learning in an active learning environment and properly guided to learn in teams using cooperative learning (CL). Since there were sixty students in each class, it was not possible to have the small-group with one dedicated tutor PBL model. Having the students already together in functioning learning teams made it natural to use the small groups in a large class model with one floating facilitator to guide them through the PBL cycle, shown in Figure 1. Referring to the figure, in Phase 1, students are guided to identify the problem and the knowledge gap (also known as the learning issues) that they must learn before proceeding to solve the problem. In Phase 2, students find information, prepare notes on the learning issues, and, guided by the facilitator, learn together before finding a consensus on the solution approach. In Phase 3, the solution is discussed with the facilitator, before having a closure and reflection session. In the small-group medical school model, facilitators sit in the small group and provide cognitive scaffolding during the PBL tutorial sessions to support students in undergoing each of the three phases of the PBL cycle and reach the desired depth in learning and inquiry. While it is challenging for a floating facilitator to monitor and support all groups closely as in the small group model, in a proper CL environment, part of the monitoring, support and feedback can be attained from peers, especially team members, instead of solely relying on the facilitator. In fact, support can be further enhanced by developing the whole class into a learning community.

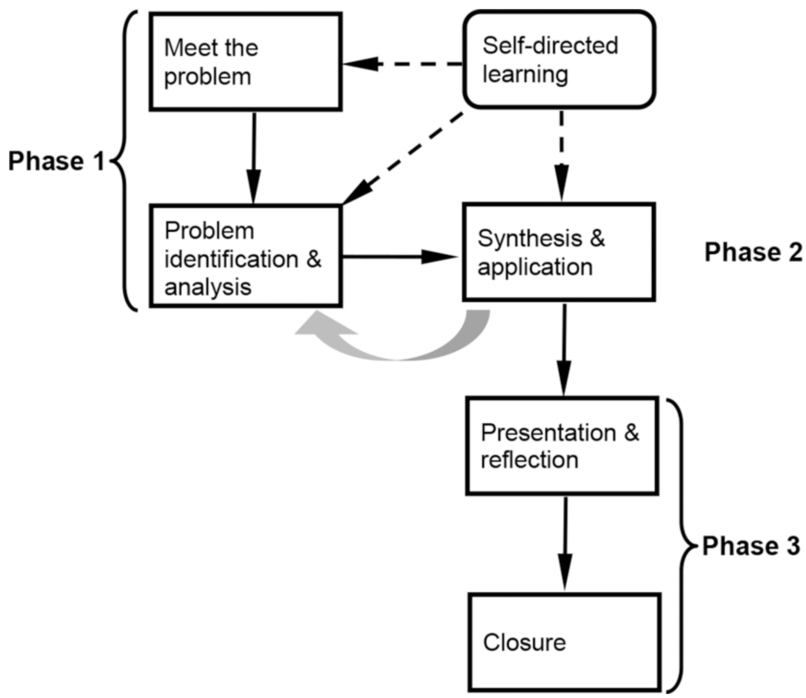

Figure 1. Typical medical school PBL cycle

A small study was made to obtain students' perception of learning through PBL. Their marks on a question that focused on the topics learned using PBL given in a test were monitored and compared to the attainment of students from three other sections (or classes) taught using lectures. This study and the detailed description of the implementation was published in Mohd-Yusof et al. (2004) and Yusof et al. (2005).

In the initial part of the implementation, there were some doubts among the two of us trying this out for the first time in our classes, as to whether PBL can work in a culture where students had always been spoon-fed the content. We were also more worried about the other lecturer's section because she was teaching academically weaker students who had previously failed or had been left behind in their normal cohort when taking the course due to failing other courses. Both of us were also afraid that students might not be able to learn as well as the three other classes taught in the usual manner, especially when the concepts they have to learn were usually problematic for students to grasp. However, with proper scaffolding through tutorial questions that students worked on in teams after the peer teaching session, students were found to understand the concepts at a deeper level, which were manifested during the active discussions in the peer teaching sessions and the higher scores obtained by students in the two sections using PBL compared to the non-PBL sections. The "weaker" students in the young lecturer's class even scored better in the question than students in the other sections.

A small study was made to gather the perception of students towards learning using PBL. From the questionnaire given to the students after they had undergone PBL, students were mostly positive about learning with PBL with almost all of the students in both sections saying that they would attend another course that used PBL. When PBL was implemented in week 8, while the students were surprised when they were given a problem to solve to learn, they were able to go through the PBL cycle together as a team since cooperative learning had been implemented since the start of the semester. Being in a safe and supportive environment to learn as a community in their classes engaged all students, even the initially reserved ones, to participate in class discussions and offer their ideas even when they might be wrong. This was a far cry from the normally quiet and reserved students in the usual lecture-based classes. There were so many volunteers when questions were posed that it was difficult at times to choose which student should speak, and some had stated in their reflections that they were not able to speak to the whole class as often as they would like to. Nevertheless, both of us viewed this as a more favourable challenge compared to having non-engaged students in our classes.

In addition to deeper learning and skills obtained from undergoing PBL, what was more important was the positive attitudes seen in students, as reported by others in the literature (Polanco et al., 2001). Even after only four weeks of PBL, students appreciated what they gained, not just in terms of the marks obtained (Yusof, 2005). This is expressed in the reflection of one of the students who wrote:

> PBL opens my eyes on how university life should be. I was able to view the word "study" from a helicopter view. From what I see among my course mates, PBL did change some of them from exam orientated to a learning style that is not only restricted to the syllabus. I'm able to think outside the box and think further, even though the changes are not drastic, it is a good thing for me.

Lessons Learned from the First PBL Implementation

Reflecting upon the initial implementation of PBL, several important lessons can be drawn (Mohd-Yusof et al., 2004a; Mohd-Yusof et al., 2004b; Yusof et al., 2005; Mohd-Yusof et al., 2011):

1. Forming a task force that takes charge of arranging initial training by experts, supporting the task force members to go for observations and giving clear expectations that they are responsible for conducting training and guiding other academic staff in PBL implementation was the right move on the part of the institution. This motivated and created a sense of responsibility among task force members to really learn well during the training so that they can implement PBL and later on disseminate the practice.
2. It was helpful to have a partner when initially implementing PBL, because self-doubts, uncertainties and difficulties, as well as the workload can be shared. Having a community for support is always desired when venturing into PBL.
3. PBL does work, and is really powerful in attaining outcomes that are difficult to achieve. Nevertheless, there must be proper planning and support in helping students to understand and go through PBL. It is helpful to remember that students' initial experience may be described as similar to those undergoing trauma (Woods, 1996). Thus, scaffolding for developing the right mind-set and attitude is just as essential as scaffolding for developing skills such as team working, self-directed learning, etc.
4. PBL is a highly student-centred, constructivist approach that can challenge the teaching and learning philosophy of the teacher or lecturer. The lecturer has to be comfortable with the fact that she is not going to teach everything that the students need to learn – her job is to facilitate learning to help students construct their understanding, rather than revealing the content. Thus, it is helpful to have a gradual change for the lecturer, not only for developing skills in implementing student centred approaches, but also in embracing a more constructivist philosophy.
5. For the small groups in a class with the floating facilitator model, it is crucial to ensure that the students have functional learning teams because part of the role of the facilitator will be taken over by the team members. In the first PBL implementation, students were already in functional learning teams because of the cooperative learning activities used earlier – so when the problem was given, guiding them to go through the PBL cycle to solve the problem as team was fairly easy since they were able to support one another as a team.

MACRO-LEVEL IMPLEMENTATION

The successful initial micro-level 4-week PBL implementation led to the expansion to a macro-level PBL implementation across all sections for the Process Control course. The course is a 3-credit hour course, with a meeting time of 3 hours per week for 14 weeks in a semester. This macro-level implementation requires more work and planning. Although the same problems were used in all sections, problems now have to be crafted for the whole semester. In addition, training and mentoring of lecturers in charge of other sections must be carried out. There were also regular discussions to ensure that the implementation was the same in all sections and that lecturers can be guided for proper implementation of PBL in the course.

The challenge in expanding PBL to the whole course is that instead of crafting one problem for four weeks of implementation, problems now have to be crafted such that the course outcomes can be the learning issues for the problems. The question now is whether the course should use one big problem, or several small problems. Going through the course outcomes and keeping in mind the principles of cooperative learning and the zone of proximal development (ZPD) for scaffolding learning, it was more suitable to craft four problems for the whole Process Control course in one semester. Each problem will therefore have a manageable amount of learning issues or new content for the students to learn, and will allow closer monitoring and support of students' learning process.

Figure 2 illustrates the summary of the four problems being used in the Process Control course. Where possible, the same industrial chemical process was used for the first three problems, while a real industrial problem was used for the

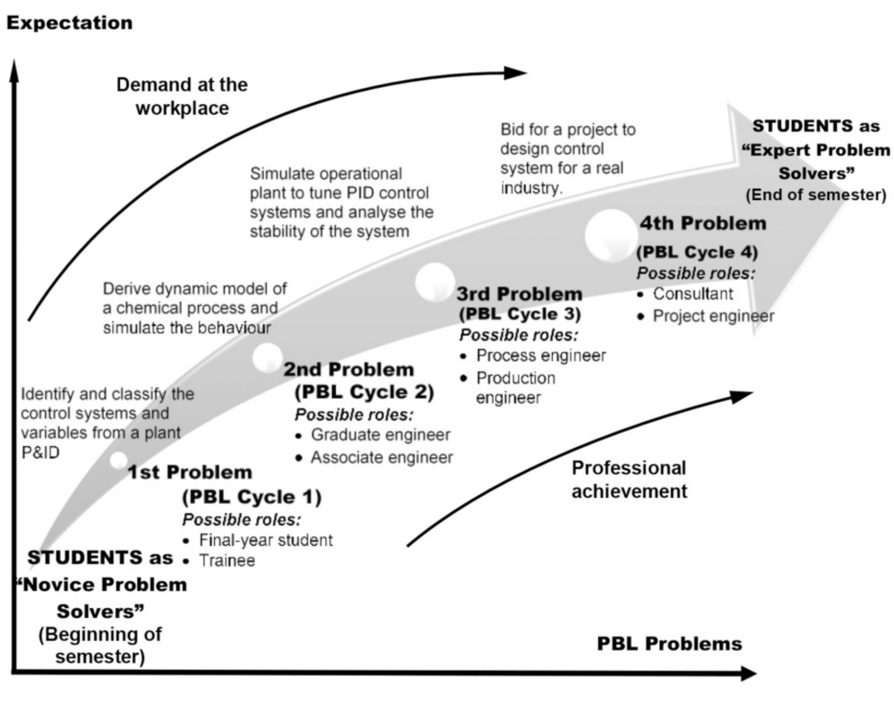

Figure 2. Series of problems for a whole semester (Mohammad-Zamry et al., 2012 and Jamaludin et al., 2012)

fourth problem. The problems were designed to immerse students in different roles in each problem, with the subsequent problem taking on roles with greater responsibilities. Since there are fourteen weeks in a semester, each problem took three to four weeks to complete. Details on crafting and planning of problems for the course can be seen in Mohammad-Zamry et al. (2012) and Jamaludin et al. (2012).

Students' Perception on PBL Macro Implementation

In addition to monitoring students' results and getting their perception on PBL, in 2007, a focused group discussion using semi-structured interview was conducted by Dr. Johannes Strobel from Purdue University on twelve final-year chemical engineering students of equally distributed gender, who had undergone PBL the previous semester in their process control course. Before conducting the focus group discussion, the students had communicated with Strobel through the course e-learning forum at the end of the previous semester in their third year when they were taking the process control course in the second semester of the 2006/2007 academic year. The students identified two main differences between PBL and traditional classes: (1) The amount of work outside of the class is more in the PBL class compared to a traditional class that does not need much preparation, and (2) Concepts learned were immediately applied in a real-world setting Strobel, 2008).

As conveyed by one student in the e-learning forum to Dr. Strobel:

> Class with PBL is different from other normal class because in PBL it emphasizes more on team working and other generic skills such as communication skill and ethics. My style of learning did change during PBL class because we need to ask more from lecturer or others if we want to get more information. It is not like normal class that the lecture will be given to us straightforward (spoon feed). Besides that, I have to read the reading materials consistently not only when the test is coming because we are required to solve the case study. If you do not read the text book, you will not able to understand the concept thus cannot solve the case study. PBL class also make me to talk more and try to communicate with others since we are working in a team. Lecturer will not give us anything that we need to know unless we ask for it and this scenario will make us more familiar with working place since no one will tell you what to do unless you ask.

Students said that they initially disliked PBL, but gradually changed to appreciation as the semester went on. They mainly disliked PBL because of the increased workload compared to a traditional class, although some argued that the workload is actually well distributed where not much had to be done before examinations, and because they had to think by themselves, and take ownership to find information and solve the problem. The students attributed their initial dislike towards PBL to learning in traditional classrooms throughout their school and previous years in the university. However, some also viewed PBL as a liberating learning experience (Strobel, 2008). Most however said that it was worth the effort, as remarked by a student in the same e-learning forum to Strobel:

> I felt not so comfortable in the beginning of PBL class because it is totally different from my style of learning and we also have to work very hard. Nevertheless, every effort that we had put in is worth because we understand the concept of process control better. PBL did make me to become a better learner because it required us to have good time management, team working and other generic skills.

Another student remarked in the same e-learning forum:

> Like I always said, I hate PBL … at the beginning, but now, lucky I'm in. Although we struggle a lot during all those case study, we are more relax when come to test. If we were committed and do our best, I think we still can score during test even without revision. Somehow this subject more or less requires concepts and thinking, which we are expert (after doing case study). Oh ya, I just realised, my study is getting more efficient, faster reading speed, better summary and justification.

Since the students had gone for their compulsory internship in industry for three months right after the semester they had undergone PBL, they were asked on the comparison between PBL and the industry setting. The students labelled the classroom PBL as authentic small scale industry experience. Most importantly, the students said that they felt not afraid and were prepared to for their industry experience, such as knowing how to start on the problem given and to ask for information. It was easy for them to adapt to the industry work environment because it was not that different from what they had to do in PBL.

SUBSEQUENT IMPLEMENTATION AND IMPROVEMENTS

The confidence gained after the PBL implementation and studies on its impact led to efforts by the task force members to encourage other lecturers to implement PBL and develop courses to train others in PBL. PBL had also been implemented in other courses in education, chemical engineering, mechanical engineering and electrical engineering. Nevertheless, some of those involved had not gone through the training with the initial group of champions. Even among those that had gone through the initial training, retraining was needed because most lecturers had not implemented any form of student centred learning approaches. This made it difficult for many of them to make the transition to implement a highly student-centred approach.

There are three important elements for successful implementation of PBL (Tan, 2003):

- The problem. An open-ended, unstructured, realistic, if not real, problem is the starting point of learning in PBL. The problem should be well crafted to engage and immerse students in learning new issues, as well as challenge existing knowledge, skills and attitude.
- The students. Students need to become self-directed learners and problem solvers. These skills are not naturally in-born, and must be motivated, prepared and supported by lecturers.
- The lecturer. The lecturer is the designer of the learning environment and is also the facilitator of learning to make students' thinking process visible. These skills can be learned and developed through training courses and mentoring.

Knowing the importance of these three elements, support must be given so that other lecturers will be able to implement PBL. The following subsections provide elaborations on the efforts on the three elements.

The Problem

To guide academic staff on crafting problems for PBL, we reflected back on the principles and objectives in problem crafting and planning as the critical factors in designing the PBL environment in a typical course, which should fulfil outcomes-based curricula. Analysing the literature, and synthesizing it with our own practice, we came up with a framework and a systematic approach for crafting problems based on the How People Learn (HPL) framework (Bransford, 2004) and Constructive Alignment (Biggs, 1996), especially if the outcome-based approach is used for the curriculum design (Mohammad-Zamry et al., 2012). The simplified framework for crafting problems in PBL is shown in Figure 3. Referring to Figure 3, there are three possible types of problems for PBL: real, authentic or fictional. Real problems are always desired, but because of constraints, real problems sometimes have to be adjusted to fit into the condition of the course. Authentic problems are those that can very well happen in the real world or industries however, the companies, settings or the people stated in the problem may not exist. Fictional problems are totally imaginary problems with made-up conditions, such as a problem set in a distant planet or galaxy. Referring to Figure 3, the letter "P" in the outer layer refers to principle of crafting problems, while the letter "O" refers to objective of the problems. A detailed description of the framework and the guide for systematically crafting problems can be found in Mohammad-Zamry et al., 2012.

In designing the learning environment for the whole course, a series of problems, such as those implemented in the Process Control course shown in Figure 2, or one big problem that covers the most of the content for the whole course can be used. However, if one big problem is used, it is recommended that the problem be broken

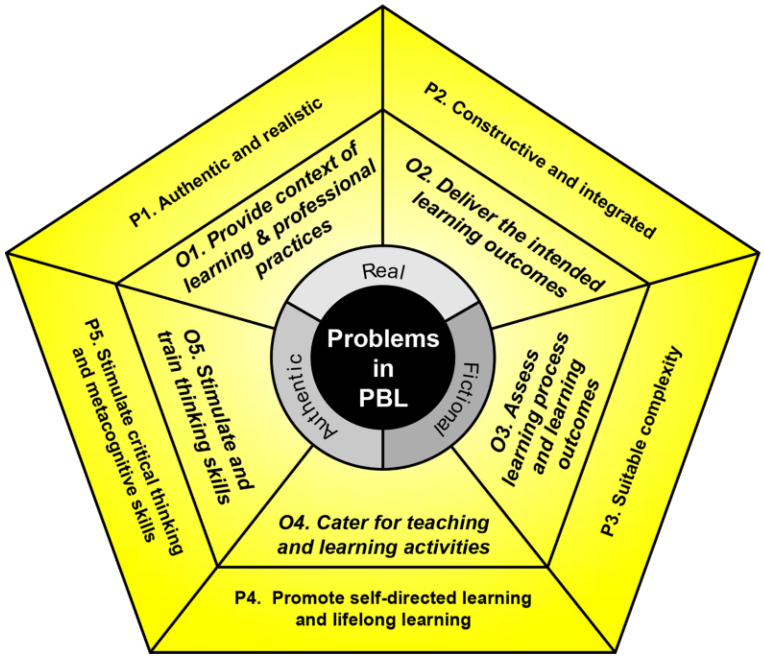

Figure 3. Framework for crafting problems in PBL

in to three to four parts to embed accountability and positive interdependence among students.

An example in using one problem for the whole course is in the Introduction to Engineering course taken by first year chemical engineering students. Since this course is taken by students who have just entered university, the first activity of the semester is on engineering overview using cooperative learning (CL). Although students still had to find information to learn about engineering, the CL assignment was not given as a problem to give students a chance to develop their team-based learning skills first. Students then learn about engineering process skills and sustainable development through PBL using one big problem. However, to make the problem and learning issues more manageable, and to provide scaffolding to gradually develop students' capability to solve the problem, the sustainable development is divided into three stages, where each stage consists of one PBL cycle, with increasing complexity of the problem. Stage 1 is for learning about sustainable development, finding information on the current world scenario on the given problem, and benchmarking. Stage 2 is focused on the specific element of sustainable development, data collection and analysis of the students' and their families' consumption or generation, and pattern of behavior. In Stage 3, students provide a practical and economical engineering solution that they can justify with the proper technology and cost analysis. At the end of Stage 3, an open exhibition was held to showcase the solution provided from each group to the community, while being evaluated by a panel consisting of experts from industries, agencies and academics. A detailed description of the CPBL implementation in this first year course can be seen in Mohd-Yusof et al. (2015), and Mohd-Yusof et al. (2016).

The Students

Students do not automatically have the skills to go through PBL. Most of them are used to learning in a traditional lecture-based setting. Thus, lecturers have to provide various types of scaffolding, not only to support skills and knowledge development, but also to motivate students towards having a learner-centric mind-set so that they can become self-directed learners.

Implementing PBL in a typical classroom requires students to develop team-based problem solving skills. Students cannot just be given the problem without any form of support. In going through the PBL cycle as a team, as mentioned earlier, CL principles were infused during activities in the course. However, as more classes and lecturers use the model, this CL element in ensuring functioning learning teams may not be apparent, especially to those new implementing student centred learning (SCL). Since having a functioning learning team is crucial for students to have a positive and successful learning experience, it became important to explicitly include CL aspects in the PBL cycle.

There are five principles of CL (Johnson et al., 2006):

1. Positive interdependence
2. Individual accountability
3. Face to face promotive interaction
4. Interpersonal skills
5. Regular group function assessment

Assigning students to work in groups does not mean that they are undergoing CL and the groups will automatically turn into functional learning teams. Only when all five principles, especially the first three principles which are also known as the three pillars of CL, exist in the learning activity can it be classified as a cooperative learning. Numerous CL activities have been designed and implemented at various levels, such as the Jigsaw activity, Team Games Tournament, Constructive structured controversy, etc. (Johnson et al., 2006). In analysing informal and formal CL activities, the prevalent pattern shown in Figure 4 stood out to embed the CL principles. Referring to Figure 4, activities in CL always start with individual effort to construct understanding to promote individual accountability (principle 2). This is followed by interaction with team members to construct a higher level of understanding, before having an overall class discussion with the instructor. The interaction in Step 2 shown in Figure 4 promotes positive interdependence as well as face to face promotive interaction.

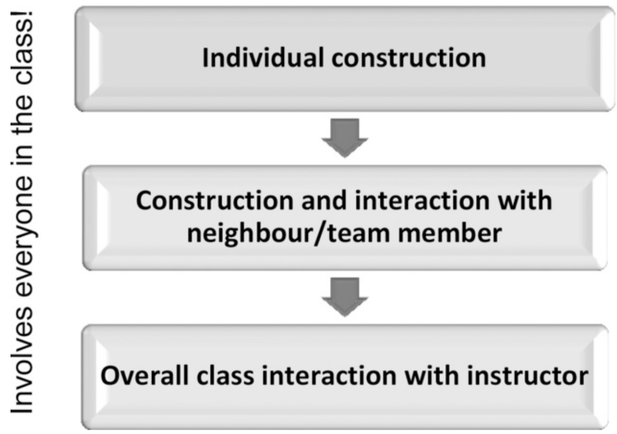

Figure 4. Pattern of activities in cooperative learning

Infusing the pattern in Figure 4 into the PBL cycle shown in Figure 1 results in the Cooperative Problem Based Learning (CPBL) framework, shown in Figure 5, which is used as a scaffolding for helping learning teams in a typical course to step by step go through the learning and problem solving process (Mohd-Yusof et al., 2011, Mohd-Yusof et al., 2016). Similar to the medical school PBL cycle shown in Figure 1, the CPBL framework consists of the same three phases:

Phase 1: problem restatement, identification and analysis
Phase 2: peer teaching, reporting, synthesis and solution formulation
Phase 3: solution presentation, closure and reflection Figure 5. The cooperative problem-based leaning model

Referring to Figure 5, Phase 1 and Phase 2 have been infused with the CL pattern to clearly identify the individual, team and overall class activities. Using the principle of Constructive Alignment (Biggs, 1996), each individual activity is assessed. For example, in Phase 1, students submit their individual problem identification before having the team and overall class problem identification activity. This will capture the students' preparation and contribution to their teams as well as the whole class discussion. Students also submit their individual peer teaching notes before their team and overall class peer teaching in Phase 2. A detailed description about the CPBL model according to the elements of Constructive Alignment can be found in Mohd-Yusof et al., 2011; Mohd-Yusof et al., 2015 and Mohd-Yusof et al., 2016. Various research had been conducted to show that in addition to deep learning, students who had undergone CPBL develop team-based problem solving skills, and professional skills such as communication skills, time management and interpersonal skills (Mohd-Yusof et al., 2016, Helmi et al., 2013; Phang et al., 2012). More discussion on the research in CPBL can be seen in the coming section on "Research and Current Efforts on CPBL".

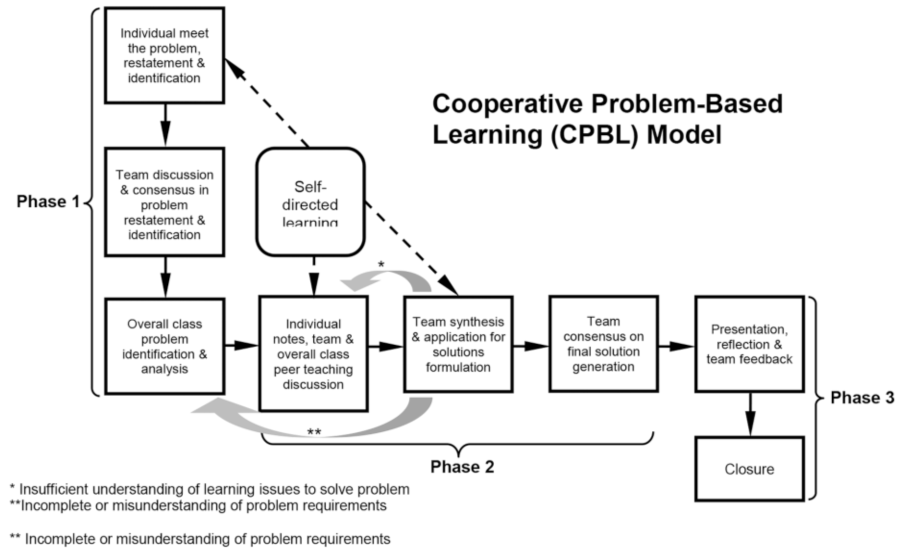

Figure 5. The cooperative problem-based leaning model

The Lecturer

In PBL, the lecturer becomes the designer of the learning environment and the facilitator. Training courses have been developed and conducted. However, it was still difficult for many to make the transition to PBL because of its highly student-centred nature. The team of trainers therefore decided to step back and provide training on a series of active learning approaches, as depicted in Figure 6, ranging from those with short active learning (AL) activities to engage students, but still more on the teacher centric side, to team-based learning using cooperative learning (CL) and finally PBL.

Referring to Figure 6, the series of training provide a gradual transition in teaching approach and perspective. Lecturers first undergo a 2-day training on AL, and will then be given time to implement the techniques learned in their classes for about several months before coming back for the 2-day CL training. After several months, if they want to continue on with the series, they will undergo the training on PBL. In each of the training session, participants were asked to share their experiences and challenges in implementing the techniques learned. They were also encouraged to form or join an existing community of practice to support one another.

Research is still on-going in looking at the transition of a lecturer from a teacher-centred to student-centred perspective on learning and teaching. From our initial research, the AL training session provides awareness, where most participants

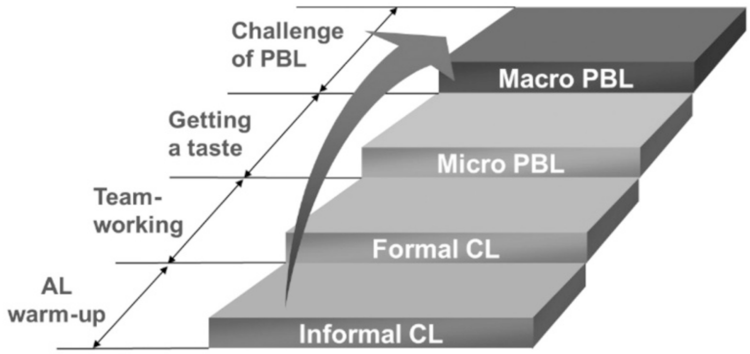

Figure 6. Gradual training and support in SCL towards PBL

are motivated to try the short structured informal CL activities to engage all their students systematically, no matter the class size.

Figure 7 summarise the typical transition process that we have observed among lecturers who had undergone the training workshops in the SCL series. From the initial awareness that participants obtained for the workshop, they form the intention for practice, which will then be translated into action during the class implementation (Radzali et al., 2013). The classroom implementation will then create more awareness on the active learning process, which may or may not reinforce the intention to further take action. At this point, several factors may influence whether or not further action is taken, such as students' feedback and teaching evaluation, the lecturer's own experience as a learner, institutional culture and support, availability of community of practice or mentor, and support/attitude of colleagues. Those that go on and try to implement the techniques further will usually result in forming a more student-centred belief as they develop skills in implementing the techniques. Having a gradual increase in the extent of student-centric approach is helpful in persuading the initial change because the gap in the shift from the usual practice of teacher-centred approach is not that big, and the change is not as drastic. So far, this gradual change seems to be more acceptable and sustainable, as it takes time to initiate and sustain the change not only in practice, but also in terms of belief in the learning and teaching process.

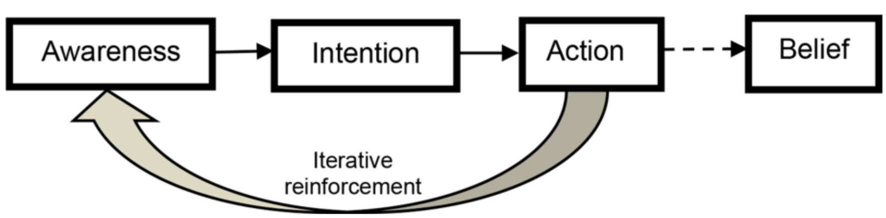

Figure 7. Transition from teacher-centred to student centred perspective

As shown in Figure 7, belief in the student centric approach can be formed with repeated implementation based on awareness and intention. This is reinforced when there is a positive and encouraging community of practice. However, if a lecturer new to the implementation were surrounded by a non-supportive community, such as colleagues who are negative about SCL, then there is a very high possibility of reversing back to the teacher-centric approach.

RESEARCH AND CURRENT EFFORTS ON CPBL

Rigorous research on CPBL implementation in different courses has been conducted since 2007 when UTM initiated the PhD in Engineering Education program. One of the research projects determined that engineering students who had undergone CPBL for one semester had significantly enhanced their team-based problem solving skills. The qualitative analysis showed how problem solving skills among engineering students was achieved through CPBL. Factors that contributed to the enhancement are categorized under four spotlights, which demonstrated how students improved their problem solving elements, motivation and learning strategies, and team working, which contributed a lot to students' problem solving assets, thus enhancing their engineering problem solving skills (Helmi et al., 2011; Mohd-Yusof et al., 2013; Helmi et al., 2013).

Another research project showed that first year engineering students undergoing the CPBL had developed their professional skills, such as communication skills, team-working skills, time management skills, etc. The CPBL environment was also successful in instilling environmental sustainability knowledge and behaviour among students (Mohd-Yusof et al., 2016; Mohd-Yusof et al., 2015; Abdul-Aziz et al., 2013).

Research was also conducted on students' perception as they undergo CPBL in a course with a lecturer that was new to implementing CPBL. Students who face CPBL for the first time will typically feel shocked over such a drastic change in the teaching and learning method and will normally go through the typical trauma cycle before reaching a higher level of performance (Phang et al., 2012). A phenomenological research design was carried out through non-participant observations, unstructured interviews and students' written self-reflections which were collected at the end of every problem. Analysing the qualitative data obtained from students in the class, four types of changes on student perceptions can be seen as students undergo the CPBL learning process:

a. those that held positive perception about CPBL from the beginning until the end
b. those that held negative perception from the beginning until the end
c. those that changed from positive in the beginning to negative perception at the end
d. those that changed from negative in the beginning to positive perception at the end

While the majority of students held positive perception towards CPBL in the end and managed to gain a variety of skills, it is interesting to note that factors that caused students who have a positive perception to appreciate CPBL are also those that caused the negative perception. The two main factors are time management and effort required to learn in a constructivist environment. Insights from the analysis of the findings shows the gaps that need to be addressed in supporting, design scaffolding and facilitating students through the myriad of emotions that they go through to finally allow them to develop positive perception so that they may gain from CPBL.

Research is being conducted on other courses on different aspects of implementing CPBL. Another university in Malaysia is currently encouraging the use of SCL approaches, especially CPBL. Efforts on training of lecturers and research on systematic transformation are on-going. A research project is also currently being conducted on metacognitive skills development in CPBL.

CPBL IN SCHOOLS

In early 2016, a three-year project for training teachers in CPBL from schools in the Iskandar Region of Johor Bahru in Malaysia by CEE was started in collaboration with the Johor State Education Department, led by the Kyoto Environmental Activities Association (KEAA) to implement low carbon education funded by Japan International Cooperation Agency (JICA). PBL for schools is intended to impart the 21st century skills such as critical thinking, problem solving, team-working, communication, and information management skills. It is also an example of STEM education where three subjects were taught in an integrated manner, namely Science, Mathematics and Living Skills. The teachers are trained and mentored to design and implement the CPBL environment framework for instilling low carbon awareness and consciousness among students. The problem is divided into three stages which increase the degree of difficulty aligned with the secondary school level of knowledge. The teachers work together in team teaching and the learning time is once a week after school so that they can teach as a team. Close monitoring is also made to provide better guidance and feedback.

After six months of implementation, both teachers and students gave positive results and feedback, although there were some complaints initially because they were not used to the student-centred approach. From the teachers' interviews and written reflections, they noticed that students became more confident and independent in their learning, gain skills such as communication, problem solving, critical thinking, team-working and information management skills, more environmentally conscious and took care of the cleanliness of the schools without any instruction from the teachers of what they see in their students. The students' reflections also show the same gains that were described. In addition, the teachers agree that PBL actually brings out the potential and talent of the students to go further in their learning.

CONCLUSION

A scholarly approach was taken in implementing PBL at the course level in a typical classroom in Universiti Teknologi Malaysia (UTM). Efforts to improve implementation led to the development of the CPBL model. CPBL has been shown to be an effective PBL model for small groups in a typical class with floating facilitators. It is flexible enough to be used at the course level without a whole curriculum approach, and can also be used for a whole curricula approach. CPBL can be used as scaffolding learning at both the university and secondary school level. CPBL is not only used as scaffolding in the medical school model of PBL, but has also been used in the project organized approach.

Taking the scholarly path in developing the PBL model, and in disseminating and providing training has managed to sustain and expand efforts on the use of the model. Although the implementation of CPBL within UTM is not very high, interest from schools and other universities are continuously growing, which seems to create further interest locally. Although this paper is based on a Malaysian experience, it can provide lessons for those interested in implementing PBL or other student-centred approaches in other parts of the world. What is clear is that good teaching can be developed and shared to have great impacts, way beyond the four walls of our classrooms. Therefore, taking the scholarly path is important for sustainability and dissemination of ideas in creating a community, especially when implementing PBL in isolation.

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3. TEN YEARS OF PROJECT-BASED LEARNING (PBL) IN INDUSTRIAL ENGINEERING AND MANAGEMENT AT THE UNIVERSITY OF MINHO

INTRODUCTION

Higher education institutions have been responding to challenges that have led to a transformation of educational practices, particularly towards the implementation of active learning strategies, in order to create meaningful teaching and learning experiences, with increasingly more autonomous, cooperative and motivated students. In the particular case of Engineering, graduates should be able to develop their professional activities, dealing with a wide range of different types of problems that require the proficiency of technical and transversal competences. Transversal competences are being recognized as equally relevant for the engineering practice, such as working with multicultural teams, communicating at different contexts, dealing with uncertain and unpredictable situations (Cai, 2013; Jackson, 2012; Lima, Mesquita, & Rocha, 2013; Passow, 2012). Aiming to increase the relevance of the teaching and learning processes, the Integrated Masters degree in Industrial Engineering and Management (IEM) an engineering program of 5 years (10 semesters), at the School of Engineering in the University of Minho, Portugal, focused their efforts on building curriculum innovation. The work developed was focused mainly on changing the teaching and learning processes to implement Interdisciplinary Projects (PBL – "Project-Based Learning"), inspired by the Powell and Weenk approach – PLEE, "Project Led Engineering Education" (Powell, 2004; Powell & Weenk, 2003). Thus, the first curriculum innovation experiences were based on Interdisciplinary Projects, which started in the context of the preparation for changes within the Bologna Process demands. Currently, interdisciplinary projects are part of the formal curriculum of the Industrial Engineering and Management program.

The increasing awareness of a different professional profile needed for Industrial Engineering and Management (IEM) graduates, requiring the development of competences, both technical and transversal, and simultaneously the ambition to have students more motivated and engaged with a meaningful learning environment, were the main reasons that led a group of teachers of the IEM program at the University of Minho to start a journey of active learning amongst their courses.

A. Guerra et al. (Eds.), PBL in Engineering Education, 33–51.

Therefore, from 2005 onwards, interdisciplinary projects were developed within the IEM program to promote the development of technical and transversal competences (also known as professional or transferable competences), engaging student teams throughout the semester in the search of a possible solution to a problem.

The purpose of this chapter is to describe the model and changing process of 10 years of Project-Based Learning in the Integrated Masters degree program of Industrial Engineering and Management (IEM) at University of Minho, Portugal. The IEM program has three formal PBL approaches in its 10-semester curriculum, i.e. semesters 1, 7 and 8. It has some non-systematic approaches in other semesters, and a final individual master thesis project of one and a half semesters. This work will describe PBL approaches of semester 1 and 7, which were selected by their specific features, as one is a first year project (semester 1) and the other a project carried out in interaction with industrial companies (semester 7).

DRIVERS FOR CHANGE

Engineers are recognized by their technical competences and for being required to design, operate, execute, and manage technological systems. Within these processes, they must apply rigorous mathematical and scientific concepts, and tools to identify, formulate and solve problems that contribute to society. Furthermore, but less recognized, engineers must have a strong sense of human interaction, both when designing solutions for the society and when planning, executing and managing the development of solutions.

The Bologna Process was an institutional movement all over the European Union (EU) that committed a large number of countries to change their Higher Education (HE) systems based on three main principles: quality, mobility and employability. These principles were the main drivers of improvement of HE systems, mainly concerning curriculum development and innovation. This included, for instance, the reorganization of the programs based on the uniformity of HE systems through a credit system (ECTS – European Credit Transfer System) with impact on student learning, teaching practice, institutional support, amongst other issues. These were great challenges for HE institutions, followed by tensions and critical issues that needed to be explored deeper (Wihlborg & Teelken, 2014).

All countries in the EU had different timings and Portugal was committed to change in 2007 integrating the first group, including the University of Minho. Thus, in 2004, considering this national and European requirement, the rectory of the University of Minho developed a set of strategies for the implementation of curriculum changes. Within these strategies, there were opportunities for discussions, pedagogical training for teachers, and a funding program for innovative educational experiences. These experiences were developed during the period before the formal Bologna curriculum change and best practices were to be included in new curricula.

CHANGE PROCESS

All these circumstances created the appropriate groundwork for curriculum innovation by groups of teachers. The previously referred to group of teachers from the IEM program involved themselves in the training opportunities provided for engineering teachers in the context of the Bologna Process. Some relevant examples of the training sessions for curriculum innovation included: Richard Felder and Rebeca Brent on Active Learning; Peter Powell in Project Led Engineering Education; Manuel Firmino Torres in Effective Communication for Teachers; Maria Assunção Flores in Assessment Processes; Natascha van Hattum-Janssen in Course Planning and Peer Evaluation. All these opportunities contributed to change or reinforce teachers' engagement with the process and the need to change the learning processes.

Of great importance for the IEM program was the opportunity to learn the principles of Project-Led Engineering Education with Professor Peter Powell (Powell, 2004; Powell & Weenk, 2003). This contact provided the necessary elements to support previous ideas and experiences with project approaches in the context of engineering education. Two of these teachers were at the time teaching first year courses and decided, with the support of the program coordinator and a colleague from another department, to create a project proposal for an educational program funded by the rectory. They strongly believed that it was possible to create projects with open problems for students of the first year and that was seen as highly innovative. The project was funded by the Rectory of the University and in March 2005, the group of teachers (authors of this study) and a number of other teachers from different departments and schools of the University of Minho got together to implement a first experience of Project-Based Learning in the second semester of the first year of the IEM program. These experiences were supported, since the beginning and during the following years, by educational researchers that also integrated the coordination team and made the difference, both in regard to the implementation and evaluation process and also the research carried out in the following years.

Simultaneous with the referred to first year experience, some of these teachers decided to implement a PBL experience in the last year of the IEM program, in interaction with industrial companies, and the first experience started in September 2005. Currently, the interdisciplinary projects in cooperation with industrial companies still occur and research developed in this field shows the relevance of the cooperation between university and industry (Lima, Mesquita, & Flores, 2014; Mesquita, Lima, & Flores, 2013).

The teachers and researchers involved in the first experiences aimed to develop a learning environment characterized by open-ended problems from real and meaningful contexts, in which teams of students should present solutions, by developing a wide range of technical and transversal competences. The aim was for students to mobilize their knowledge, attitudes, principles, etc., to identify, formulate and solve open-ended problems. To achieve this goal, the Project-Based Learning approach was chosen.

Figure 1 represents a timeline of the main milestones concerning the change process between 2004 and 2013. Some of these milestones have been described in the previous paragraphs, namely the funding program and the pedagogical training. Further, this timeline adds a new element: projects were implemented without a formal structure of a project course during the first editions. Additionally, even the formal curriculum created for the Bologna Process did not include a project course in the first year. Between 2006/07 and 2012/13 the project of the first year was implemented based on an agreement between the teachers of the different courses and the program coordinator. It can be said that this project was implemented without a formal structure in the curriculum and the program found a valid solution. Thus, despite the fact that PBL was implemented in the first semester of the year, it included formal project courses solely in the 4th year, semesters 7 and 8.

The implementation of PBL without a formal course is an important fact of the change process. At the beginning, it gave the opportunity to acquire experience, evaluate the process and prove that it is possible to innovate in the ways of teaching and learning. During this process, other teachers and the institution had the opportunity to gain an increasing trust in the process and to formally allow the inclusion of PBL in the MIEGI Bologna Curriculum. Despite the fact that it was not possible to include a formal course in the first year, the results during the first years of the new curriculum and the recognition of the importance of PBL for the majority of the department, allowed the inclusion of a formal course in the first year starting in 2012/13.

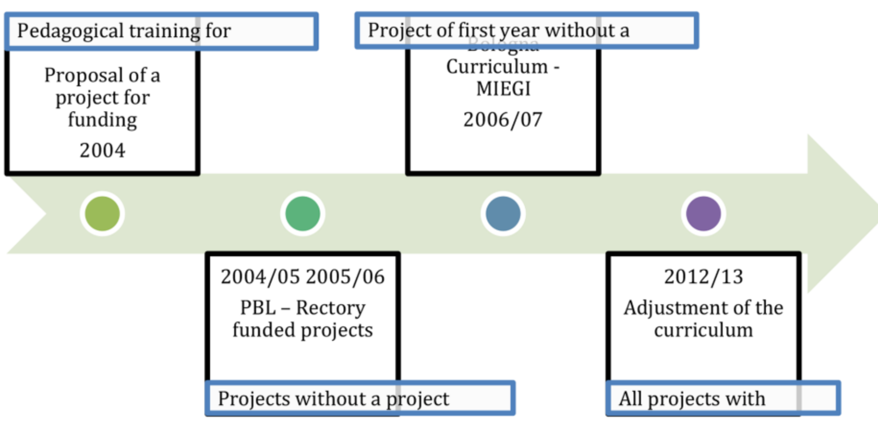

Figure 1. Timeline of years 2004 to 2013

During the first years of the PBL implementation, teachers and researchers were much focused on showing that students were developing deep and rigorous technical competences, adding to transversal competences like teamwork, communication, making decisions with scarce information, formulating and solving problems. With the aim of showing these results, it was important to collect and analyse data, and also start publishing about these experiences. Additionally, a PhD (Fernandes, 2011) aimed at evaluating the impact of PBL on student learning and teacher's work was developed. Later on, another PhD (Mesquita, 2015), aimed at the definition of the IEM profile, allowed data collection from students, teachers and professionals relating to the MIEGI and its PBL approaches. Simultaneously, the research work developed by teachers and researchers, focused on themes such as assessment processes, teamwork, project management, professional profile, teacher's and tutor's work, student engagement, curriculum development, university-business cooperation, and operational improvement of classes.

It is possible to say that the focus on continuous improvement of the process, involving students, teachers and engineering professionals, based on an increasing support of research on engineering education, created an environment of resilient change. This resilience contributed to an ongoing history of the process and management of change of the (more than) 10 years of PBL of the Industrial Engineering and Management program at the School of Engineering at the University of Minho. This is not only a history of a group of teachers and researchers, but also a history of the Department of Production and Systems and all its teachers and collaborators who trusted and believed in this process, with institutional support from the School of Engineering of the University of Minho. Ultimately, this history would not be written without persistent and innovative teachers, simultaneously supported by and supporting open-minded educational researchers and enthusiastic students.

PBL MODEL AND ELEMENTS OF CURRICULUM

The PBL model implemented in IEM triggered and engaged students' learning, acting as a means for identifying the relevance of the contents in the professional practice, and increasing students' and teachers' motivation and application of theory. In these projects, teams made up of 7 to 9 students integrate the courses of the semester, exploring, researching, being creative, and making decisions. The project solutions proposed by the teams are mainly based on the integration of knowledge and competencies from each course of the semesters' study plan, thereby contributing to the development of the required learning outcomes. Technical guidance from teachers of all courses is provided to teams and further support from a teacher who plays the role of a tutor is also given. He/she contributes to support project management, teamwork, and communication. In other words, the tutor is a key-element for the development of students' transversal competences.

The PBL of the first semester begins on the first day of class for the 1st year and intends to integrate the contents of the courses of this semester. That way it involves initial courses of engineering and basic sciences, in a project that addresses the issue of sustainability. In the implementation of PBL in semester 7, teams of students aim to develop a project in an industrial environment that, in general terms, involves two phases: (i) analysis and diagnosis of the production system of a company and

(ii) development of proposals for improvement. Dealing directly with companies and their real problems causes a strong motivation both for students and teachers. So far, nine editions of PBL were carried out in interaction with 17 companies, involving more than 35 teams of 249 students. In these contexts, longitudinal studies have been conducted based on two PhD projects identifying the positive results of this learning methodology.

The general project approach of IEM considers the integration of the semester courses and eventually, external partners (usually industrial companies), as illustrated by Figure 2. There is also the possibility of non-integration of a course if the project theme and goals do not create a good match with that course's contents and objectives.

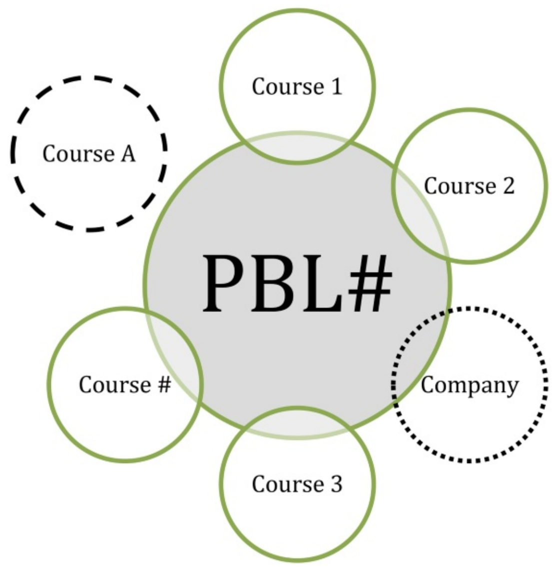

Figure 2. Illustration of the PBL interaction between project, courses and external partners

PBL Model and Curriculum Elements in the First Semester – Project 1

PBL implemented in the first semester, first year of the Industrial Engineering and Management program (IEM11–PBL) has been implemented since the 2004/05 academic year (Lima, Dinis-Carvalho, Flores, & Hattum-Janssen, 2007) and during a decade, 12 editions (or cohorts) were implemented, encompassing more than 520 students and 70 work teams. The PBL model implemented at IEM11 (IEM11–PBL) is based on the six courses of the semester, three from the School of Sciences and three from the School of Engineering (Alves et al., 2012). Table 1 presents the courses, their acronyms (Acr.), European Credits Transfer System (ECTS) of each course, scientific area and school. It should be noted that one ECTS represents 25–30 hours of student work and the IEM program is a five-year program (10 semesters) with 300 ECTS.

Table 1. Courses of the 1st year, 1st semester of the IEM program

Acr.	*Course*	*ECTS*	*Scientific area*	*School of*
LAlg.	Linear Algebra	5	Basic Sciences	Sciences
CC	Calculus C	5	Basic Sciences	
GC	General Chemistry	5	Basic Sciences	
AP	Algorithms and Programming	5	Specialty Sciences	Engineering
IIEM	Introduction of Industrial Engineering and Management	5	Specialty Sciences	
IPIEM1 = (Project)	Integrated Project in Industrial Engineering and Management I	5	Engineering Sciences	

The learning project is developed in the context of the Integrated Project of Industrial Engineering and Management (IPIEM1) course, also called "Project". Each teacher responsible for each course defines the content of each course that is incorporated into the Project.

The development of an integrated PBL approach from day one rests on a number of rationales, namely: to engage the students from the start on the learning process; to promote active learners and meaningful and integrated learning; to stimulate and reward the development of individual technical competences and knowledge dissemination among peers; to promote the development of teamwork skills and a number of other transversal competences. The range of technical competences to be developed, as defined by a number of courses, is therefore translated into an open challenge (the project theme) that the team has to tackle, by designing, developing, and ultimately making a compelling argument around a product and the respective production system. The learning outcomes are defined in the project guide, which is a document prepared by the coordination team, which supports and guides the students throughout the semester. In this document, students find information about the PBL methodology, the teachers' contacts, tutor information, learning outcomes for each course unit, scheduled classes and project milestones, assessment model and physical resources (e.g. room project, lockers, …) and the e-learning platform.

The coordination team usually includes six or seven teachers related to the Project Supporting Courses (PSC) and six tutors (one or two teachers are simultaneously teachers and tutors). Educational researchers have also been involved in this team.

As the members come from different schools/departments, there is always a wide diversity of ideas and experiences. The staff team does not change much from year to year, except in the case of Math (e.g. Calculus C), which during many years changed almost on a yearly basis. In Alves, Sousa, Fernandes et al. (2016), it is possible to analyse the years of experience of each teacher as well as a detailed description of the IEM11_PBL.

The project theme is usually related with sustainability issues for two main reasons: (1) to raise students awareness on this underlying dimension of human development, and (2) to be contemporary and attractive for the students (Moreira, Mesquita, & Hattum-Janssen, 2011). Table 2 presents a timeframe with the list of the 12 PBL editions implemented over the period of a decade.

Table 2. Editions and themes of a decade of PBL projects at IEM11

Edition	*Project theme*
2004/05	Specification of a biodiesel production system
2005/06	Specification of a production system to transform forest biomass
2006/07	Specification of a fuel cells production system
2006/07	Space Tourism
2007/08	Desalination of sea water
2008/09	Production of batteries for an electric car: specification of the battery and its production system
2009/10	Use of organic waste for the production of bio-alcohol
2010/11	Air2Water: specification of a portable device for production of drinking water from air humidity
2011/12	Clean-up and recovery of crude oil from sea spills
2012/13	Specification of a disassembly line for recycling of WEEE (waste electrical and electronic equipment)
2013/14	Design of a more sustainable packaging and specification of the production system
2014/15	Recovery and transformation of cooking oils waste

The IEM11_PBL process includes five phases: (1) preparation, (2) setup, (3) start-up, (4) execution and (5) end (Lima et al., 2012). The first semester starts in September and finishes in February, corresponding to 20 weeks of activities (including the evaluation weeks). In Phase 1, prior to the start of the semester, the possible project themes are identified and the human resources involved are allocated. In Phase 2, the definition and specification of the project theme, definition of project schedule (including milestones) and assessment model, and, elaboration of the project's guide (document provided to students including all the relevant information about the project) are set out. Phase 3 is marked by the start of classes, and includes a project presentation session, setting up of student teams and training (e.g. teamwork and communication skills) and, finally, the assessment of the pilot project (teams of students have one week to perform a kind of state-of-the-art analysis on the subject of the project's theme). In Phase 4, the students execute the process, i.e., have classes, tutorial meetings, develop prototypes (Figure 3), monitor progress and receive feedback.

a) b) c)

Figure 3. (a) Production system prototype in Lego Mindstorms; (b) a product prostotype (cohort 2013_14); (c) students disassembling a product (cohort 2012_13)

During the whole process, the IPIEM1 students are divided into six teams of about seven to nine students each. Each team has the support of a tutor. Each team must organize their tasks properly and manage their project in a formal way. Peer assessment and individual evaluation are used as mechanisms to prevent free riding, to monitor team performance, and to develop team work competences. The project progress and individual competencies are monitored during the semester by assessing the project deliverables after the accomplishment of the milestones, by the PSC teachers. Findings from research show that students and teachers agree in the difficulty of assessing this learning process, however they continue, engaged in their continuous improvement (Fernandes, Flores, & Lima, 2012b; Fernandes, Mesquita, Flores, & Lima, 2014). Some of the main difficulties identified by students are related to the individual assessment of each team member and the integration of contents from all courses in the project. For teachers, the main difficulties are linked to assessing student's competences and providing a grade. They find that it is not a trivial process to grade the development of competences.

The main part of the summative assessment process is done during the final phase (phase 5). This process involves the calculation of the student's final grade, taking into account: (1) assessment of the project's final reports, oral presentations and prototypes; (2) individual written tests by students and (3) peer assessment.

The assessment model is represented in Figure 4. Each component has a different weight, as shown, and this model can change every year.

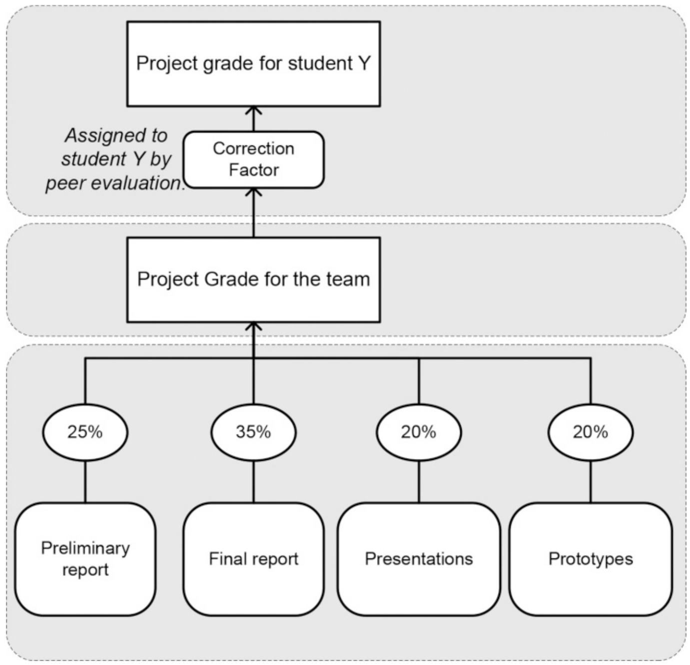

Figure 4. Assessment model of PBL semester in year 2012/13

A final workshop is also prepared in this final phase to address the concerns, difficulties and feedback of students about the PBL process through an online questionnaire and some focus groups.

Since the first year, students and teachers, supported by educational researchers, have the important goal of continuous improvement of the learning process. Difficulties are part of the process but teachers are willing to learn how to manage them (Alves, Sousa, Moreira, et al., 2016) and develop further research to improve the process and implement new ideas and suggestions from students and all stakeholders involved (Alves & Leão, 2015). For example, one of the main changes suggested by the students was the formal existence of a course called "project" to be integrated in the program. This happened in the academic year 2012/13 (Alves et al., 2014).

PBL Model and Curriculum Elements in the Seventh Semester – Project 2

As previously referred in the introduction, our program is an Integrated Masters degree in Industrial Engineering and Management, an engineering program of 5 consecutive years (10 semesters). The program can receive a marginal number of students in every semester by transfer processes, but the master program is not separated from the bachelor. Thus, the great majority of the students enrolled in this project had the experience of the first year project. Students who did not have that experience will have the opportunity to talk with colleagues, the tutor and the coordinator of the project to clarify any doubts. After several years of evaluation of the projects, this issue has never appeared as problem, as the new students will gain experience during the process.

The PBL model adopted for the 7th semester involves the development of a project within industry, incorporating the knowledge and competences inherent to all the courses of the semester (Lima, Dinis-Carvalho, et al., 2014; Lima, Mesquita, Dinis-Carvalho, & Sousa, 2015; Lima, Mesquita, et al., 2014). Typically, 5 to 6 teams of students are created (each one with 7 to 9 students) and each company, depending on its size, may receive 1 or 2 teams. The courses of the semester are: (i) Organization of Production Systems II (OSP2), (ii) Information Systems for Production (SIP), (iii) Production Integrated Management (GIP), (iv) Ergonomic Study of Workplaces (EEPT), (v) Simulation (SIM) and (vi) Integrated Project on Industrial Engineering and Management II (PIEGI2). The course PIEGI2 formally includes the PBL concept on the curriculum, and its grading system considers not only the developed technical competences but also transversal competences, as well as peer assessment.

Besides the support of the course teachers, each team of students has a tutor to help in the project management issues (including, when necessary, conflict management). On the first visit to the company, the tutor goes with the team (to introduce students and clarify the project's purpose) but the subsequent visits (typically on a weekly basis) are managed by the team.

Along the years, the typology of these projects has followed a common pattern, mentioned at the beginning of this section: (i) analysis and diagnosis of the production system, and (ii) development of improvement proposals. The duration of the first phase should not exceed half of the semester and the analysis and diagnosis is conducted in the context of all the courses of the semester. More specifically, the production system is subject to: (i) characterization and classification, (ii) performance evaluation, (iii) waste identification, (iv) identification of the main functions and techniques of production planning and control and how they are integrated, (v) identification of the information flow, (vi) evaluation of the adequacy of existing software regarding the functional and information requisites of the production system, and (vii) characterization of the workstations' ergonomics and physical environment. Items (i) to (iii) are inherent to the course OSP2, (iv) and (v) to GIP, (v) and (vi) to SIP and (vii) to EEPT. Note that (v) is conducted in the context of both GIP and SIP. The contents of the course SIM (namely the simulation models) are only applied in the second phase of the project in order to explore possible alternative solutions and estimate the corresponding results.

The second phase lasts until the end of semester and the teams are expected to develop solutions for the identified problems. Eventually, a single improvement addressing a single problem (maybe involving a single course) may be proposed, if, obviously, its relevance/impact is considered as important by all the stakeholders.

The monitoring of the project progress involves several milestones (Table 3), many of them associated to some kind of deliverables (e.g. presentations, papers and eventual prototypes).

Table 3. Milestones of a typical 7th semester PBL edition

Milestone	*Action/deliverable*
1	First session with the students (to explain the purpose of the project)
2	First visit to the company
3	Project Charter/Base Plan
4	1st formal presentation of the project progress (analysis and diagnosis of the production system)
5	1st report on the project progress (initial paper)
6	2nd formal presentation of the project progress (improvement proposals)
7	Final report (final paper with 8000 words) + blog + prototypes)
8	Final presentation and discussion

Since 2005/06 academic year there were 11 PBL editions. It should be noted that during the first two editions, before the curriculum change, the projects were developed in the first semester of the fifth year, involving fewer courses. Table 4 indicates the companies involved along with the corresponding number of teams and students. The companies are from different types of industries, namely: (i) medical equipment, (ii) metal mechanics, (iii) electronic devices for the automotive industry, (iv) textiles and clothing, (v) footwear, (vi) saws and files, (vii) semiconductors, (viii) electrical wiring for the automotive industry, (ix) packaging materials, (x) capacitors, (xi) tyres, and (xii) wood and furniture. This diversity is quite positive because different environments are addressed (each one with specific types of problems), contributing thus to a more enriching experience, not only for students but also for the teachers.

An important issue in this PBL model involving industry is the definition of projects to be assigned to student teams. Two months before the beginning of the semester, the coordinator of the project, with the help of two or three teachers of the semester, starts the contacts with companies. These contacts are mainly based on the networking of the teachers and, usually, the contact is made with 6 to 8 companies. If the number of companies is smaller than the number of teams, the company will have difficulty managing the high number of students in their facilities. Thus, having as many companies as teams makes it easier to get companies interested in receiving

Table 4. Seventh semester PBL editions since 2005/06

Edition	*Companies*	*Teams*	*Students*
2005/06	Moldartpóvoa	2	16
2006/07	Bosch (Blaupunkt)	3	19
2007/08	PROHS/JSM	4	28
2008/09	Actaris; Bosch; ETMA; Texal	4	27
2009/10	Kyaia; Camport; AmiShoes	5	39
2010/11	Preh	6	40
2011/12	Bosch, SNA, Irmãos Salgado (têxtil)	5	31
2012/13	Bosch (2), Delphi (2), SNA (2)	6	49
2013/14	Bosch (2), Delphi, Nanium, To Work For, Leoni	6	51
2014/15	Bosch, Continental ITA, Leoni, Rembalcom, Vishay	5	42
2015/16	Continental ITA, IKEA Industry, Leoni, Rembalcom, SNA, Vishay	6	47

the teams, but increases the number of communication channels and efforts to align with all companies' expectations. Repeating companies in consecutive years allows making this process easier. In general, companies define their projects using two main different approaches. Approach 1 – the company leaves all the decisions to the students. Students must select a production system (area) where the project should take place and then the students also must identify problems to be analysed and possible solutions. Approach 2 – the company assigns a specific part of the production system and the problems to be addressed. Large companies tend to provide projects defined in more detail with little room for changes while smaller companies tend to leave most decisions to student teams. In any case, all projects must be previously analysed by PBL coordinators to assure the alignment to the PBL supporting courses with the objectives of the project course.

In the first phase of the project (analysis and diagnosis of the production system) all student teams tend to follow more or less the same approach. Typically teams go through the following list of possible steps:

- Collect general data about the production system (type of products, type of processes, number of workers, layout …).
- Build a Value Stream Map (a technical tool to identify the process steps) and identify and measure production waste.
- Collect data regarding existing performance indicators and data to create important new ones.
- Identify and describe the existing information systems.
- Diagnose working conditions regarding ergonomics, noise and lighting conditions.

In the second phase of the projects, students must identify and select one or two improvement opportunities, design the solutions and implement them. Examples of types of interventions are:

- Layout changes in order to improve production flows, productivity and lead times.
- Reduce setup times in machines using SMED method.
- Design production cells for a specific product family.
- Improve the internal logistics systems (include supermarkets design, improving warehouse layouts, and “mizusumashi” systems implementation).
- Improve workstation organization to improve working conditions and performance.
- Design and implement pull flow systems such as Kanban systems in order to reduce work-in-process and lead-times.

During the development of tasks in phase 1 and phase 2, students must develop the competences expected by the project supporting courses, simultaneously learning the courses’ contents by means of the problems they are solving, and applying the contents to solve those problems. The development of the courses’ competences is the base element of this PBL model. Additionally, they will be developing several transversal competences because they are developing this team project, namely: team work, project management, communication in professional contexts, creativity, problem solving and making decisions with scarce information.

The assessment model adopted in the 7th semester PBL project includes a number of elements of different types (Fernandes, Flores, & Lima, 2012a; Lima, Mesquita, Fernandes, Marinho-Araújo, & Rabelo, 2015) and is represented in Figure 5. The final grade of a student for a given course X is obtained from the individual grade achieved through continuous assessment of course X and from the individual grade of the project. The individual grade of the project is obtained by multiplying the team grade of the project by a correction factor (CF) determined by peer assessment. The team grade of the project considers the assessment of: initial paper (20%), final paper (50%) and presentations (3 presentations: 5% + 10% + 15%). If some students are able to submit and publish a paper based on their project work, a bonus of 5% is attributed to their grade.

FUTURE PERSPECTIVES AND VISIONS

The PBL approach implemented since 2005 is quite stable in the IEM curriculum. Nevertheless, improvements are always being implemented during the years. In semester 1, the main change was related to the introduction of a project course, which formalized the way teachers were involved and changed some assessment practices. In semester 7, several changes in the process resulted mainly from the suggestions collected from students, teachers and professionals, during the process evaluation phase, developed at the end of the semester. As an example, a change implemented a few years ago, allowed students to quit integrating some of the courses at the middle

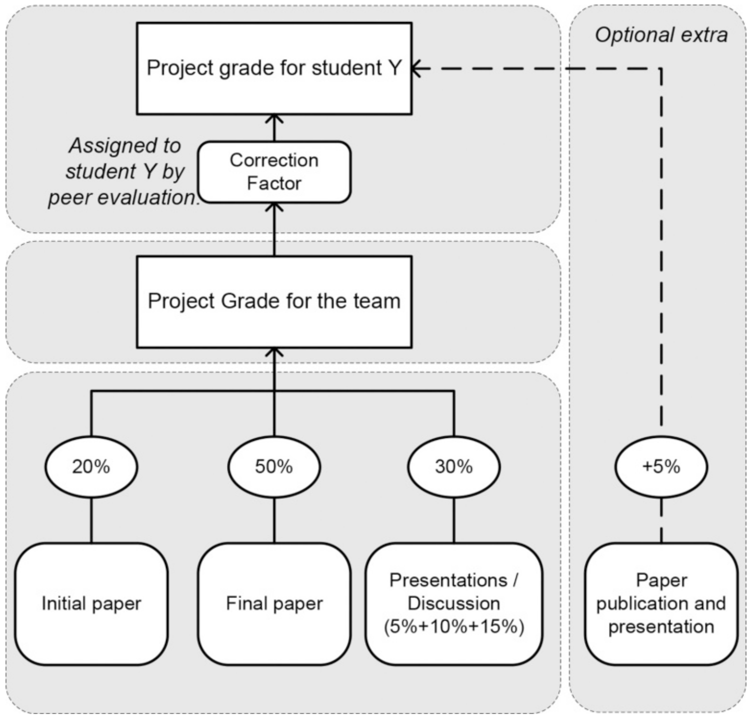

Figure 5. Assessment model of the 7th semester PBL project

of the semester (after the problem diagnosis) in order to focus on some specific requirements of the companies.

Some of the main challenges of the PBL model, according to teachers and researchers involved, are the following:

- Maintain project workspaces available for all teams during the whole semester. This is one of the main differences of our model in comparison with other projects at the University of Minho.
- Create more PBL approaches in the curricula.
- Create opportunities for continuous pedagogical training and professional development of teachers.
- Continuously strengthen teacher's motivation for the PBL processes and, in general, introduce innovation in the learning processes.
- Create some homogeneity between the tutors' performance and practices.
- Keep the continuous interest of companies in the students' projects.
- Develop increased focus in projects that involve companies, simultaneously satisfying the students, teachers and professionals' expectations.
- Improve the interdisciplinary approaches between different knowledge areas.

- Improve the project management approaches by the teams of students and by the coordination team.
- Improve and/or develop new models for the assessment of competences.
- Increase the recognition of engineering education research among the engineering community, simultaneously by its impact on the education of engineers and its impact on engineering fields.

There are common visions between the teachers and researchers involved in PBL at IEM program at the School of Engineering of the University of Minho and the main one is that it is always possible to improve the process and the results. The staff involved are continuously putting forth efforts to create the best opportunities for the development of students' competences. This vision is centered on the motivation to engage students in processes that allow them to try and to fail, to learn with mediation, to develop rigorous technical competences with commitment, effort and fun. In this way, the PBL process aims to keep reducing the gap between the developed competences and the required competences for the professional practice and for the needs of the society.

The experience of PBL in the IEM program has shown evidence of the benefits of this approach at different levels and that there is still much more that can be done. There should be opportunities for more projects in the curriculum, more projects in interaction with companies and with the society, more projects in interaction with other cultures and students from other programs, increased interaction with staff from other departments, engineering education research recognized by peers, and more opportunities for staff development. In summary, a sustainable world needs learner-centered systems to be in the backpacks of engineering educators and researchers, and problem and project-based learning principles can be the baseline for such systems.

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BART JOHNSON AND RON ULSETH

4. IRON RANGE ENGINEERING MODEL

INTRODUCTION

The Iron Range Engineering (IRE) model of PBL, an adaptation of the Aalborg model (Kolmos, Fink, & Krogh, 2004), began delivery in January of 2010. IRE is located in rural northeastern Minnesota in the United States. The PBL curriculum was designed and implemented as an upper-division program delivering the final two years of a four-year engineering bachelor's degree.

Distinguishing characteristics of the IRE model include the use of real industry projects, explicit focus on the development of the student technically, professionally, and as a creative designer, vertically integrated student teams, oral examinations, formative assessment, and continuous improvement.

Recent research on the development of the PBL graduates as self-directed learners and their acquisition of professional competence has been completed and brief summaries are presented.

DRIVERS FOR CHANGE

Motivations

For several decades, there have been calls for change in the abilities of new engineering graduates (Beanland & Hadgraft, 2013; Beering, 2007; National Academy of Engineering, 2004). These calls have gone largely unheeded by engineering education (Sheppard, Macatangay, Colby, & Sullivan, 2008). This is particularly true in the United States where Iron Range Engineering is located.

The authors began their engineering education careers at Itasca Community College in Grand Rapids, Minnesota. The Itasca engineering program delivered the first two years (lower-division) of the four-year bachelor's of engineering. Students would transfer to a regional university to complete the final two years of the bachelor's (upper-division). In the 1990's we recognized the need for change that was being proposed in the US by ABET (ABET.org, 2015). However, as time went by, it became obvious that the traditional engineering programs were not changing the learning activities needed to develop the outcomes being asked for by industry and by the accreditation board (Sheppard et al., 2008). Further, the National Academy of Engineering began identifying and publishing the attributes expected of engineers by the year 2020 (National Academy of Engineering, 2004; Vest, 2005).

A. Guerra et al. (Eds.), PBL in Engineering Education, 53–69.

During the same time frame, the How People Learn (Bransford, Brown, & Cocking, 2000) movement began and more understanding of the weaknesses of the lecture-based reception of knowledge mode was making its way to professors in higher education. In 1997, the American Psychological Association published their learner-centered psychological principles (APA, 1997). These principles, which are social constructivist in nature, provided pathways to leave the traditional lecture model to improve student learning and to better develop the desired outcomes in engineering graduates.

In 2004, the authors gathered a group of engineering educators from across the United States to begin discussions about developing and implementing a new curricular model that would explicitly address a new-look engineering graduate and pedagogically would better align with student learning (Cole, 2012).

Choice for PBL

In 2009, funding was acquired for a pilot implementation (Iron-Range-Resources, 2010). The development team had identified the desired attributes of the new model. However, the group was unaware of the PBL models that had been in place in Denmark and other places for over 30 years. Sheri Sheppard, one of the members of the newly established national advisory board, at a meeting of the advisory group (that was happening in Austin, Texas during the annual American Society of Engineering Educators national conference) made the connection. She recognized the alignment between what was desired by this new group and the PBL model at Aalborg University in Denmark. The leaders of the development team flew to Denmark to learn the Aalborg model in much more detail. PBL became the pedagogical framework for Iron Range Engineering.

It is developed at the ground level by the faculty and students in the place and for the place of its implementation. In other words, it is a model that can be adapted rather than adopted. This was a difficult lesson to learn. The team thought it would be easy to "package" the Aalborg model and deliver it in Minnesota. However, the needs of the region, the students, and the faculty were different, so there were many early modifications. During those early meetings with Anette, she very clearly made the point that PBL is a social construct.

PBL MODEL AND ELEMENTS OF CURRICULUM

Iron Range Engineering embraces a model of continuous improvement that results in substantial innovation and change in the PBL model each year (Bates & Ulseth, 2013). The continuous improvement approach is described in more detail in the following section on implementation and management of change. However, this means that any description of the PBL model and elements of the curriculum is a snapshot of the model at that point in time.

Objectives

The primary objective of the Iron Range Engineering program is to provide learning activities, guidance, and feedback so that students can become the engineer they want to be. The students approach the engineering education experience as one of self-development. The program identifies baseline knowledge and abilities in every outcome. Students are required to meet the baseline and then encouraged to discover their passion areas and exceed the baseline in those areas. Thus, each graduate has a unique skillset determined by his or her own desires. The outcomes are communicated to the students in two ways. First, the outcomes are listed in their syllabi and portrayed as a poster in their workspace. The outcomes, as can be seen in Table 1, are categorized into professional, technical, and design domains.

Table 1. Iron Range Engineering graduate student outcomes (Iron-Range-Engineering, 2016)

Technical outcomes	*Design outcomes*	*Professional outcomes*
Technical 1. An ability to apply knowledge of mathematics, science, and engineering	Design 1. An ability to design a system, component, or process to meet desired needs within realistic constraints	Professional 1. An understanding of professional and ethical responsibility
Technical 2. An ability to design and conduct experiments, as well as to analyze and interpret data	Design 2. An ability to function on multidisciplinary teams.	Professional 2. An ability to communicate effectively
Technical 3. An ability to identify, formulate, and solve engineering problems	Design 3. An ability to lead, manage people and projects	Professional 3. An ability to inclusively work in a diverse environment
Technical 4. A recognition of the need for and an ability to engage in life-long learning	Design 4. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Professional 4. A knowledge of contemporary issue
Technical 5. An ability to engage in entrepreneurial activities	Design 5. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	

Secondly, in an effort to make the outcomes more understandable and less sterile for their everyday implementation, the students and faculty worked together to create a model called *Being an Engineer*. In this perspective of the outcomes, the ideas have been put in separate “bite-sized” phrases that can become mantras for the students who are first learning the outcomes and trying to make the outcomes a part of themselves. Students have binders they use in their daily work. The *Being an Engineer* outcomes are on the front cover of the binders. These simplified outcomes are presented in Table 2.

Table 2. Being an engineer (simplified outcomes)

Perform on teams	Act ethically
Write technical documents	Be professionally responsible
Give presentations	Know contemporary issues
Be a self-directed learner	Lead people
Conduct experiments (design, conduct, analyze)	Manage projects
	Act entrepreneurially
Know and use fundamental principles	Be inclusive
Be reflective	Use modern tools
Solve open-ended problems	Embrace continuous improvement
Design systems and components to constraints and contexts	Practice life-work balance to manage happiness

Types of Problems, Projects and Lectures

The projects, and how they interact with the lecture part of the student learning experience, are at the heart of any project-learning program. For the curricular element of types of problems, projects, and lectures, there are closed-ended problems at one end of the spectrum, which are identified with the traditional specific steps to a solution and a specific answer. At the other end of the spectrum, projects are ill-defined which leaves both the approach and the final solution to be determined by the teams and the students. These types of projects support the interdisciplinary approach of Iron Range Engineering model PBL. In this model, the lectures support the project. The emphasis shifts from knowledge-transfer to guiding students through the knowledge acquisition process as directed by their project work (Ulseth, 2016).

The project cycle in the IRE program lasts one academic semester. During the semester, one team, with the guidance of a project facilitator, completes a project for a client. The client is normally an industry partner; however, students can choose to do an entrepreneurial project in which they are their own client, inventing their own product or process. The industrial projects are real needs the company has for engineering solutions. The intent is for the companies to implement the student solutions, as often happens.

Progression, Size, and Duration

Projects last one 16-week semester. Teams are composed of 3–8 students. The process starts prior to the semester when students are queried about their interests in project types for the upcoming semester. Potential interest areas include, but are not limited to these: industrial mining, industrial other, manufacturing, consulting, biomedical, or entrepreneurial.

Based on the results of the survey, the academic staff sends out a call for proposals to the program's current and potential industrial partners. Partners submit a completed project solicitation form. Students interested in an entrepreneurial project complete the same form. Once the industry partners and entrepreneurial students have submitted complete solicitation forms, the forms are compiled into one document that is deemed the "projects menu." The projects menu is distributed to all students. Students then select their top three choices. Academic staff compiles all of the student desires and create teams. Other considerations that staff use when assembling teams include prior student experiences and student personalities.

The intent is to create a vertically integrated team with students from different semesters of the program and with different skill sets and development needs. Once a team has been assigned to a project, a project facilitator from the academic staff is selected for the team. Prior to the first day of the semester, the project facilitator will have met with the client to get a clearer understanding of the project scope.

The projects serve as the backbone for the student learning of the design, technical, and professional outcomes. The projects are selected to support the student competency development process, such that they are able to demonstrate all 14 competencies by the time of graduation.

Students' Learning

The learning by students in the IRE model is approached from each of the three domains: technical, professional, and design. The use of these domains helps students classify the value of the learning to their future career. However, the domains are not treated as silos. Students use the skills from one domain in the practice of other domains on a constant basis. This interaction is explicit and highly valued.

Technical learning. Technical learning is designed to integrate with the project. Near the beginning of the project, students acquire fundamental knowledge. As the project progresses, students acquire more advanced knowledge that is necessary to complete the project. Students acquire technical knowledge in "learning conversations" rather than in lectures. Students perform the first acquisition of knowledge prior to the learning conversation with their instructor and peers. They do this through watching short (Khan-Academy style) videos prepared by their instructor or through reading assignments. Then in the class session, through a question and answer session, conversation is held to assist the student develop her own conceptual model of the engineering principles.

Students complete their technical learning in 32 one-credit courses (called competencies ~ 14 hours face-to-face and 30 hours independent). Each competency includes a process-learning activity. In these activities, students design experiments or some similar activity where they make a hypothesis, build experimental setups, collect and analyze data, compare actual results to predicted results, and prepare a written report. Students complete eight of these activities per semester for each of their four semesters.

Oral exams are a characteristic of the student learning. Each student takes an oral exam where he describes his conceptual and problem-solving knowledge for each competency (eight per semester). Oral exams can be either individual or small group.

Beyond the learning of the individual technical competencies, students practice integrating this knowledge through solving complex open-ended problems. This act is practiced throughout each semester and culminates in a one-hour final oral exam at the end of the semester.

Professional learning. Professional learning is viewed as an individual's own development in the execution of daily action and communication. Wherever a person is at a point in time along a continuum of low development to high development, the person should be aware of that level, monitor it for desired changes, set goals for those changes, and make action plans to meet the goals. From the "Being an Engineer" list in Figure 1, the following are considered professional skills and attributes: performing on teams, writing, presenting, being a self-directed learner, being reflective, acting ethically, being professionally responsible, knowing contemporary issues, managing projects, being inclusive, embracing continuous improvement, and practicing happiness.

This is a major portion of the list. It takes considerable effort to guide students in the development of these abilities. A quarter of the curriculum is dedicated to this development. In the previous section on motivations, this level of dedication to developing the professional was perceived as missing in traditional engineering educations and became a major part of this PBL curriculum.

Of the list of professional abilities from above, the "being professionally responsible" may need further explanation. This ability refers to the following actions: being responsive to communication, being prompt, representing oneself and one's organization well, being respectful, being helpful, and being accountable (Ulseth, 2016).

The project serves as the platform for the practice of professionalism. Through interactions with the client, the facilitator, the faculty panels, and each other, the students deploy strategies and learn from the failures and successes of those strategies. Strategies are delivered through weekly seminars by academic staff and external experts. Feedback on failures and successes comes frequently from peers and facilitators. Students employ continuous improvement on their personal development through the creation and maintenance of a "professional development plan" (PDP). Each semester, the students evaluate their current level of ability in each of the professional areas listed above. They write goals and action plans for those areas where they want to develop followed by periodic monitoring of their progress. Successful students acquire the belief that professional development will be a career-long practice.

Design learning. Design learning is guided by a weekly design workshop where students learn the elements of design and processes for navigating those elements. Substantial reflection by the design team is scaffolded to empower longer-term learning of the design strategies.

Each project includes a team of 3–8 members, a team room, and a facilitator (either a practicing professional engineer or a staff member). Industry clients or student entrepreneurs propose the projects. The one-semester projects are authentic. In other words, staff members do not reformat the projects. Students interact directly with their client. The facilitator stands to the side and facilitates student learning rather than standing between the client and the group as a liaison. The teams create extensive written documentation and give six technical presentations. Three times per semester the team goes before a review panel to defend their work and work processes.

Academic Staff and Facilitation

Academic staff consists of a core of academicians supported by a network of professional engineers. This integration of professors and experienced engineers provides a synergy whereby the professors gain an appreciation for the needs of engineering practice, and the engineering professionals gain skills in understanding pedagogy, motivation, and learn to give valuable formative feedback. Each semester, the professors facilitate approximately half of the student teams and the engineering professionals facilitate the other half. Occasionally, final semester students will take the role of facilitator. The professors provide approximately 90% of the learning guidance in the technical domain with adjunct engineers providing the other 10%. The facilitation of professional learning happens at many levels. First, the culture of the program is one of open feedback. Therefore, all members of the community are encouraged to provide guidance to one another in professional action. Second, the project facilitator takes an active role in monitoring the professional action and development of each team member. Third, clients are encouraged to provide developmental feedback on professionalism. Finally, the team members themselves take ownership in providing feedback to one another.

Assessment

Formative assessment is the focus of the program. Academic staff members are more interested in enabling continuous development of the students than on assigning evaluative grades. Students are encouraged to put the entirety of their focus on their own development and not on their grades. This is difficult for students to achieve, as they have nearly 15 years of previous education that was grade-driven.

Formative assessment uses a combination of verbal feedback and low-stakes number scale. The scale is as follows: 0-not submitted, 1-poor, 2-needs improvement, 3-acceptable, 4-desired, 5-exemplary. These numbers give students continuous feedback on the quality of their work. Early semester numbers are not counted towards summative evaluation. They are used simply to help the students calibrate. As the semester continues, the weighting increases. Summative assessment is heavily focused on performance in the last two weeks of the semester when all of the feedback should have resulted in acceptable to exemplary performance.

IMPLEMENTATION PROCESS AND MANAGEMENT OF CHANGE

When the Implementation/Change towards PBL Started?

The change process towards PBL is described earlier in the section on motivation. The implementation started in fall semester 2009 when a group of 14 students who were given the moniker *Generation 1* joined the program to help design the curriculum. For that semester, they were paid as engineering interns and helped craft the upcoming semester that would be the first semester of PBL curriculum delivery. During that first planning semester, the students tested small projects and crafted ideas for how technical, professional, and design learning activities would look. The program faculty worked side-by-side with the students during this time to create the syllabi for the inaugural semester.

The inaugural semester began with far less structure than the program would eventually evolve towards. This was especially true in the domain of technical learning where students were expected to organically assimilate the technical principles needed for the completion of their project. Aspects of the project that started in the inaugural semester and remain to the present day are the industry, client-based projects, an emphasis on reflection, the professional development plan, design reviews, a high volume of presentations of work, oral exams, and seminar workshops for the transmission of professionalism strategies.

Who Was Involved and Why?

On the ground, there were 14 students, two engineering faculty members, and one staff member. The national advisory team provided substantial guidance and support. There were two educational institutions involved. They were Itasca Community College, where the idea originally germinated and a new partner, Minnesota State University, Mankato that would be the degree-granting institution. Upper administrations (the president and dean levels) were heavily invested in the partnership and the idea of succeeding with a PBL curriculum. This small group allowed for great flexibility in adapting to a way of acting and learning that were foreign to all.

Main Challenges

There were two main challenges. First was the challenge of gaining acceptance by the engineering faculty at the university. The university was located 250 miles away from this satellite program, but the on-campus faculty were not inclined to accept a PBL model that was such a drastic change from their traditional programs. The need for the faculty acceptance was due to the power they held in allowing new curriculums to be approved at the college level. The second challenge was in traversing the steep curve from a conceptual idea of how the curriculum should look towards a working curriculum that students and faculty could employ.

The change process started bottom-up as the two faculty members were part of the team of people who had actively been seeking a new model for engineering education for more than five years and were now being given the opportunity. They garnered support from the presidents of the two institutions who then created a top-down change process. The challenge came in the middle at the teaching faculty level in the traditional engineering programs on the main campus. They had the new program being thrust upon them from above, which was met with a natural resistance due to a lack of autonomy. From below, they had outsiders describing a new model for learning. This model was drastically different than the traditional model that they had been educated under and in which they had spent their careers teaching. They felt that if the new model were better, that meant their own model was worse, and they rejected the idea that there could be anything better than traditional. During a sponsored research study on this change process four years after the initial start-up, one of the faculty leaders of the time was quoted as saying “PBL is poison.” The following quote was collected during the research project.

> I think the biggest challenge was they wanted to try and have one of our current engineering departments take ownership of it, and none of them was willing to, partially, again, because they felt it was being foisted on them. And part of it is they had doubts about the proposed method of delivery and so on, being more individualized kind of learning. I mean, they were worried that their accreditation might be at risk if they also were sponsoring that. … So, I think that was probably the toughest part of it, and I’m still not sure [the program has] much buy-in from those who were in the engineering programs at the time. *State University Faculty.* (Allendoerfer, Bates, Karlin, Ulseth, & Ewert, 2015)

A highlight of the present day IRE model is the acceptance of continuous improvement as a way to make each semester better than the one before. A struggle during the first several semesters of the program was caused by implementing change too frequently. The conceptual curriculum that was in place on the first day of the first semester was based on theory of what should work and the practice of PBL in other places. It was not yet calibrated to the people and place of Iron Range Engineering. There were many disconnects. Many students and teachers were frustrated when an activity that was expected to achieve a result did not. This caused the implementation team to seek new methods. Unfortunately, as new methods were constantly being employed, students became frustrated. A sense of "why should I do what you ask of me today when you are going to change it tomorrow?" came over the student group.

How Challenges Were Overcome

Allendoerfer identified three strategies that empowered the change process to succeed. (1) having "champions" at all levels, (2) creating new boxes into which the new program could be placed, and (3) having "translators" at key bridging points between stakeholder groups (Allendoerfer et al., 2015).

"Champions" refers to people with passion who will work hard to overcome obstacles to achieve the goals necessary. In the IRE startup phase, there were champions at the student level, the teaching staff level, at the president, vice-president, and dean levels, and in each of the support areas on the main campus such as financial aid, registrar, etc. Change became difficult when anyone of these champions faltered.

"New boxes" refers to examples such as creating a new department for the program rather than having it reside in one of the on-campus departments or creating a new degree rather than awarding the same degree as on-campus.

"Translators" were needed when conflict arose between two groups. The translator was a person who had enough respect from both groups that she could iron out details of compromise without escalation to further conflict.

The challenge of overcoming the frequent changes within the students was ultimately overcome when an external evaluator (Marra & Plumb, 2012) observed the problem and recommended a new policy whereby change could only be instituted at the beginning of a new semester. Any changes identified in the middle of a semester would be set aside and implemented for the next semester. This solution eliminated the challenge.

IRE Model Attributes – Student Identified

Important to understanding the IRE model are the attributes students identify as the distinguishing characteristics of their experience. A recent analysis was completed with regards to curricular and learning theory and the student learning experience (Johnson, 2016b). An outcome of this study was a collection of the *distinguishing characteristics* of the model, highlighted in Figure 1.

STUDENTS AS SELF-DIRECTED LEARNERS AND THEIR ACQUISITION OF PROFESSIONAL COMPETENCE

Two studies on the IRE model were recently completed on the development of students who complete the PBL program. One study analyzed the students' development of *self-directed learning abilities* and the other analyzed students' *professional competency development*.

Technical Learning	*Professional Learning*
• Flipped classroom: learning conversations • Deep learning activities in each course • Oral exams • Open-ended problem solving • Self-directed learning skill development	• Professional Development Plan • Personal trajectory in professional development • Engineering practice environment • Professional expectations
Design Learning • Authentic industry problems • One-semester projects • Extensive verbal communication of design progress • 3-8 person teams • Facilitation • 3 design panel reviews per semester	*Overall Program* • Team rooms • Reflection throughout • Continuous improvement • Explicitness • Continual feedback to students

Figure 1. IRE distinguishing characteristics (Johnson, 2016b)

Self-Directed Learning in PBL

Ulseth (2016) published the self-directed learning (SDL) study results. A mixed-methods approach was taken. Quantitatively, a pre/post comparison study was completed between students who graduated from the IRE PBL program and students who completed traditional engineering bachelor's programs. The Self-Directed Learning Readiness Scale (Guglielmino, 1977), an established instrument, was used to measure student self-directedness prior to and after the PBL and non-PBL educations. Three comparisons of note were (Ulseth, 2016):

- Significant differences were observed between performance prior to the PBL experience ($M = 66.1$, $SD = 23.5$) and upon graduation from the PBL program ($M = 75.8$, $SD = 17.5$), $t = 2.539$, $p<.05$.
- Significant differences were *not* observed between performance prior to entering the traditional final two years ($M = 56.0$, $SD = 26.5$) and upon graduation from the traditional program ($M = 61.5$, $SD = 26.8$), $t =1.168$, not significant $p>.05$.
- Significant differences were observed between post-performance of the PBL graduates ($M = 75.8$, $SD = 17.5$) and the non-PBL graduates ($M = 61.6$, $SD = 26.8$), $t =3.290$, $p<.05$.

The qualitative study sought to identify how the PBL students experienced their SDL development. Three findings were observed. First, the PBL students showed highly developed SDL abilities upon graduation (Ulseth, 2016). Second, a phenomenographic outcome space (Ulseth & Johnson, 2016a) was developed. This outcome space delineated the variety of different ways self-directed learning was experienced by PBL graduates. Third, was the development of a composite model

(Ulseth & Johnson, 2016b) of how PBL students implement self-directed learning. The outcome space and composite model are available upon request or can be found as published. The intent of the findings of the qualitative study was to provide information for curricular decision makers to contemplate when considering the implementation of PBL.

Professional Competency Development in PBL

Johnson (2016) published the professional competency development study results. A mixed-methods approach was taken. Quantitatively, a pre/post comparison study was completed between students who graduated from the IRE PBL program and students who completed traditional engineering bachelor's programs. The quantitative study seeks to identify if a difference exists between PBL and non-PBL students in their pre- to post- self-reported importance and performance for the professional competencies.

For this purpose, two instruments were developed. The first instrument (Individual Professional Development Instrument) focuses on the individual professional abilities and was developed to allow students to position themselves relative to normative standards. The second instrument (Team Professional Development Instrument) identifies students' beliefs about the importance of professional competencies and their current performance level within the context of functioning as a member of a team. The instruments are available upon request or can be found as published.

Both instruments were utilized pre- and post- upper division. Both groups appear to start with similar potential in their motivation and, therefore, similar potential in their identifying with or finding importance in the learning process of professional competencies. Therefore, any differences in growth between the two groups could be attributed to the learning process and curriculum they experience in the upper-division. The key findings of the quantitative study are (Johnson & Ulseth, 2016a):

- Non-PBL group reports higher Pre *Performance* in *Team* context as compared to PBL group
- Non-PBL group reports lower Post *Importance* for both instruments as compared to PBL Group
- Non-PBL group reduces in *Importance* (Pre to Post) in *Individual* context
- PBL group increases in *Performance* (Pre to Post) for both *Team* and *Individual* contexts
- PBL group has no change in *Importance* (Pre to Post) for both contexts. Scores start and stay at a high level.

The qualitative study sought to gain an understanding of the student experience and also identify which elements of the PBL curriculum affected the student experience. Three curricular elements which can transcend all PBL programs, were identified as part of experience in developing these student participants' professional competencies (Johnson, 2016a; Johnson & Ulseth, 2016b):

1. Projects (industry in this study) completed in a team environment with facilitators and clients that foster and reinforce the development of professional competencies.
2. Program cultural expectations for professional competency practice in all aspects of an engineering program.
3. The importance in embracing the role of defining moments for students in the development of professional competencies. The defining moments are most effective when tied to genuine engineering activities and participant-directed learning activities.

A unique curricular element identified, for incorporation in other curriculums, is the extensive learning activities that explicitly define the professional expectations for students and facilitates the student development of them. It is important to recognize the value of spending significant student and program time on these activities. Key program learning activities are the professional development plans, weekly professional seminars, extensive student presentation with peer feedback, and the structured team member peer feedback.

FUTURE PERSPECTIVES AND VISIONS

Changes to Initial Model

Continuous improvement was a part of the initial start-up out of necessity. However, the development of a structured continuous improvement model meant that progressive change became a part of the fabric of the PBL program.

After two years of informal continuous improvement, the model in Figure 2 was formalized. Throughout every semester, inputs are solicited from students, staff, external advisors, and from the program's portfolio assessment program. These inputs are presented at the *first faculty summit* that takes place immediately at the end of the semester. The ideas are all discussed and given a first evaluation as to whether the improvement should be immediately implemented, rejected, or saved for future consideration. A member of the faculty is given ownership over each idea to be implemented and is to prepare an implementation plan. The time before the next semester's start is reflection time for all members to contemplate the ideas discussed at first faculty summit. Then, near the beginning of the next semester a *second faculty summit* is held. At this summit, all faculty are encouraged to share any reflections that are pertinent to the new ideas discussed at the previous summit. These reflections and the presentations of the implementation plan result in further discussion and ultimately a plan for how all changes will be implemented in the syllabi for the upcoming semester.

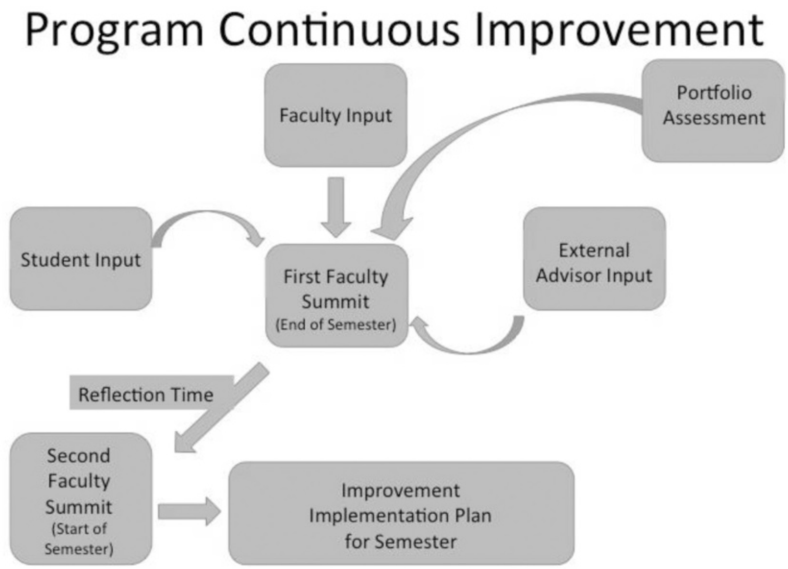

Figure 2. IRE continuous improvement model (Bates & Ulseth, 2013)

The existence of this model is, in itself, a change to the initial model. Further, its existence has meant the addition of substantial changes being implemented every semester. Following are various changes that have been implemented since the beginning of the PBL model:

- Technical learning has evolved from lectures by faculty in the beginning to a more active and flipped-classroom learning conversation.
- Teams were initially comprised of all students from the same generation at the same point in their education. Teams are now vertically integrated comprising members who are at every semester in their progression.
- Balance has been achieved between student focus on their learning and completion of the project for the client. Early students neglected personal development in favor of project completion.
- The focus on design learning has improved as structured learning activities and formal design reviews have evolved.
- Student achievement of outcomes has improved as expectations that were originally implicit have become highly explicit.
- The level of expectation of professional responsibility has risen substantially over time. With the higher expectation has come a higher level of performance.
- For many years, new students in their first semester struggled greatly with the transition to the model. To help students adapt, a weekly seminar has been implemented just for students in the first semester. Learning activities are all

aligned with understanding the language and expectations of the PBL model. This seminar is referred to as the *New Gen Seminar*.
- A weekly learning activity was added in year three to improve student focus on the development of creativity and open-ended problem solving. In this activity, students develop and practice strategies to approach innovation and complex problems. This activity led to the implementation of an individual final oral exam where an open-ended problem in need of an innovative solution is presented to the student. They take one hour to demonstrate a solution to a panel of faculty and industry experts.
- A recent change to the student experience in the PBL model has been an explicit development of a culture of inclusivity and non-entitlement. Aligned with the learning of professionalism, becoming inclusive is an essential tool to success on teams and in industry. Entitlement by students, where they feel they are owed some aspect of their education rather than being responsible for their own learning is detrimental to their development and the learning culture. The explicitness of these two focus areas is a change that has resulted in culture improvement and a better professional development trajectory for students. Inclusivity has been added as one of the student outcomes.
- A lower-division program has been added to the model. The original model consisted of upper-division only. Entering students had to have completed the first two years of the bachelor's degree in a traditional model before entering the PBL model. In 2014, the IRE program began accepting first-year students.

These are only a few of the many changes made to the PBL model since its inception. They were chose for inclusion here due to their importance in describing the IRE PBL model.

Present Challenges

Present challenges to the model are related to economics, geographic location, and maintenance of change.

Program funding is related to a tax on iron ore production. Due to international economic factors, iron production is down substantially, resulting in increased competition. This puts the future of sustained funding in jeopardy.

Iron Range Engineering is located in a rural setting in northeastern Minnesota. Attracting and retaining engineering professors to the region is a current challenge. Recent turnover among junior faculty has resulted from this problem.

Ruth Graham (2012) states that reform programs in the five to ten year period after graduation of the first generation of students are susceptible to the challenge of maintaining as "most reform programs experience a gradual course-by-course drift back to a more traditional curriculum". As the IRE model approaches this time frame, focus will be specifically put on avoiding this "drift".

Future Plans

An option under consideration by regional stakeholders is to "double-down" on the IRE model. Through recent economic summits, IRE has consistently been identified as one of the most innovative impacts to the region's economic development. At a time when the iron mining industry is in an economic downturn, rather than decrease funding to the model, there is consideration that the model could be expanded from a 50 student PBL program to a 500 student PBL college.

In regards to maintaining the PBL model into the future, the program sees its continuous improvement system as being the key to staying fresh for students and maintaining innovation. Graham (2012) further points out that an attribute of programs that survive the five to ten year challenge is an "on-going focus on educational innovation and reinvention."

To address the challenge of retaining junior faculty, a future plan may need to involve eliminating the desire to retain professors. A counter approach could be to embrace the role of being a place where junior faculty members rotate after 2–3 years. This model offers the opportunity to continually bring fresh ideas to the program while sharing the PBL experience with a wider number of engineering educators.

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5. PBL IN ENGINEERING EDUCATION

Republic Polytechnic's Experience

INTRODUCTION

Polytechnics in Singapore were set up with the mission to train mid-level professionals to support the technological and economic development of Singapore. Republic Polytechnic (RP) is one of five polytechnics in Singapore entrusted with this role of enacting a practice-based educational system to prepare learners to contribute meaningfully to key industries and emerging fields of professionalism. Established in 2002 as Singapore's newest polytechnic, there was space for RP to conceptualise and implement an institution-wide pedagogical approach from the onset. RP strategically adopted problem-based learning (PBL) as the core pedagogy for all of its diploma programmes, leveraging its social constructivist principles to design its academic system and school infrastructure (Alwis, 2012). PBL was regarded as a suitable teaching and learning approach to meet the challenges of developing graduates with the desired attributes identified by the Ministry of Education (2009), namely confidence, self-directedness in learning and being an active contributor and a concerned citizen. These attributes have become ever more relevant in the present day with the ongoing restructuring of Singapore's economy that has resulted in traditional industries being replaced or made obsolete by new industries. Possessing the ability, adaptability, and foresight to learn new skills and foster a lifelong learning disposition after graduation, is key to surviving in this dynamic and complex environment. One of the oldest and largest schools in RP is the School of Engineering, which offers nine full-time diplomas in a wide range of engineering fields, including emerging fields such as aerospace engineering, supply chain management, and aviation management. The school adopted PBL to structure and deliver all of its engineering programmes, carrying out an extensive study to ensure that the development of its PBL engineering curriculum continues to meet the needs of the growing and diverse engineering profession.

As early as 2002, there were increasing calls for engineering education reform across the world. The following lists a summary of observations (Dym, 1999) on the common features of engineering education that are now being challenged:

1. Engineering curriculum has been designed to be highly structured, locked into overly long, serial course sequences.

A. Guerra et al. (Eds.), PBL in Engineering Education, 71–88.

2. The curricular organisation has been institutionalised within an engineering science model of engineering, and is delivered within academic cultures that clearly conform to the scientific research enterprise.
3. Engineering schools seem to convey to all students the idea that mathematics is the language of engineering.
4. Engineering schools have done a much better job teaching analysis than they have done teaching design.
5. Engineering schools conduct the engineering education enterprise in an environment in which each student's performance is largely assessed in individual terms, often in styles that encourage each student to see himself/herself as being in competition with her peers.

The consequence of such an entrenched pedagogical approach to engineering education is that engineering graduates often find it challenging to mathematically formulate a real-life problem they face in their job. They are uncomfortable in making decisions based on qualitative factors. While they are adept in analysis, they cannot synthesise a solution, which is more important for an actual engineering job. Because they study different engineering subjects in silos, and are assessed individually, engineering graduates lack opportunities to develop their communication and collaborative skills. In a nutshell, they are unprepared for the engineering profession they need to practice in when they leave the education system.

Many of the calls for engineering education reform from industry have focused primarily on issues related to the attitudes and skills required to prepare engineers generally for the profession, such as communication skills, teamwork, lifelong learning, and professional ethics. These efforts have also been supported by initiatives to change the learning environment in which engineering is taught and to rely less on traditional lecture formats and increasingly on the creative aspects of engineering using active learning to more effectively engage students.

The School of Engineering in RP has looked at various new engineering education formats in the world, including Studio for engineering (Little & Cardenas, 2001), Engineering clinic (Bright & Phillip, 1999), CDIO (Conceive—Design—Implement—Operate) (Crawley, 2001), Project-based learning in engineering education (Frank, Lavy, & Elata, 2003), and PBL (Wang, Fong, & Alwis, 2005; Wang, Hong, & Hisham, 2009). In recognising that student engagement is critical to the success of these new learning approaches, it identified the following factors as important considerations in engaging students: activation of students' prior knowledge, leveraging their personal experiences, and focusing on their desire to achieve certain objectives in their lives. Students learn best through engagement and active learning, and by using self-monitoring and reflection to guide their learning. All these elements are included in the design of engineering curriculum using PBL in the School of Engineering.

This chapter will describe the basic framework of PBL in RP and its adoption in the School of Engineering, followed by the framework of programme design for a three-year diploma course using the cases of two subjects as examples to explain their problem design, curriculum delivery, and assessment design. These case studies provide an overview of how engineering content can be organised and delivered through PBL, and how different subject domains are structured in PBL. The authors will also discuss the challenges encountered during the implementation of PBL and the measures taken to overcome these obstacles.

THE PBL MODEL IN REPUBLIC POLYTECHNIC

RP's engineering diploma programmes are three-year programmes, and students need to acquire 120 modular credits in order to graduate with a diploma. The domain knowledge is organised into modules, and typically each module carries four modular credits. Besides regular modules taken in school, all students are also required to complete a 20-week internship and a final year project during their final year of study. A typical diploma programme in the School of Engineering in RP is shown in Figure 1 to illustrate the curriculum structure.

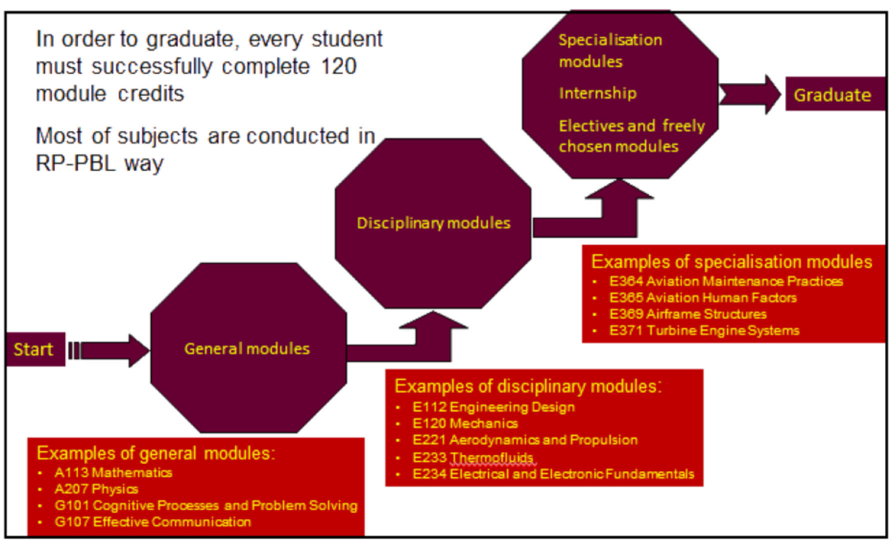


Figure 1. Curriculum structure of diploma in aerospace engineering

RP has adopted a unique implementation of PBL characterised by organising modules around problems. In this PBL framework, students work in small teams—guided by a lecturer—to resolve bite-sized problems (Yew & O'Grady, 2012) that typically span one learning day, or in some instances, a few weeks. The strength of this approach is that it offers students opportunities to reflect regularly on how they are learning. By virtue of students' frequent exposure to real world problems, concepts are introduced to and discussed by students in an iterative manner, requiring them to apply knowledge to unique or authentic situations. Students are required to think critically while learning collaboratively in responding soundly to each problem. All learning engagements are typically initiated by a problem statement or scenario which demands a response from student teams who research and consolidate their ideas and findings, culminating in a presentation, defence, and reflection by the students (Wang & Fong, 2007).

In RP's PBL environment, students are supported by pre-lesson activities and readings, encouraged to tap on their prior knowledge, be resourceful and think critically to co-construct knowledge with their peers and lecturers. Typically, a problem that is often multi-dimensional and inter-disciplinary, and reflective of an authentic work or life situation, is presented to students. Students then work in teams to develop hypotheses and solutions. Lecturers guide them through a range of resources, examples and questions. The lecturer is instrumental in facilitating the learning process and the students' metacognition. Throughout the day, students experience different phases of learning where they analyse the given problem, scope its learning issues, carry out individual research during self-study time, collaborate with their peers to consolidate and defend a response to the problem, and reflect on their learning approaches and outcomes. This approach is complemented by other instructional strategies such as seminars, demonstrations, laboratory work, and workplace simulations and attachments to broaden disciplinary understanding and industry exposure.

The iterative and immersive learning approach is RP's strategy to apply PBL to meet its specific mission of transforming secondary school graduates into technical professionals who are resourceful and responsive to real-time situations.

ADOPTING PBL FOR ENGINEERING

In light of these challenges faced by engineering graduates, a greater focus on learning application is critical to the success of professional education. In the context of the School of Engineering, problems are designed to initiate learning and to organise the inquiry and knowledge-seeking path, instead of the conventional approach that places an application problem after theoretical concepts or topics have been introduced. Besides promoting the development of critical knowledge construction, it also contributes to the development of skills and attitudes deemed important for professional practice in the engineering field. The main difference between PBL and other types of active, student-centred learning processes is its emphasis on weaving concepts by means of challenges in the form of problems relevant to students' future practice.

In the School of Engineering, the design of the problem statement is guided by the key principles of PBL, where the application of content understanding to novel situations and the activation of individual and collective prior knowledge feature prominently (Barrows & Tamblyn, 1980). The design of the learning activities for students is guided by Kolb's experiential learning model, which comprises four stages, as shown in Figure 2: Concrete Experience is followed by Reflective Observation that generates Abstract Conceptualisation. This leads to Active Experimentation that will generate a new Concrete Experience.

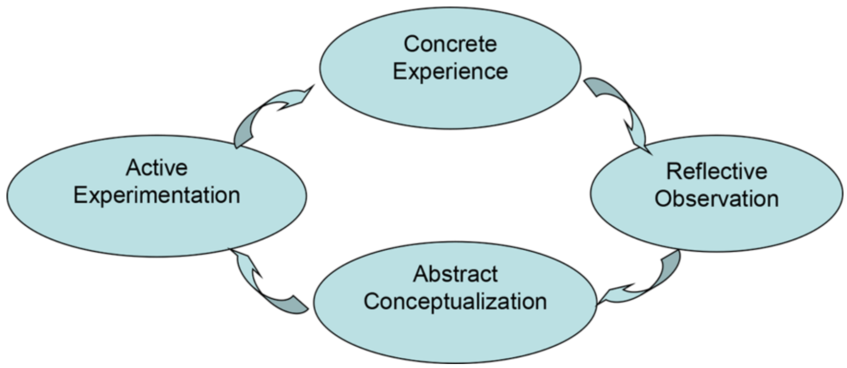


Figure 2. Kolb's experiential learning cycle (Kolb, 1984)

In the School of Engineering's PBL context, concrete experience in the model includes the past experience of students in their daily life, their experience gained through simulations in the classroom (Wang & Fong, 2006), and their hands-on experience gathered in laboratories and during field trips. With a well-designed problem statement, these experiences will trigger students' curiosity to explore concepts and ideas further. In the second stage, students try to figure out the reasons why a concept or idea is important and what they need to learn in order to understand it deeply. In the third stage, information about the concept or idea is collected through online resources, textbooks, and discussions. Abstract conceptualisation happens at this stage to take students to a higher level of understanding, with the support of scaffolding and help from the facilitator. Finally, in the fourth stage, students apply the concept or idea in problem-solving and experiment actively based on their deeper understanding. In this way, students are engaged throughout the day in active sense-making.

STUDENT ENGAGEMENT AND REFLECTIVE LEARNING

Student engagement refers to a "student's willingness, need, desire and compulsion to participate in, and be successful in, the learning process promoting higher level thinking for enduring understanding" (Bomia et al., 1997). In RP, three key elements in its PBL process play an important role in sustaining student engagement: the learning environment, problem statement and learning activities, and reflection, as shown in Figure 3.

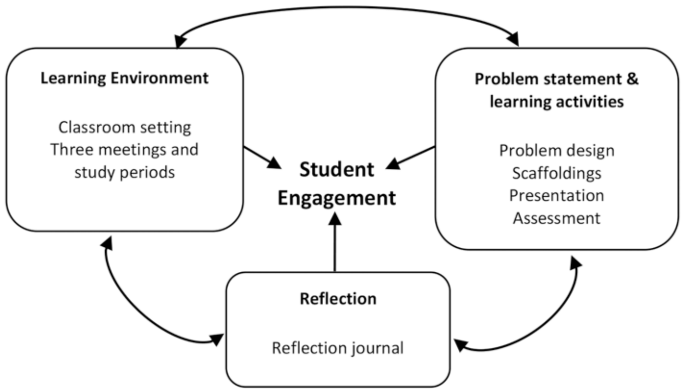


Figure 3. Three key elements to sustain student engagement in RP

Learning Environment

To engage students effectively, a conducive learning environment is essential. In a typical class of about 25, students are organised into teams of five and work within their team to respond to the given problem. The classroom layout is designed in such a way that five students congregate around a table. Students are expected to share their own ideas, conduct research, and develop possible solutions together with their teammates. Learning and social bonding among students are achieved through this collaborative classroom environment.

There are three learning phases in a typical PBL day. In the first learning phase, students must unpack and scope the problem to figure out the information they need to acquire to provide solutions to the problem. In the second learning phase, students select strategies and even test out solutions to the problem. As they navigate the various complex considerations demanded of the problem, they are expected to apply the concepts they acquire collaboratively. To help them understand and apply this new knowledge in a meaningful way, a lecturer acts as a facilitator to guide students in all learning phases. During the third learning phase, students present their response to the problem statement, and address questions from their classmates and facilitator to further refine their critical engagement and understanding of the concepts. The three learning phases are interspersed with two study periods for students to engage in self-directed learning and research.

Problem Statement and Learning Activities

The problem statement is the key to trigger students' learning, and is typically scoped for the duration of the specific lesson. The problem design is therefore a critical component of the learning process in guiding students on an inquiry path to help them evaluate a given scenario, identify, search and gather relevant information, work in teams, reason and justify to form opinions, apply various known tools, convince others and reflect regularly on whatever they do (Wang, Fong, & Alwis, 2005).

For this level of critical inquiry to take place, there needs to be a rethink in the way engineering fundamentals are taught. In RP's engineering curriculum, topics are re-organised as key ideas that define the subject. For each key idea, a context is crafted to invite and motivate students to question or consider the scenario. At this initial stage, the topical content is secondary and will get expressed as students formulate their responses. Each problem sets an achievable, meaningful, and relevant target for the PBL lesson, thus encouraging students to feasibly achieve milestones as they complete their learning activities.

The students in RP are predominantly secondary school graduates who have experienced a more traditional schooling experience, and thus may be unfamiliar with a PBL environment such as this. To help them, well-designed scaffolding is provided to guide them towards developing a more comprehensive and polished response to the problem statement. Soft scaffolding occurs more dynamically through skilful facilitation by the lecturer and through team discussions, while hard scaffolding is pre-planned with learner difficulties in mind in the form of worksheets, resources, and other learning tools that accompany the problem statement (Saye & Brush, 2002).

In the third learning phase, students are required to present and defend their solution in front of their classmates and facilitator, which enhance their communication and critical thinking skills. Presentations are a recurring and formal part of the lesson, and constitute a component of students' continuous assessment.

Students regularly receive formative feedback from their peers and lecturers so that they are reflective about their strengths and areas for improvement. They are also assessed through regular, continuous assessment grades underpinned by a broad assessment rubric that gauges the level of: (i) attainment of knowledge and skills; (ii) engagement with knowledge and skills (metacognition); and, (iii) engagement in collaborative learning. Additionally, students submit a learning/reflection journal after each lesson package or theme. Other forms of summative assessment include individual assignments, written examinations, project work and practical tests.

Together with summative assessments in the form of assignments and examinations, the holistic nature of these combined assessment strategies capture the process and outcomes of learning for students to demonstrate their depth of understanding and application of the required learning in a myriad of settings.

Reflection

Reflective thinking is an important part of PBL. As a teaching and learning strategy, the problem from a real world context becomes the catalyst for students to acquire both knowledge and process outcomes. This becomes most meaningful when students also engage in the process of reflective thinking, as it allows an individual to make sense of his or her experience, and provides him or her with an opportunity to challenge current thoughts and feelings about events and potentially change future behaviour. Reflection is engineered through a reflection journal (RJ) question or prompt after the third learning phase, so that student can reflect on their learning and consider how they can enact improvements for subsequent learning sessions.

PROBLEM DESIGN: CASE STUDIES

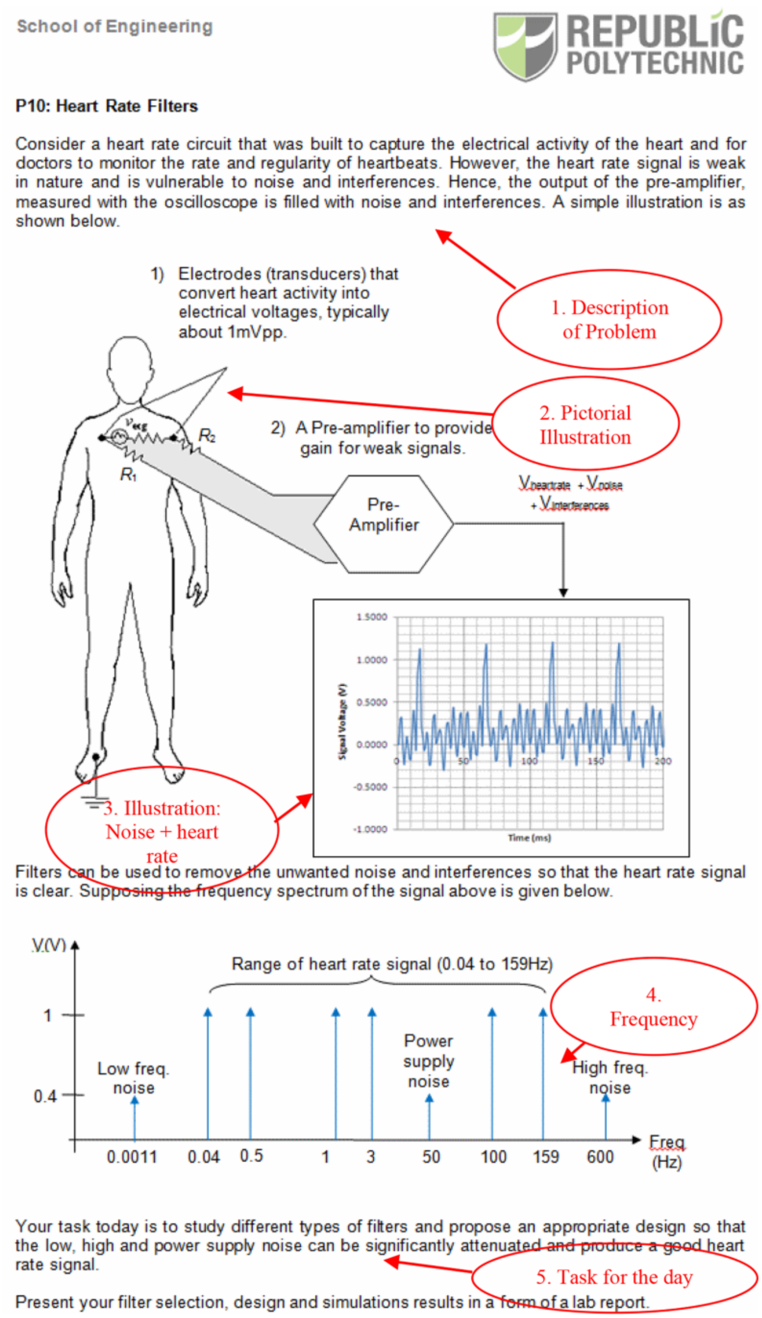
In this section, two real problem packages in the School of Engineering will be used to illustrate student engagement and reflective learning in RP.

Case Study 1: The Heart Rate Filter Problem in Linear Circuit and Control

The heart rate filter was one of the problems presented to students in the course module “Linear Circuits and Control”. The learning objectives for this problem were to design a filter and use the designed filter for a real application. It should be noted that students had acquired knowledge of basic filters and common types of filters such as low and high pass filters, higher order filters in previous problems.

The problem design begins with the formation of a problem trigger. Considerations during the problem design phase include motivational issues and authenticity. Whenever possible, the trigger should also be kept relevant to the industry to better prepare students for future challenges in the work place. These characteristics of problem crafting increase the student’s willingness and desire to participate in the learning process. In this case, the problem described the need for filters for the biomedical industry where heart rate signals obtained from electrodes are noisy in nature. Figure 4 shows the basic formulation and layout of the problem statement.

As discussed earlier, scaffoldings accompany the problem statement in guiding students in their learning. There is no restriction to the form of scaffold other than its relevance and usefulness. Soft and hard scaffolds can be used to support students in making sense of a new or complex concept or task. While most students may have an initial idea of how a heart rate signal is captured and displayed in medical devices in hospitals, they often lack the experience of capturing, processing, and displaying the signal. In the case of the heart rate filter problem, a scaffold was created using Microsoft Excel spread sheet software to better illustrate the effect of unwanted signals (noise) which distort a desirable heart signal (Figure 5). The scaffold simulated this experience as a way to facilitate students’ reflective observation.


School of Engineering

REPUBLIC POLYTECHNIC

P10: Heart Rate Filters

Consider a heart rate circuit that was built to capture the electrical activity of the heart and for doctors to monitor the rate and regularity of heartbeats. However, the heart rate signal is weak in nature and is vulnerable to noise and interferences. Hence, the output of the pre-amplifier, measured with the oscilloscope is filled with noise and interferences. A simple illustration is as shown below.

Filters can be used to remove the unwanted noise and interferences so that the heart rate signal is clear. Supposing the frequency spectrum of the signal above is given below.

Your task today is to study different types of filters and propose an appropriate design so that the low, high and power supply noise can be significantly attenuated and produce a good heart rate signal.

Present your filter selection, design and simulations results in a form of a lab report.

Figure 4. The problem statement of heart rate filter

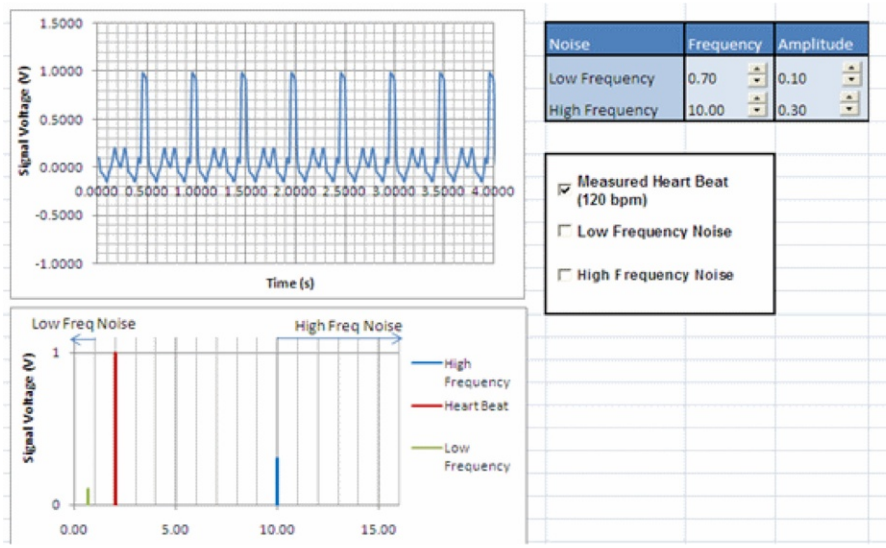


Figure 5. Scaffold created using Excel

The worksheet is another hard scaffold provided to students. The questions raised in the worksheet are carefully designed by faculty staff to help students logically build an understanding of concepts requiring a high level of abstraction. For this problem, students are typically able to figure out the formation of a band pass filter or a band stop filter by using a high-pass filter, a low-pass filter, and a summing filter, but they have difficulties dealing with notch filters. Questions in the worksheet help students move from simpler concepts to more abstract concepts, such as central frequency, quality factor, and the design of a notch filter. An academic team of experts adjusts the level of guidance according to prior knowledge and the experiences of students. Finally, the classroom facilitator is an important soft scaffold. In this problem, facilitators help students learn to use electronic design software (e.g. PSpice) to simulate their filter designs whenever necessary. The facilitator monitors the team dynamics in each group, facilitates self-directed learning of individual students, and ensures students are engaged throughout the three learning phases.

Through the context of filtering noises from heart rate signal, students are more motivated to explore the new concepts inherent in the problem. This can be seen from their reflection journals (RJ) after the class. Table 1 shows some of the responses from students who have experienced the “Heart Rate Filter” problem.

The reflection journal question was deliberately crafted to probe into student motivation for the day. Most students were able to relate the heart rate filter circuit design to the medical equipment used in industry. The problem scenario helps to trigger students’ interest in their learning, even for those students who may find it initially difficult.

Table 1. Reflection journal response quoted from student

Reflection journal question	*Students' responses*
How do you find today's problem on the application of filters? Do you think it will be beneficial to you?	Student A: Today I have tried my best to understand well and perform for this problem. I found that today's problem is not very tough and class discussion enhanced my understanding.
	Student B: I find that, by learning the day's problem about filters, give a better view and a larger scope on what are we trying to focus on about handling medical equipments (*sic*).
	Student C: To me it is very beneficial and important as it is regarding and how to handle the equipments (*sic*) stuffs. Not only that, it is also link to what we will do after we graduate. Therefore, having to learn and understanding the scope of how the filtering works, it benefits me for now and also during the working industry.
	Student D: As usual, the basic knowledge is very important. Actually we have learnt about filters in the Problem 7. From then on, each day's problem is going to feed the knowledge of filter step by step to us. So I link today's problem to the previous two problems. I think they are very helpful for me to understand the new knowledge.

Case Study 2: Arrival/Departure Scheduling Problem in Airside Operations and Air Traffic Management

Airside Operations and Air Traffic Management is a module offered to students in the Diploma in Aviation Management as a specialisation subject. While the earlier case study deals with theoretical understanding of biomedical electronics, the problems in this module require students to assume the role of an air traffic controller to help them develop the perspectives and approaches of these professionals. In the civil aviation industry, which is highly regulated due to safety and security concerns; the context of the problem triggers can often only be recreated through simulations.

Here is an example of a problem statement for this subject:

A simulation exercise has been set up in the Virtual Aerodrome Laboratory (VAL). 12 aircraft are scheduled to take-off and land safely at Changi Airport. Your objective is to safely and expeditiously direct the following aircrafts as shown in the flight schedule below:

Airlines	*Flight*	*Arrival/ Departure*	*Source/ Destination*	*Scheduled Time*	*Gate*
Singapore Airlines	SQ246	Arrival	Brisbane	0524hr	E4
Singapore Airlines	SQ305	Arrival	London	0605hr	F33
Singapore Airlines	SQ327	Arrival	Manchester	0718hr	A20

(Continued)

(Continued)

Airlines	*Flight*	*Arrival/ Departure*	*Source/ Destination*	*Scheduled Time*	*Gate*
Qantas Airways	QF81	Arrival	Sydney	1630hr	D35
Qantas Airways	QF35	Arrival	Melbourne	1725hr	C15
Emirates	EK352	Arrival	Dubai	0821hr	D49
AirAsia	AK774	Departure	Kuching	1145hr	C24
AirAsia	AK750	Departure	Penang	1145hr	C15
AirAsia	AK706	Departure	Kuala Lumpur	1210hr	D35
Tigerair	TR2106	Departure	Bangkok	1245hr	F52
Tigerair	TR2158	Departure	Phuket	1815hr	F56
Tigerair	TR2282	Departure	Bali	0715hr	F54

By the end of the lesson, students are expected to be able to: (i) convey relevant meteorological information to departing and arriving aircraft over radio using proper phraseology; (ii) issue the appropriate clearances to aircraft at various stages of departure and arrival; and (iii) identify the correct taxi way and runway to use in order to prevent runway incursions and excursions. In examining these learning outcomes, the reader will notice that concepts such as runway incursions, aircraft clearances, and meteorology are all incorporated into the lesson as information that students will need to acquire and apply in order to successfully complete the task of the day. Thus, to a student, "runway incursion" is no longer just a definition, nor are aircraft clearances simply numbers to be remembered for knowledge testing. Through this simulation, students get to see how these bits of knowledge from textbooks are actually relevant in the real world. Experience has shown that students are generally enthused when the lesson is conducted in the Virtual Aerodrome Laboratory.

The hard scaffolding strategy used in this lesson is provided through a laboratory sheet, which differs from a worksheet in that it contains tasks instead of questions. This laboratory sheet is designed to ensure students have the opportunity to practice the skills that they are supposed to acquire for the lesson.

As demonstrated by the two cases above, RP's adaptation of PBL emphasises learning engineering fundamentals through a well-designed context and a series of engaging activities which form the structure for students to work in small teams to deal with conceptual and practical issues. As students work through the problems, they identify their learning issues, gather the relevant information, communicate their ideas, and develop a possible solution to the problem. They would then need to present and justify their solution to the class. Through this approach, students are able to improve their capability to understand through learning how to learn.

CHALLENGES

Implementing a PBL curriculum in engineering subjects that are traditionally delivered via lectures invariably comes with its own challenges. The following section describes some of the challenges that the School of Engineering encountered in using PBL to organise and deliver the content of its curriculum.

Resistance from Students

> I saw PBL as something that took loads of time to accomplish very little learning. (MsPurtell, 2007)

The above quote captures the feelings a substantial group of students have towards their experience of PBL. RP is not alone in experiencing negative student perceptions about learning in PBL classes (Alessio, 2012). PBL, being a student-centred learning approach, requires students to actively participate in the learning process, where greater accountability for learning adds stress to students, with any negative feelings harboured towards the lesson impacting their learning. Hence it is important to identify the possible reasons for such resistance towards PBL:

Transition from didactic teaching to constructivist pedagogy. A period of adaptation is often required for a fresh secondary school graduate who enters RP. Having come from a learning environment where the teacher is primarily the source of knowledge and direction, students are often not confident with their own ability to figure things out independently.

Dysfunctional teams. PBL, being a pedagogy that is grounded in socio-constructivism, requires a team of students to work collaboratively to construct their own knowledge and understanding of the problem at hand. However the reality is students new to team work do not always know how to contribute meaningfully or equally, with personality differences and working styles resulting in poor team dynamics – this can lead to superficial learning as a way for members to manage these stresses. Linguistic or cultural conflicts are also sometimes causes of dysfunctional teams, especially in Singapore's multicultural context. Having to work in a dysfunctional team is hugely demotivating to the affected students and in the long run, if left unchecked, erodes the learning enthusiasm of a student (Scharf, Behdinan, & Foster, 2015).

Boredom. Boredom in the classroom is one of the most common emotions experienced by students. It is a negative, deactivating emotion (Pekrun et al., 2010) and has been shown to have a negative impact on students' motivation and academic achievements (Tze, Daniels, & Klassen, 2015). Dislike for the teacher, lack of involvement, and being under-challenged or over-challenged were found to be possible causes of boredom in class (Daschmann & Stupnisky, 2011). In the context of the School of Engineering, students may find PBL initially novel but subsequently repetitive as they go through the daily routine of problem analysis-solution-presentation. Compared with PBL models adopted by other institutions of higher learning which may either take a hybrid approach towards PBL or restrict their PBL implementation to selected modules, the higher frequency of repetitive activities in RP's PBL cycle can condition students towards a mechanical response towards the learning process and reduce their cognitive effort – this may lead them to feel "under-challenged" by the lesson. There are also days when students feel over-challenged by the problem given to them if the cognitive demands are higher and students do not have the sufficient foundational knowledge to engage in them. If these emotions are coupled with a dislike for the lecturer of the class, the student is likely to disengage from the lesson and boredom sets in.

Staff Recruitment

Resistance to a repetitive PBL model may also come from teaching staff, particularly when their personal learning experience with engineering subjects is through the traditional didactic approach. The challenges that the German Malaysian Institute experienced with their Engineering lecturers (Zin, Williams, & Sher, 2015) echo the experiences of RP staff, in that the role of a lecturer as a facilitator of learning places stressful demands on both technical and social competencies. The lecturer must be cognisant of individual students' level of understanding; be skilful at using verbal and non-verbal means to draw out discussions within the teams; and be constantly attuned to emotions and attitudes running within the teams so that conflicts can be pre-empted and managed (Jusoh, Isa, & Razali, 2015). It is always a challenge to recruit, train, and retain the "right person" for the job.

Business continuity. In the 13 years of implementing PBL, RP was affected by two national crises, which disrupted the normal conduct of classes: the first was the Severe Acute Respiratory Syndrome (SARS) outbreak in 2003, and the second was the H1N1 flu outbreak in 2010. During these two incidents, entire classes of students were quarantined at home for days at a time, with limited room for conducting replacement lessons due to the full-day structure of RP's PBL approach. The institution is currently exploring the possibility of allowing for greater flexibility in time-tabling to address such challenges, while ensuring that the quality of learning is not compromised.

EVOLVING PBL IN ENGINEERING EDUCATION

The PBL approach adopted by the School of Engineering has evolved partly in response to the challenges described above. It has broadened over the years to include other modes of implementing PBL while still retaining the essence of PBL. The following section describes three pedagogical variations that School of Engineering has employed for selected subjects.

Interactive seminar. Abdulwahed, Jaworski and Crawford (2012) noted an increasing trend in the use of student-centred learning methods to teach mathematics. In a pure constructivist-learning environment, mathematics concepts would be constructed by students through teamwork and discussions. However a study by Baxter, Woodward and Olson (2001) has shown that high-ability students are more likely to participate in discussions than low-ability students. Consequently low-ability students are less likely benefit from this method of learning mathematics. The learning difficulties for this group of students are further amplified by their lack of a firm foundation in the subject prior to entering the polytechnic. To help low-ability students overcome these hurdles, an integrated approach comprising of direct instruction and collaborative learning is adopted for Mathematics. This approach is referred to as an "interactive seminar", which is organised as bite-sized mini-lectures interspersed with practice questions, and which is followed by a collaborative learning session, where students work in smaller classes with their lecturer to delve more deeply into issues, identify misconceptions, and help them overcome their learning hurdles.

E-Learning. E-learning, or the use of information and communication technology to facilitate and support learning (Jenkins & Hanson, 2003), is also heavily leveraged as a strategy in the School of Engineering. In the context of PBL, e-learning is not synonymous with distance learning or computer-based training. Lesson objectives cannot be achieved by simply making course content available online without a means of communication between participants of the lesson (Violante & Vezzetti, 2014). The component of collaborative learning should still be present in an e-learning lesson.

One example of leveraging technology in teaching is Engineering Design, a foundational course for all first-year engineering students. It is conducted in e-learning mode to increase the authenticity of the learning experience. Design problems are abound in the real world, and in a subject such as Engineering Design, students are encouraged to identify design problems as they go about their day-to-day activities. Therefore there is little reason for restricting students to the confines of the classroom in this subject. Instead, students will think of an authentic design problem on their own and go through an iterative design process to generate a technical solution to the design problem. A physical product is created from the technical solution and finally students are assessed via a product presentation at the end of the semester. Face-to-face contact time with lecturers takes up less than 50% of the total curriculum hours. Contact hours are meant for lecturers to guide students on the use of computer-aided design software packages in the design studio. Apart from structured face-to-face sessions, lecturer-student and student-student interactions take place during weekly online discussion sessions.

Project-based learning. Project-based learning organises a student's learning around projects. However not any project can qualify to be included in a project-based learning curriculum. According to Thomas (2000), a project must fulfil five criteria before it can be considered an "instance of project-based learning" – these are: centrality, driving question, constructive investigations, autonomy, and realism. For subjects with complexities that require students to spend more time than what is available in a typical PBL lesson, project-based learning becomes a feasible alternative.

Aerodynamics and Propulsion is one such subject. The concepts therein are often multi-faceted and require a longer period of engagement for students to work through meaningful solutions.

CONCLUSION AND FUTURE PLANS

With contextualisation of abstract engineering concepts, engineering students can be more effectively engaged in their learning process. Properly designed problem triggers, hard scaffolds like simulation and worksheets and soft scaffolds like class discussion, and opportunities for self-directed learning all work together to ensure that engineering students in Republic Polytechnic are able to develop problem-solving skills and shape professional attitudes.

Beyond content acquisition, soft skills are critical in preparing engineers for the profession, such as communication skills, teamwork, lifelong learning and work ethics. Students immersed in PBL have experienced improvement in their understanding of engineering practices, and matured into independent learners with problem solving skills. Feedback from internship employers who take on engineering interns for up to a 24-week internship immersion programme has been very positive.

In the near future, the School of Engineering in RP will continue to explore other pedagogical variations such as cognitive apprenticeship, project-based learning and flipped classroom to complement its PBL approach, with a focus on authentic learning and authentic assessment through more integration with industry. This will provide more concrete experience for students and better prepare them for real world challenges when they graduate from their studies.

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6. PBL EXPERIENCE IN ENGINEERING SCHOOL OF MONDRAGON UNIVERSITY

INTRODUCTION

Mondragon University has been implementing PBL since 2002. On this date, a process was initiated in the development of the Teaching Learning Process, which emphasized the use of the project-based learning method.

This methodology brought with it a change in the focus of training, moving from content to competences, and broadening the learning objective to interdisciplinary technical competences, transversal competences, and the use of ICTs in multilingual environments. Changes in organization, space, assessment, facilitation, teamwork, etc. have also been necessary.

As PBL has proved to be highly motivating for students, it has been applied to all programmes in every semester in Mondragon University's engineering school. This chapter provides an overview of the process that has allowed the faculty to define the common PBL framework.

TRANSFORMATION PROCESS OVERVIEW

Context of Mondragon University

Mondragon Goi Eskola Politeknikoa [MGEP: Mondragon Higher Polytechnic School] is a non-profit integrated educational cooperative within the University of Mondragon. It is essential to point out that it is a mixed cooperative, made up of three different types of members in equal numbers: worker members, user members (students), and collaborating members (companies and administration).

In order to adapt our study and educational programmes to the new demands of society (Arana-Arexolaleiba, Zubizarreta et al., 2005), we have begun a process of creating a new educational model that coherently embraces the new degrees and curriculum. Our programmes (Bioengineering, Mechanical Design, Industrial Organisation, Electronics…) are designed in accordance to the set of competences needed in each programme which must be achieved through active methodologies; identified competences such as problem solving, project management, team-work, could be learned by means project based learning (PBL).

The new teaching practices needed in this process, and in the process itself, are not new for those who make up MGEP. In 2000, we began a process that used

A. Guerra et al. (Eds.), PBL in Engineering Education, 89–102.

active teaching methodologies in the classroom. The design of active teaching-learning activities should be as close as possible to natural situations, so that the students learn by doing (Dewey, 1975). External experts and internal teaching staff communities of practice led this first experience. This gave the teaching staff the opportunity to develop the skills needed to manage the new activities and new forms of intervention, which were very helpful when we began a thorough redesign of our educational programme.

Transformation Process

We will, at this point, describe the steps taken to bring our qualifications into conformity with the new guidelines, and the results that were obtained.

The adaptation of our qualification to the EHEA guidelines, included in the Bologna Declaration, was applied to all teaching methods and materials (Zubizarreta, 2006). We considered features such as (critical thinking, student engagement…) that might have an impact on the training of our students. To this end, a model that would help us achieve the goals contained in the Bologna Declaration was created. With the model's structure open, a participatory process and shared responsibility led to a real and close involvement of the teaching staff, which allowed us to adapt and renew our educational product.

The primary goal of MGEP is to prepare profiles with markedly professional character in an industrial environment. Our historical link with this industrial world has been the core in conforming this view. Thus, at the beginning of this process we started with a diagnosis of the training needs of all the students and collaborating partners.

The first stage (Figure 1) of the diagnosis began with the analysis of the context and the professional environments that were to receive the graduates, of the mission of the university, and of its strategic plan. This is what Mario de Miguel (De Miguel Diaz, 1995) calls the criterion of legitimacy, which is the result of the contrast between the goals of the degree and the aims and mission of the university. The guidelines of the Ministry of Education and Science and the programme stated for such certification were also taken into consideration. This is what Zabalza (1998) calls the external frame of reference, i.e., standard conditions that are to be met.

To carry out this diagnosis, a collection of data on the current situation from different sources (companies receiving graduates, former students, and employment demands by the graduated Engineers) was proposed as part of a research work (Zubizarreta, 2006). In order to determine the expectations of the employers, and the opinions of the alumni, we gathered all possible data related to the level of competence (level 1 not necessary, level 4 mandatory) that all engineers must achieve, i.e., data that would help us identify the competence that the engineering graduates should have. We have identified that our students had good technical

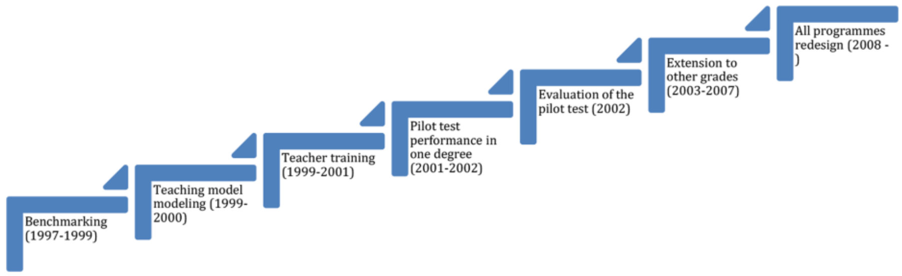

Figure 1. Change process

competences but deficiencies in transversal competences (problem solving, project management, leadership…), foreign languages and values.

One of the training characteristics offered by MGEP is its relationship with nearby companies and its involvement in the collaborating activities among them. The distinctive characteristic of the qualifications in MGEP is that the students have developed their projects in those companies in the last year of a four-year cycle of technical engineering. This training period in a company is highly valued, not only by the students themselves, but also by the companies. In addition, project work was an adequate method to learn transversal competences and values. With this background, the proposal made by the teachers was to introduce learning processes based on projects (PBL) in the classroom, generating the necessary context for team projects.

In our previous educational model, the teaching was focused on the subjects. The students learnt individually and socialization was not encouraged. The teacher played the role of an expert in one discipline, using a technique of showing the related concepts in order, and instructing their students in the solving of tasks and exercises, along with laboratory training. The learning content in their presentation in the classroom was mono-disciplinary. As for the context, they were provided with all necessary resources for an on-site learning.

Thus, a transformation was required to move from a subject-focus learning to PBL. To achieve this ambitious, but necessary, objective, a process began by modifying the elements integrated in learning to meet the new challenge, i.e. the context, the students, the teacher, and the content. None of the following aspects were prepared for a change: the spaces, the distribution of instructional time, the teachers' actions, the procedures for the students' work, nor even the contents. Therefore, the decision to modify the learning elements led to further decisions, such as where project work would be done (laboratories, classrooms, library, computing room, workshops…), how to distribute the instructional time (to this point, they had been based on one two- hour session a day per subject, combining different lessons), what training the teachers needed in order to manage this new methodology, and how to prepare students (who were used to lectures or to watching from their desks the teachers' demonstrations or to following guided practices in laboratories). Now, the students are encouraged to move around, search, test, build, and experiment. Additionally, we had to choose the interdisciplinary content needed to work on each project, while we had previously worked on mono-disciplinary content, in which issues were treated from the perspective of the subject, with a limited view.

KEY ELEMENTS OF THE TRANSFORMATION

Active Methodologies: Project Based Learning (PBL)

One of the key elements that promoted the change process was the introduction of PBL. To do so, we started designing a framework to include PBL; a collaborative learning context, in which students would work in teams, where students would share their doubts and solutions. A teacher, highly skilled in the discipline, would act as the students' learning facilitator. The contents of interdisciplinary learning would assist the student by making possible an exchange of know-how among subjects, achieving a global vision and professional roles defined in the professional profile. As for the setting, the university should provide spaces where teamwork would be possible, such as laboratories and computing areas. Students should be encouraged to spend more time in such facilities and less time at their desks.

Project organization creates a link between training and research, since a project can be defined as a thorough investigation of something worth studying (Díaz Villa, 2002). This creates a connection between two of the university functions, namely research and training. This new approach requires the adaptation of organisational structures, content, facilities, activities' time distribution, etc.

In this context, MGEP teaching staff established an action plan. It was agreed that the needs of a transitional period where all the necessary intermediate steps would be taken in order to achieve the target model (Fink, 1999; Díaz Villa, 2002; Kolmos, 2004). One of the first steps was to implement PBL in an experimental programme (Electronics) in the 2nd and 3rd year. Later on, PBL was implemented into more programmes (Computer Science, Telecommunication…).

At that time, the main goal was to train teachers on the use of PBL. A staff development programme was set up for those teachers who took part in the new experience, which was monitored by Aalborg University. As Anette Kolmos says:

> … The PBL has never been developed on the basis of a theory or particular theories, but has been developed from the pragmatic level, where the trial and error over a period of time has been predominant. (Kolmos, 2004, p. 79)

After the transitional period, in 2008, all the programmes were redesigned. Not only did we implement PBL in all programmes, but also int all bachelor and master degrees' semesters.

Transversal Competences

The strategy followed by MGEP was to develop contexts where transversal competences and values would be developed along with the specific disciplinary competences, embodied in the educational intervention methods.

The meaning of the word competence can be found in (Bunk, 1994). Bunk, a member of the Work Studies Association and business organisation in the German Federal Republic, talks about the competence-based training, defining it as: "possesses professional competence: one who has the knowledge, skills and attitudes necessary to practice a profession, one who can solve professional problems in an independent and flexible manner and is capable to assist in his/her professional environment and work organization".

The professional training meets two goals, as seen in Echeverria (1993).

- A technical competence achievement (scientific elements and specific profession knowledge, working techniques…)
- Transversal competence achievement (interests, values, behaviour on the social structure of the job position or task).

At this point, the focus of attention was on those competences non-specific to a job position or task, what we have called transversal competences.

When we talk about transversal skills we are referring to those skills that, despite not being specific to a job position or profession, are necessary to be performed on the level required by the job in a competent manner. At the same time, they should allow a continuous adjustment to the changing labour market.

A more global way of defining transversal competences is to understand them as a set of wide range of knowledge, skills and attitudes which affect different tasks, and which are developed in different situations. Therefore, they can be generalised and be transferred, they can perfectly be achieved from experience, and they can result in an efficient professional execution.

In response to the M.U. mission requirement, which describes the needs of our students to be trained in technical and transversal competences, a group of teachers established the values and the culture of the university (www.mondragon.edu). They also set the transversal competences that should be developed by all the students in each degree of M.U.

For that reason, a study, which was analysed and approved by the Directors' team, was undertaken. It endowed a strategic character on the development of the transversal skills of the subject curricula.

The selected transversal skills became one of the key elements to be cultivated in the degrees we offered to our students in MGEP. The selected competences were the following: thinking orientated to problem solving, decision making, effective communication, teamwork, global vision, leadership and learning to learn.

In order to develop these competences through the different degrees, two approaches were defined: one that would be set up in the short term, and the other in the medium term.

- Short term: Insertion of transversal competences in the curriculum with external help. Each of the selected transversal competences would be especially identified with one or several subjects from the programme, and it would be in the context of these subjects where we would work. The trainers who took part in the development of these competences would meet two different profiles: on the one hand, the expert in the specific discipline where the transversal competence was to be developed, and on the other hand, the expert of the transversal competences responsible for the students' theoretical training as well as for helping the teacher of the specific subject.
- Medium term: Disregarding external support, it is the teachers of different disciplines who work on the transversal disciplines. This would make the teachers highly involved in the development of such competences.

PBL MODEL OF ENGINEERING FACULTY OF MONDRAGON UNIVERSITY

PBL Model

The engineering school of Mondragon University has a common educational framework for all the diplomas. In this section, we are going to describe the PBL model. Not only are we going to focus on PBL progression, size and duration, but we will also focus on the expected learning outcomes, problem cases scenarios, academic staff role and assessment.

PBL Progression, Size and Duration

The engineering school of Mondragon University has a common educational framework for all the diplomas. It is a mixed model where there are activities related to courses at the beginning of the semester, and an interdisciplinary PBL at the end of the semester. In most cases, there are 5 courses per semester 3 of which are involved in each PBL. The PBL can take between 20% and 50% of all the ECTS (European Credit Transfer System) during each semester. In the first year's semesters it takes only 20%, but this percentage increases reaching 50% in the 3rd year (Figure 2). The 4th year project is an individual real-world project. It can be done in a company or in a research lab.

As an example, the 2nd and 3rd semesters are structured as follows: the first 12 weeks are lecture based, and the last 6 weeks are interdisciplinary PBL. The lecture based period starts in the second week of September and finishes at the end of November. The PBL period starts in December and finishes at the end of January with a PBL exam. In the PBL period there are no lecture courses.

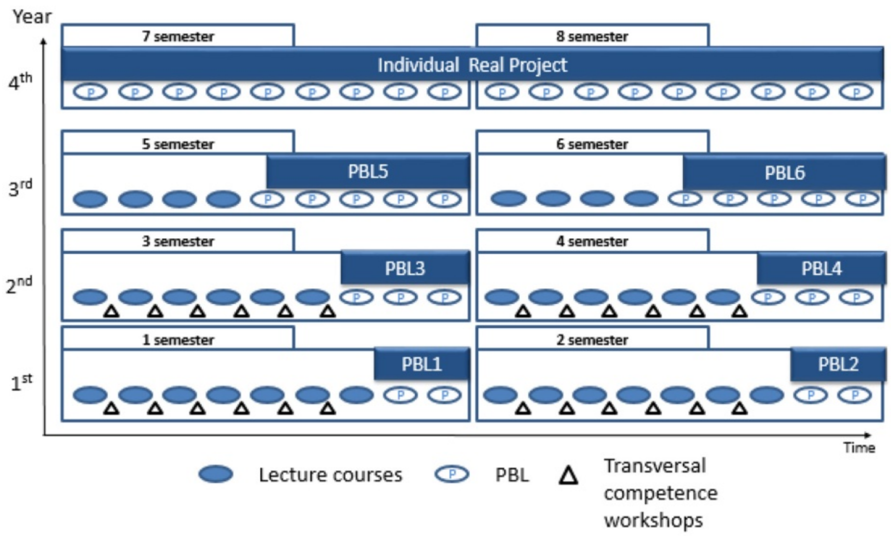

Figure 2. MGEP curriculum structure

Intended Learning Outcomes (ILO) Involved in the PBL

Each course has a set of Intended Learning Outcomes (ILOs). ILOs are defined as "learning results" which have to be measurable in the academic context. When defined, the teacher should verify that, on the one hand, it is related with a least one competence defined by the education ministry, and on the other hand, it can be achieved in the given time frame. In addition, it must be formulated as follows: Verb + object + condition, where the verb was taken from SOLO taxonomy (Biggs & Tang, 2007). For example: "Design a computer based programme respecting the user specification".

As an example, the list below shows the expected ILOs in PBL3 in two particular programmes: Computer Sciences (CS) and Telecommunication (T). The ILOs are grouped into transversal and technical ones.

Transversal Skills

- Solve problems by means of state of the art knowledge evaluating and selecting the most appropriate solution.
- Organise and manage project work using ICT tools.
- Present project work in English using digital tools and multimedia.
- Write a project report describing how and why they have done it using the appropriate writing rules.

Digital Systems

- Design a complex digital system using basic digital components.
- Argue decisions taken during design process using theoretical basis.
- Implement a digital system, using computer assisted design tools.
- Debug an implemented digital system using simulators.

Computer Network

- Build communication links between different sub-networks.
- Create sub-networks by means of VLSM and CIDR segmentation techniques.

Programming

- Understand and use the concepts of class and object.
- Understand and use the concepts of inheritance and polymorphism.
- Understand and use the knowledge management of exceptions.
- Develop applications that employ libraries and frameworks.
- Develop applications in a form that facilitate the development of their parts in parallel and their subsequent integration.

Signal Theory (Only for Telecommunication)

- Analyse periodic signals using mathematical models using time and frequency domain techniques.
- Filter periodic signals using frequency based techniques.

Systems (Only for Computer Science)

- Create users and groups assigning permissions to directories both in Windows and Linux.
- Install and configure DNS servers in Windows and Linux and DHCP in Windows.
- Install Samba in Linux using files.
- Identify mapping tasks of network folders and security backups of key files in Windows.

The SOLO taxonomy was proposed by Biggs and Collis in 1982. This theory analyses how far the student has been able to grasp the information in terms of identification of relevant aspects and their relationship/integration. There are 5 levels: Each level represents a different rearrangement of mental schemes. Whenever more mental schemes are restructured, more relations are made among the concepts, and in consequence, deeper learning is achieved:

1. Pre-structural (Bits of unconnected and nonsense information)

2. Uni-structural (Identify, recite, follow a recipe)
3. Multi-structural (Classify, combine, enumerate)
4. Relational (Apply, solve problems, relate, compare, analyse)
5. Extended-abstract (Create, generalize, hypothesize, theorize, evaluate)

A preliminary overview of ILOs level in terms of SOLO taxonomy shows that most of them belong to level 3 and 4 (see Table 1); 15 ILOs out of 17 in Telecommunication and 16 ILOs out of 19 in Computer Science. The most characteristic verbs are: solve problems, organise and manage, design, argue, develop, analyse and create.

Table 1. ILOs vs. SOLO taxonomy

SOLO level	*CS*	*T*
1	2	1
2	1	1
3	12	11
4	4	4
Total	19	17

The number of ILOs and the level of each ILO (in term of SOLO taxonomy) which students are expected to achieve at the end of PBL constrains the problem case scenarios, the students work, the teachers' roles and the assessment as we will see in the next sections.

Problem Case Scenarios

Each student team can have the same or similar types of problems where a series of technologies are needed to solve them (each team is composed of 4–6 students). The group of teachers involved in the PBL defines problem scenarios. For example, a PBL3 problem case scenario could be:

> A chain of hypermarkets, established in several countries, want to automate the process of cleaning the floor by means of remotely controlled robots. To do this, they are interested in a system consisting of the following elements:
>
> - The robot is able to communicate with a central station. It can receive and execute orders (start, stop, pathway…) and it can return its report.
> - A program installed in the central station can compute the path from the initial to final position. This program can also display the robot's state and its position in real time.
>
> You are asked to design and implement a technical solution.

Student teams start analysing the problem and they continue searching for the bibliography. Once they start having a more clear idea about the project, they make a first solution proposal. They must consider what they should solve, but also the ILO they need to achieve, the available material and the time frame allocated to the project. This project proposal is presented to all the teachers involved in the project (1st milestone) and they receive the feedback. In the next phase student teams create a more detailed design and start implementing parts of them. In the 2nd milestone students should present, again, all the design and preliminary results to the involved teacher where they receive feedback. During the last phase of the PBL, students finish their experiment (Figure 3), collect and analyse the results, and document. The 3rd and final milestone is the PBL exam, where students should present their work.

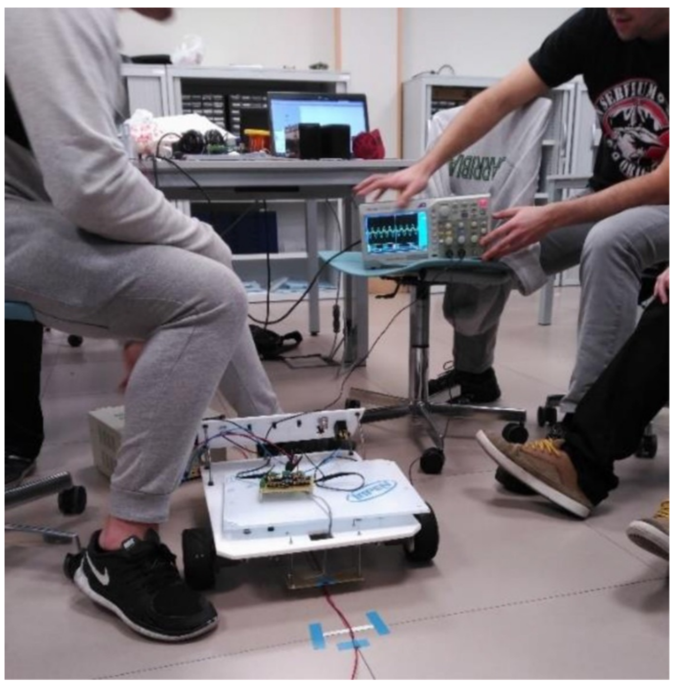

Figure 3. Robot

Academic Staff and Facilitation – Teacher Roles – Tutor and Expert

There are two roles involved in the PBL: the tutor and the expert.

On the one hand, the tutor is responsible to facilitate the process during the supervision sessions. As a guideline to help the supervisor's role, we have defined the main tasks she or he has to carry out during those sessions:

- Facilitate project organisation and project planning.
- Facilitate team-work meeting (at least once a week).
- Facilitate report writing.
- Facilitate students' team in everyday work, whenever they ask for it, or if there are conflicts, or in case they need provisions.
- Verify that the team is on the track.
- Formative and summative assessment of transversal competences.

On the other hand, the expert acts as an expert or project consultant. The students can meet the expert whenever they need. The expert is also responsible to assess technical skills.

Before the PBL period, we have six two-hour workshops where teamwork, literacy, planning, report writing, oral presentation and of course PBL methodology are introduced. These workshops were created in order to deal with transversal competences, and are generally distributed during the lecture-based period. On the first year, we start introducing the basis of PBL methodology, team-work, structure of scientific writing … On the second year, we concentrate on project organisation and planning, reflective journal, coherence and argumentation in scientific writing.

Assessment

At the end of the PBL there is a PBL examination. The PBL is assessed and graded by the expert and the supervisor. Each one considers a set of ILOs, similar to those defined in Table 1. To carry out the assessment, the activities are organized in four main blocks (Table 2):

- Writing report: Students must deliver a writing report at the end of PBL. This report is used to assess both technical (by the expert) and transversal competence (by the supervisor). The report can be written in three different languages: Basque, Spanish and English. The language that needs to be used in each PBL is defined at faculty level, and this applies to all the programmes of the faculty.
- Project presentation (Figure 4 (a)): Each team of students make an oral presentation of their work to all the semester teachers (Experts and supervisors). The languages used in the presentation are the same as those for the writing report.
- Solution demonstration (Figure 4 (b)): Students make a demonstration of their solution in front of all the assessors (Experts and supervisors). Partially technical skills are assessed at this moment. It is a product-oriented assessment.
- Individual technical exam: Each student responds to the expert's questions. In most of the cases it is an oral exam, but it can also be a written one. Different settings are used: in an individual setting the student is alone with the expert(s); whereas in a team setting, the PBL team is in front of the expert(s), however, only one of them is allowed to respond the expert's questions. Some experts prefer to make a written exam. In the latter, all students do the test at the same time and in the same place.

Table 2. PBL elements of assessment

	ILOs		Teacher role	
	Transversal competence	*Technical competence*	*Expert*	*Supervisor*
Writing report	X	X	X	X
Project presentation	X		X	X
Solution demonstration		X	X	
Individual exam		X	X	

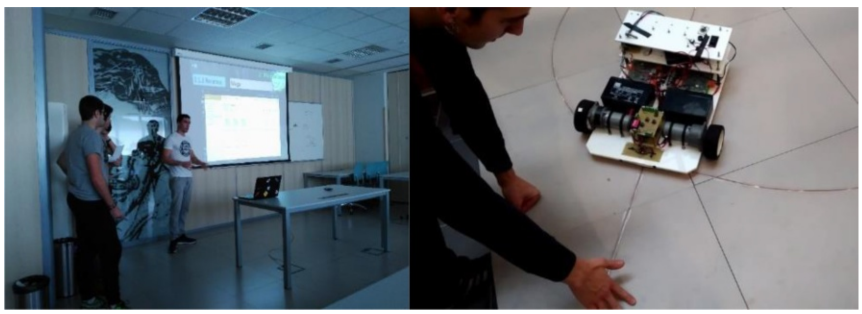

Figure 4. Presentation (a) Demonstration (b)

DISCUSSION

This chapter has shown a specific PBL implementation. The engineering school of Mondragon University has 15 years of experience in implementing PBL (Arana-Arexolaleiba, Zubizarreta et al., 2005). Nowadays, PBL is an institutionally accepted method, and it is used in each and every programme and semester (Arana-Arexolaleiba & Zubizarreta, 2015). In this process, several things have been changed. On the one hand, the role of the teacher has changed. In this model, teachers assume the role of facilitators as well as the role of experts. On the other hand, students' roles have also been changed becoming the centre of their own learning processes.

Another aspect included in the teaching-learning process is the combination of knowledge from the different disciplines within the project. For this, the teamwork carried out by the teachers of the programme and more specifically of the semester of the programme has been paramount.

One of the achievements, among others, has been to raise students' motivation. Students are involved in a very satisfactory manner with the aim of the project.

As for the improvement issues that are perceived, we can point out the assessment of PBL. The large number of students per teacher and the lack of training of the latter in the supervision of the students is seen as somewhat weak. It is at this point that the need to train teachers in methods and strategies of assessment and facilitation emerges.

Another aspect of near future improvement is related to the integration of theoretical and practical knowledge of students. At this point, it is very important to start a process of strengthening the students' capacity to reflect on what was done during the project.

As a general conclusion, the authors claim that the institution is in the middle of a changing process, going from a more classical learning approach towards a socio-constructivism learning approach. There is still room for improvement by creating a more positive learning environment based on socio-constructive learning theories, where a deeper learning approach can be achieved by giving more relevance to the learning process itself. Hamiza Wan Muhd Zin, Williams and Sher (2015) stres40s that this process needs time and the lecturers need to equip themselves with facilitation skills.

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7. ESPRIT PBL CASE STUDY

INTRODUCTION

Since its launch in 2003, Esprit (Tunisian private school of engineering) has been concerned with the striking finding of the non-adequacy of the engineering training with the labour market needs. Indeed, most Tunisian schools of engineering put a strong emphasis on delivering theory-based training, which focused mostly on competencies related to the discipline of engineering rather than other life skills or transferable skills that learners might need when they integrate into the professional world.

Esprit was aware from the beginning that there was a very limited, if not a non-existent, collaboration between universities and company managers, leading often to a discrepancy between what is required from the employers and what was delivered to engineering students in terms of their university studies.

The school was strongly aware that to meet the demands of the current job market, future engineers needed to be trained differently. The slogan "*former autrement*" (training alternatively) shows that Esprit's vision was to distance itself from other learning providers. A special attention was paid to the practical aspect of the students' training with the main challenge to train a new generation of engineers who are strongly competitive and employable.

So along with the formal academic training provided, Esprit had success implementing active learning pedagogy with the aim to foster a more conducive learning setting. As shown below, these are some of the decisive measures undertaken by the school for a more effective training:

- Shifting towards active learning pedagogy.
- Implementing a constructivist approach to learning (Wilson, 1996).
- Providing a course programme based on more practical aspects that match the needs and requirements set by company managers.
- Encouraging students to carry out mini-projects in the first 3 years and one major project in their 4th year. The purpose behind these projects is to encourage learners to apply the knowledge and skills they acquired through their course, hence, to reinforce and deepen their learning. In their fourth year, students are expected to work in pairs on a mid-term (semestral) project worth 4 ECTS.
- Initiating and maintaining collaboration with different stakeholders involved in the learning process in order to identify the different needs. For this reason,

A. Guerra et al. (Eds.), PBL in Engineering Education, 103–118.

a Strategic Orientation Board involving business managers in the field of ICT was established to gather more information regarding the labour market requirements. Companies strongly insisted on the importance of soft skills such as communication, project management, teamwork, and individual autonomy.

- Encouraging strong peer- collaboration between teachers in order to foster the exchange of expertise and experience.
- Initiating and implementing mentorship programmes for the benefit of learners and tutors alike.

TRIGGERS FOR CHANGE

The reform has not happened overnight but rather it has followed a far-sighted strategy and process. These are some of the reasons that have encouraged Esprit to initiate the reform:

- The unemployment rate in Tunisia has encouraged the orientation towards the international market and therefore the need to develop the learners' soft skills for stronger employability. The rate of unemployment has highlighted one major issue that students might have acquired the knowledge of engineering but have not learnt how to be engineers, hence, the reason for new methods and approaches of teaching and learning.
- The advent of mobile phones, the internet, and other high technologies. These external drives have also contributed to the different changes that have occurred as far as learning/teaching methodologies are concerned. The use of the different types of technologies outside and inside the classrooms, have reinforced the belief that schools cannot keep on teaching students the same way. "The connected generation" needs and expects more challenging ways to learn. Thus, any traditional methods would only slow down their progress and hinder their motivation.
- Feedback from fresh graduates / interns showed that the initial training offered by Esprit in terms of projects and in-class tasks did not meet the employers' requirements. The feedback highlights some weaknesses as far as collaborative work is concerned.
- The initial training has not effectively helped the learners to acquire a responsible attitude towards learning. The teacher was still the disseminator of knowledge by delivering the course content and suggesting the classroom activities (projects or practical work) and therefore there was an urgent need to challenge the students' comfort zone.
- Projects (based mainly on pair-work) are restricted to what is presented and acquired in class. Despite the fact that projects have had a strong impact on the students' working habits, methods, and approaches to learning, there was still a claim that the situation had not reached the requirements of the different companies that had been approached by our students when carrying out their

graduation project for engineering studies or when applying for a position within the same company.

- The urgent need to standardize the procedures and practices in terms of teaching methods and assessments within all Esprit campuses.
- The political events that occurred in Tunisia from 2011 following the Tunisian revolution have strongly contributed to many changes across various areas in the Tunisian culture and obviously education is one of them. Indeed, a huge drive for change within the classroom has been a logical consequence to the extent that students have become more vocal in calling for educational reforms.

Due to all of these factors, we started to examine a reform of our practices, which led in time to the adoption of PBL.

THE ORIGINS OF PBL AT ESPRIT

The interest towards Problem-Based Learning approach started in 2010 following the visit of Professor Radhi MHIRI (hereafter Professor R.M.) from ETS (Montreal, Canada), who introduced PBL to the Director- General as well as to the Director of Studies. It was clear from the start that this approach matches the school's philosophy and vision on how engineering programs should be delivered. Another meeting was set up by Management to invite Professor R.M. once again along with his colleague Denis Bedars; a prominent professor in Education Science at Sherbrooke University (Canada) and an international expert in the field of PBL.

A three-day workshop was then organized during the spring holiday in March 2011, a couple of months after the Tunisian revolution. Over 20 instructors from various disciplines took part in this workshop to gain insight into this new approach. The workshop turned out to be a positive experience for the participants who expressed the need for similar opportunities. The same year, the director of studies had a training week at the Polytechnic School of Louvain-La-Neuve (LLN) in Belgium.

This first- hand initiation to PBL has led to its implementation in the common core level in this case, first year students. It was restricted to a computer-programming course that was planned for the second term of the same academic year. This pilot scheme turned out to be successful with students and teachers alike.

A succession of workshops and seminars have taken place ever since. In May 2012, two professors of mathematics organized a seminar for the teaching staff followed by a workshop involving all instructors. Finally, they met with mathematics instructors who had previously shown some reluctance towards the implementation of PBL into their courses.

Recommendations have been put forward to administrators to adopt PBL across the curricula, as it was time for more inclusive actions. This led to the appointment of a committee, chaired by the director of Studies and composed of Heads of Departments to pilot this reform and put forward a schedule for the official implementation of PBL. After the decision was made, the official incorporation of PBL into our curricula began in September 2012 with computer and telecommunication engineering programs. The 1st and 4th year classes were the first to be impacted by this reform. Various sub-committees were set up to deal with various aspects of this reform as shown in the Table 1.

Table 1. Tasks of the PBL sub-committees

Year 1	*Year 4*
Identifying the learning outcomes	
Reorganizing the syllabi by reducing face-to-face contact	
Problem situations design	Proposal for project topics (Multidisciplinary work)
PBL Welcome Week: Introduction to PBL	

Over the period June–July 2012, the committees worked against the clock before the summer break in order to prepare the official documents to put forward for approval to the School's Scientific Board.

Students were not involved at any stage of the process prior to the reform. 1st year students were briefed on this approach before the start of the term, during the initiation week, while 4th year students were informed of this reform during the announcement of the project topics and group formation and this was soon after the start of the term.

During the first year of PBL, some parents expressed concerns regarding the effectiveness of this new approach. Their skepticism was mainly related to the new teacher's role in the classroom compared to what it was before the implementation of PBL.

ESPRIT PBL MODEL

Students joining ESPRIT right after obtaining the baccalaureate examination have to spend 5 years until graduation. They collect 300 ECTS (European Credit Transfer System), 60 ECTS per year. Each semester takes 16 weeks applied as follows: 14 weeks of study and 2 weeks for examination. The second semester of the 5th year is earmarked for an internship carried out in a business setting.

Curriculum Organization

The curriculum is mainly organized in integrated projects (IP) and integrated courses (IC) that include lectures, tutorials and practical work.

The first academic year starts with an induction/initiation week (PBL-Welcome Week) which aims to prepare the students for the new working environment i.e. icebreaking and collaborative work. The actual course begins on the second week with many forms of active pedagogy.

From semester 2 to semester 8, integrated projects are planned in line with the integrated courses.

At the end of each year, a PBL Bash event is organized to showcase the accomplishments produced by students from all levels and specializations combined.

In Table 2, the curriculum organization is mapped across the five academic years.

Table 2. Timeline of the 5 years

Years	*1st semester*		*2nd semester*	*End of year*
1st	PBL-WelcomeWeek	I-Courses	I-Courses I-Project	PBL Bash
2nd	I-Courses I-Project		I-Courses I-Project	
3rd	I-Courses I-Project		I-Courses	
4th	I-Courses I-Project		I-Courses I-Project	
5th	I-Courses		Internship for graduation project	

In what follows, we will depict the 'Welcome Week' and the 'Project Bash'.

IP (integrated projects) and IC (integrated courses) specifics will be further explained in the following section.

PBL-welcome week. Coming straight from high school, freshmen needed to be initiated to the active pedagogy. It was then agreed upon that during their first week at Esprit, their tutors would schedule many activities for them. We intended to give them the opportunity to work in groups through games, courses, panels and projects (Louati, 2016).

On their first day, a general gathering is organized at the auditorium, all of the 300 students are asked one single question: "Why did you choose to study at Esprit?"

They have to select an answer from a specific list: recommendation, pedagogy, training course, future employment, training, environment, location, advertising or your own criteria (Figure 1).

Answering this question was the first step to initiate the students to teamwork. In the beginning, they were asked to answer the question individually and then after working in groups of two, then four, then 64, until we got one answer from all of them.

Performing this task with a bigger group each time, meeting new people, having to choose the group's name, discussing new ideas and at the end, choosing one answer, made the students discover this new way of being in class, they realized

Figure 1. Welcome week

that they can learn through this new teaching approach. They did not merely take a ready-made solution, they actually had to face different 'problems' and find out the solution with the help of the group. Working together was possible, it came with hardships but it was interesting and instructive.

Day two of the PBL-Welcome Week, students are handed the topics of the project and the various tasks they have to perform:

- Deciding on the group's name
- Creating the logo
- Researching engineering skills
- Choosing the product
- Creating a poster and an advert
- Writing the report

All these tasks were programmed and organized in a way that we could guide the students and show them what PBL is all about; how they can work in groups and get to the solving problem stage.

Table 3 depicts the stages of the PBL-Welcome Week.

PBL bash. At the end of the academic year, we organize the PBL Bash.
This event is held at Esprit to showcase the projects and the performance of students from all fields and levels combined. Students, organized in teams, have been assigned a booth where their projects are on display to instructors, families, friends and companies. The local media is also invited (Figure 2).

For freshmen (1st year students) and juniors (third year students), this event is the last project assessment; they will have to show their production and its main idea to a jury panel.

However, it is different for the second and fourth year students, only the best groups will have the chance to take part in the PBL Bash.

Table 3. Stages of the PBL welcome week

	Activities
Monday	1-Meeting with other team members. 2-Brainstorming to the engineering skills. 3-Brainstorming ideas to offer innovative products.
Tuesday	Establishing a task schedule for the project development.
Wednesday	Conferences on : Project management; Engineering Skills; Innovation
	Cultural event for integration.
Thursday	1-Detailed Product Description 2-Discussion of the video clip storyline 3-Discussion of the content and form of the poster
	Submission of reports
Friday	Presentation of the poster (at the beginning) Delivery of the advert (at the end of the session).
Saturday	Closing ceremony Award distribution

Figure 2. PBL bash

This event is a great experience for learners. For the first year students, it is a chance to have an overview of the other student's projects and for those who study electromechanical and civil engineering, since they do not study systematically with the PBL pedagogy yet, it is a chance to discover how other students do it.

Teaching Methods

Integrated courses. They are called integrated because the teacher can combine lectures, tutorials, and practical work in the same session to classes of 32 at most. Different kinds of teaching methods can be used: teacher-centered, Problem Based Learning or other types of active pedagogy.

Teacher-centered approach. Lessons are knowledge transmission-oriented and mainly driven by the teacher. The majority of the activities are precise and well structured. They are performed individually, with limited interaction among students.

Problem situation (ProSit). It's a Problem Based approach where students are presented with a real-life situation where they are required to understand, analyse and solve a problem and come up with an effective solution. Students will not only acquire the knowledge but also the competencies needed to solve such problems (Denis, 2011). The principle of group work is emphasized in this context with 4 to 6 members in a team. Problem situations are carried out through 3 sessions, 2 of them are held in the classroom. From the very beginning, students are presented with the problem situation. In groups, they have to work collaboratively to understand the problem, reformulate it with driving questions, and then come up with various hypotheses. Students are then required to work individually by researching and answering several questions. They will have to show their work to the class the following week. It is a synthesis of the problem itself and the suggested solutions (Alaya, 2015; Said, 2015).

Miscellaneous active pedagogy approaches. The learning process is based on the interaction between the students and their instructor, on the one hand and the students with each other, on the other hand. This environment emphasizes the role and responsibility of the student. For instance, in a flipped classroom, (blended learning vs. backward approach) the students themselves will have to deliver the course before the tutor (Alaya, 2016) Several activities and assignments are conducted by groups of 4 to 6 students with a team-based learning approach (Bousbia, 2016; Khojet El Khil, 2016; Potter, 2016).

Integrated projects (Project Based Learning). IP are set of coordinated and controlled activities undertaken to achieve measurable objectives compliant with specific requirements of time, cost and resources (ISO-10006, 2003). The project lasts one semester and is conducted by groups of 5 to 6 students under the continuous supervision of a facilitator who monitors the progress of various stages of the project implementation.

The issues addressed are generally open, complex, and poorly structured, but in direct connection with the business needs of the industry collaborating with facilitators in project proposals. Actually, learners and instructors alike work on existing projects ordered by companies.

Under the PBL approach, the project is not the purpose of learning, it is the means. It is not confined to the simple application of knowledge already acquired in previous courses but it also allows for the development of new skills and the acquisition of more knowledge. For each project, a set of learning outcomes is defined. In addition to skills that can be reached by classical courses, the project-based learning provides opportunities to the students to climb to more sophisticated skills such as: project management (time management, planning, organization, leadership, risk management, etc.) and teamwork (motivation, delegation, communication, conflict resolution, etc.). Participating in many projects, prepares students for project management in the engineering workplace (Gharbi, 2015).

In line with the project, some courses are relevant to the project and could be evaluated in the project and others are independent and are measured separately.

Compared to the ProSit*,* the project is more time-consuming and presses for several interrelated problems that entail multidisciplinary prerequisites from several previous and present courses in addition to new research. That is why we call them integrated projects. The students need to master task breakdown with an appropriate workload for each member and subsequently good integration of their finished work to achieve the final solution. The project process is less structured for both facilitators and students, which offers more opportunities for the try-and-fail approach.

Curriculum breakdown. Figure 3 shows the pro rata of each pedagogical approach within the five-year curriculum. The annual 60 ECTS have been divided up between teacher centred, active, and PBL pedagogies. When a course uses more than one approach, the corresponding ECTS are split among each one.

Assessment Methods

Assessments vary according to the learning methods used in the classroom. In a traditional setting, the learning outcomes are mainly assessed through written examinations. In an active pedagogy context, oral and practical assignments are added to the written examination (Boud, 2007).

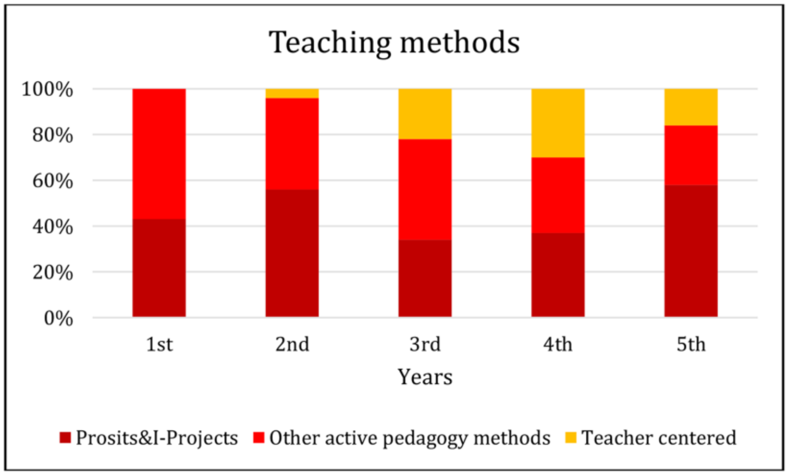

Figure 3. Teaching methods

Assessments in a PBL classroom using ProSits take place on a weekly basis through a written report describing the problem situation as well as the suggested solutions. The final grade of the course is calculated on the basis of the sum of all the grades obtained from the ProSits.

Assessing the integrated projects remains the trickiest type of assessment given the length of the period and the number of ECTS allocated to these projects.

Like with other pedagogical approaches, in PBL projects, we need to design an assessment method that accurately measures the degree of achievement of the learning outcomes the students are supposed to acquire and implement later on. These learning outcomes are clearly defined in a rubric that facilitators use to observe the students' progress during all the stages of the project. An online collaborative platform provides the communication means between learners and facilitators. At the end of each stage (3 to 4 per project), feedback is provided to students and a grade is assigned for each stage. In the final assessment, a technical evaluation panel verifies the integration of all the contributions by the team members and another jury evaluates a marketing presentation of the product resulting from the project.

The formula to calculate the project's final grade has evolved year after year since the adoption of PBL. The key challenge remains the assessment of teamwork. In this sense, we must see to it that:

- Good students will not give up on teamwork and not focus exclusively on the individual part of the assignment.
- Good students will not be penalized by their poorest-performing team members.
- The weakest students will not benefit from the usually higher group grade.

To obtain the project ECTS, FinalScore must be greater than or equal to 10. Otherwise, the project must be redone during the summer holidays.

FinalScore = IndivScore* **I**% + GpeScore * **G**%.

I and G are used as parameters to adjust the final score in favor of the project's objectives.

IndivScore and GpeScore are obtained by calculating the average of grades obtained during the different steps. The GpeScore will be the same for all the team members. However, the IndivScore takes into account each student's participation in the project.

Adjustment of parameters (I & G)

To make sure the individual achievements and skills are validated first, when the IndivScore is below 10/20, group score is not taken into account (I=100%; G=0%) and FinalScore will be the IndivScore. Then the project is not validated.

In order to reduce the impact of GpeScore on indivScore, G is set at 10%. So if the (GpeScore-IndivScore) is greater than 3, then the FinalScore will be (IndivScore * 90% + GpeScore * 10%).

To avoid that the individually good students neglect teamwork, the GrpScore will be considered at 40%. So If (IndivScore–GpeScore) is greater than 3 : (I=60%; G=40%). FinalScore will be (IndivScore * 60% + GpeScore * 40%).

Figure 4 shows a recap of the employed formulae.

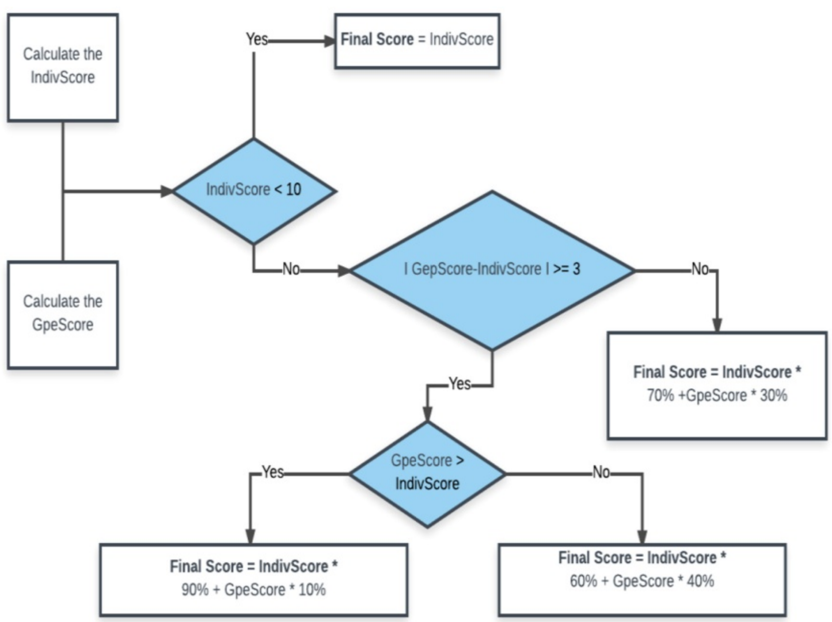

Figure 4. Project score calculation

CHALLENGES

To implement PBL at Esprit, many adjustments have been made and various measures taken to ensure a smooth transition from active learning to problem-based learning (Bettaieb, 2013).

Table 4 shows a comparison through 14 criteria between the practice of active learning before the adoption of PBL (2003–2011) and the one after (2012–2016).

Table 4. Before PBL vs. after PBL

		Before PBL	*After PBL*
1	Relation to problems	Problem Solving	Problem-based learning
2	Number of team members	2 members	5–6 members
3	Number of projects per semester	Many mini-projects/ semester	One project per semester
4	Type of problem	Well structured subject	Ill-structured
5	Complexity of the problem	Medium	High
6	Relation to the other courses	Application of the previous courses	New learning outcomes with the project
7	Competencies engaged	Mono-disciplinary	Multidisciplinary
8	Number of subjects	One subject for a pair of students	Five various topics (One for each team in the same)
9	Students role	Respond to the detailed and precise needs	Contribute in detailing the needs and in choosing the methodology and tools
10	Supervisor role	Coaching	Coaching and assessing
11	Number of supervisors	A coach for each pair of students	2 or 3 per class (5 teams)
12	Company role	Not directly involved	Providing subjects and coaching
13	Assessment	Final exam	Continuous and final exams
14	Repeat session	At the end of the year	The next year

Other measures encompass many areas from the physical setting i.e. the classroom to students' attitude towards this new learning approach through modifying the curriculum itself.

At times, we have run up against some particular challenges.

Six key issues in PBL implementation were identified and actions taken to alleviate some of the difficulties resulting from PBL implementation. This has been broken down as follows:

1. Reluctance to PBL: At the beginning, students were reluctant towards PBL implementation and could not accept the new role they have been assigned. They barely accepted the fact that a lesson starts with a problem when they were used to resolving problems after acquiring the necessary tools and knowledge that would enable them to do so. With PBL, the learning steps are reversed starting with a problem statement that would lead eventually to knowledge acquisition.
2. Conflict Management: Working in teams of 5–6 students has caused various problems, especially interpersonal ones. Conflicts arise when deliverable deadlines draw near and when some of the team members start doubting about each other's commitment and contribution. There are two main reasons for conflicts between team members:
   a. Team-working: itself as most students have been used to individual work and therefore they have little tolerance to each other's shortcoming
   b. Peer assessment: the assumption that only the teacher is entitled to assess the learners prevents their receptiveness to critiques. For these reasons, a need to build teamwork skills among students through more collaborative teambuilding/ training sessions and therefore peer-assessment is found to be necessary.
3. Inadequacy of the workspace: One of the most important characteristics that define a PBL classroom is group work: Students work with their peers to solve problems and come up with solutions. Neat rows of forward-facing desks are not suitable for this approach. In a PBL classroom we would see 5 teams with 5 to 6 students each. This number is unlikely to work comfortably in a traditional setting. For these reasons, the physical setting should be designed and organized in a way that supports collaboration with all what it entails as noise and movement. Classroom should be designed to fit this context for a more collaborative work.
4. Initiation period: A single week of PBL commonly called PBL Welcome Week has been proven to be not enough to engage learners in the PBL process. A mandatory PBL course is necessary to ensure that students grasp the whole concept and steps of PBL. A course that allows them to master all the different steps of the process and more importantly to be aware of what their expectations are in terms of their own roles as well as their teachers' role in the classroom.
5. A call for a stronger professional coaching: Closer contact with companies in order to provide a wide array of project topics and ProSits (problem situations) is now believed to be essential. This measure can be achieved through downstream and upstream effort done by the school to guarantee a constant professional collaboration between the students and the companies.
6. Staff development: Accustoming faculty members to new active pedagogy methods was not a walk in the park. It required an ongoing training effort We called upon the PBL Aalborg Center's expertise to host 2 instructors for a weeklong

training on the Aalborg PBL model. Later on, two workshops were organized in 2013 and 2015 hosted by Erik de Graaff, Mona Lisa Dahms, and Lars Peter Jensen from Aalborg UNESCO Centre. These workshops covered various themes such as problem crafting, facilitation, assessment, PBL Model, etc. Two extra workshops on assessment and flipped classrooms were later set up with Denis Bedars and Radhi Mhiri from Sherbrooke and ETS. Apart from international guest professors, senior faculty members regularly hold training sessions on PBL.

PBL PROSPECTIVE PROJECTS

Five-Year Out Assessment of the PBL Experiment

Students who started out PBL in 2012–2013 will be seniors (5th year) in 2016–2017. In semester 2 of 2016–2017, they will head for in-company internships at the end of which, they will defend their work. Student-oriented and coach-oriented questionnaires and surveys will be introduced to get deeper insight on the benefits and limitations of PBL and this from various perspectives. Host companies (especially those who formerly hosted other Esprit students) will be approached for their feedback.

Expanding the PBL Experiment to Other Specialties

We are about to extend the use of PBL to other specialties with the necessary adjustments needed to fit the specifics of each specialty; Civil Engineering and Electromechanical Engineering. Esprit is currently launching a Business School due to start in 2016–2017. PBL will be adopted within a few courses.

Creation of a Teaching and Learning Center

The purpose of this center is to serve the following functions:

- Evaluation of the student learning by the students themselves.
- Instructor training (facilitation, assessment, problem and project crafting, etc.)
- Instructional material production such as MOOCs, media content for flipped classrooms, online resources.

Hosting Conferences in Engineering Education or PBL

Our faculty members have begun to publish research on their application of PBL. These initiatives must be encouraged to better disseminate our model and obtain constructive feedback for improvements. We should also consider inviting conferences in the field of engineering education, active pedagogy or PBL to take place within the school. It will give all of our staff opportunities for exchange and establishment o partnerships with other colleagues around the world.

Students' Involvement

The student activity was restricted to the usual assignments (problem solving, project delivery within teams). We intend to empower students and make them more proactive: updating e-portfolios, carrying out self-assessment, peer assessment, and playing the role of facilitator in PBL sessions with lower classes.

Alumni Involvement

Alumni are considered to be the key product of any university and their role can be very positive for new students. Esprit has a network of more than 3500 alumni. We are currently reaching out to them to get them more involved in topic proposals and in the evaluation panels.

International Cooperation:

We have agreements with foreign universities to launch joint projects. It is an excellent opportunity for instructors and students alike to benefit from the know-how and experience of their international counterparts.

CONCLUSION

The PBL approach proved to be effective in providing future engineers with the best training possible. It fosters their skills for complex technical problem resolutions through multidisciplinary projects and teamwork. It motivates students by immersing them in real-life situations and by offering them many opportunities for autonomy and control over their own learning.

The PBL approach does not fit in one universal and unique model. It is applied in different institutions; each one designs and tailors its own model, starting from the existing ones and adopting the approach during its deployment. Feedback from students, parents, instructors, administration and businesses is a useful input for eventual changes and adaptations of the model, hence the importance of a continuous assessment of the approach.

The teachers' research work, experience and feedback are also a great way that allows for the continuous improvement of this teaching/learning model.

The adoption of PBL at Esprit has affected the curricula, and workspace, as well as teaching practices inside the classroom. The reform has also involved all stakeholders: students, faculty and administration. PBL has been introduced after a period of planning and preparation such as the PBL initiation period designed for 1st year students as well as the training offered to Esprit instructors. The involvement of the administration proved to be essential since it has contributed constructively to the success of the reform.

The deployment of PBL has not restricted the use of other teaching and learning methods but quite the contrary, other teaching methods such as active pedagogy or the traditional method are still applied across Esprit engineering programs (Alaya, 2016). Indeed, combining different teaching approaches can only reinforce PBL for a viable sustainability.

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8. PERSPECTIVES ON ENGINEERING CURRICULUM CHANGE

Problem based, project organised learning (PBL) is a learning methodology that has been used to reform engineering education. The implementation of PBL is mainly used to address engineering challenges like globalization, sustainable development, employability, technological innovation, whereas young engineers are equipped with knowledge and competencies needed (Du, de Graaff, & Kolmos, 2009; Graaff & Kolmos, 2007). Furthermore, engineering education organisations and accreditation bodies recognize the need of such competencies in engineering programs (ABET, 2016; ENAEE, 2012; National Academy of Engineering, 2004, 2005; UNESCO, 2010). This book compiles seven examples of curricula change and PBL implementation, including strategies, drivers, challenges and perspectives the authors go through. With this book we hoped to inspire engineering education community, institutions and educators to transform their practices and promote an education of quality for the 21st century.

In this chapter, we summarize and discuss aspects of change of engineering curricula and PBL implementation based on examples described. We particularly emphasise:

- Drivers, approaches, strategies and levels of change,
- Groups of people involved,
- Diversity of PBL models,
- Present challenges

DRIVERS, APPROACHES, STRATEGIES AND LEVELS OF CHANGE

In this section, we discuss the type of drivers for change and relate them to approaches, strategies and levels of change. We understand drivers as factors that constitute the main reasons to change engineering curricula from being traditional, and lecture-based to more active and problem based. Furthermore, these reasons shape and determine some aspects of the change process as well as resources allocated, challenges faced and people involved.

A. Guerra et al. (Eds.), PBL in Engineering Education, 119–133.

Drivers for Change

We categorize the drivers into four groups depending on their origin. The four categories are: educational, professional, political and societal.

Educational drivers have their origin in factors intrinsic to institution such as students, learning, curriculum development, etc. Examples of educational drivers are found in all chapters namely increase of students' intake (Mohd-Yusof, Chapter 2; Bettaieb, Chapter 7), need to increase students' motivation and meaningful learning (Lima et al., Chapter 3). Professional drivers refer to factors originated in practice of the engineering profession and work place. In the PBL models, this type of driver refers to the need for competencies, both technical and transversal, demanded by the industry and workplace. For example, Johnson and Ulseth state:

> […] the traditional engineering programs were not changing the learning activities needed to develop the outcomes being asked for by industry and by the accreditation board. (Johnson & Ulseth, Chapter 4)

Even though the factor is the need for a new qualification profile, which is also related with learning process, its origin comes from industry. In this sense, the profession defines the learning objectives, defined in the curriculum.

Political drivers refer to reasons related to policies namely from governmental, accreditation boards, etc. These also determine what kind of learning objectives should be achieved and type of qualification profile students graduate with. An interesting example is posed by Wang et al. (Chapter 5), who state that PBL "*was found as suitable learning methodology to development the attributes found relevant by the Ministry of Education*". Two other examples are from European universities, University of Minho (Lima et al., Chapter 3) and Mondragon University (Arana-Arexolaleiba & Zubizarreta, Chapter 6) where the Bologna Declaration had a relevant role to foster curriculum change and innovation. In 1999, through the Bologna Declaration, 48 European countries united political efforts to build an educational area where higher education systems are continuously adapted, making them more compatible and strengthening their quality, with main goal to increase staff and students' mobility and to facilitate employability (European Higher Education Area, n.d.).

The last group of drivers refer to societal drivers, which are related to social factors that indirectly impact the engineering profession and educational systems. In this sense, rapid technological development and innovation bring a new generation of students to university (Mohd-Yusof, Chapter 2, Bettaieb, Chapter 7), which pushes for curriculum change. Table 1 summarizes the main drivers.

In sum, the PBL models compiled in the book present several drivers to curriculum change and implementation of PBL. Even though the different cases are driven by common factors, they are also contextual and influenced differently by the approaches, strategies and levels of curriculum change.

Table 1. Group of drivers and examples reported in the PBL models described in the book

Drivers	*Examples*
Educational	Increase of students intake Increase students' motivation Promote meaningful learning
Professional	Need for technical and transversal competences Employability
Political	Bologna Declaration and EHEA guidelines Washington Accord Tunisian Revolution Attributes defined by Ministry of Education
Societal	Changing/ restructuring economies Rapid technological development and innovation brings a new generation of students

In the first chapter, Kolmos refers to three university modes and problem scopes according to the overall curriculum aim (Kolmos, Chapter 1). In mode (1), academic university, the overall aim is to construct theoretical learning and the process of knowledge. This is known as the "traditional university". University mode (2) is characterised as being market driven, focusing on collaboration with companies and development of skills and knowledge for practice. Last, the university mode (3) calls for re-building of the curriculum and a combined approach of mode 1 and 2. In this mode, university is driven by a vision for a better and more equal society.

Based on the drivers, overall aims and collaborations presented, the PBL models compiled in the book navigate between university mode (1) and mode (2). Nevertheless, the process change involves different strategies, calls for re-structuration of curriculum organization and re-definition of learning objectives, roles, and facilities of the learning environment. Figure 1 illustrates the relationship between the university modes and the examples of PBL models.

In the following sections, we address other aspects such as strategies to change and collaborations which emphasise the relation between the curriculum change drivers and university mode 2.

Approaches, Strategies and Levels of Change

Two main approaches to change can be identified: bottom-up and top-down. These approaches depend on who, and where, the incentives to change have their point of departure (Guerra, 2014). Therefore, in the cases described in this book, there are change processes with bottom up approaches which were initiated by academic staff and later involved, or get support from, top management. Example of bottom-up approaches described in this book are: Process Control and Dynamics course

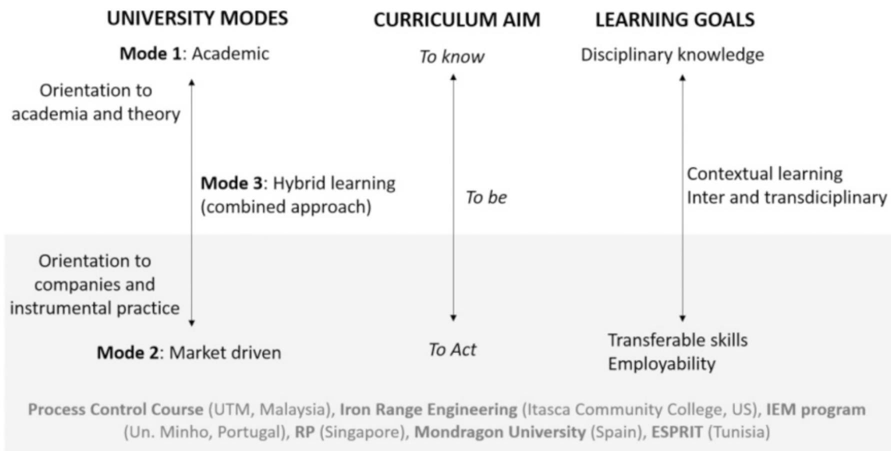

Figure 1. Relation between university modes, curriculum aim and learning goals (based on Kolmos, p. 3) and examples of PBL models (situated in grey area)

at Universiti Teknologi Malaysia (UTM), Malaysia, (Mohd-Yusof, Chapter 2), Integrated Master degree in Industrial Engineering and Management, at School of Engineering in the University of Minho, Portugal (Lima et al., Chapter 3), and Iron Range Engineering Model from Itasca Community College, US (Johnson & Ulseth, Chapter 4), where group of educators come together with aim to develop and implement new curricular models. On the other hand, (Wang et al., Chapter 5), Arana-Arexolaleiba and Zubizarreta, (Chapter 6) and Bettaieb (Chapter 7) described examples of top-down approaches, where the change process departures from top levels (e.g. government policies, management, etc.). For example, Wang et al. (Chapter 5) provides an example of how governments can change the institution's mission as it is stated:

> Polytechnics in Singapore were set up with the mission to train mid-level professionals to support the technological and economic development of Singapore. […] PBL was regarded as a suitable teaching and learning approach to meet the challenges of developing graduates with the desired attributes identified by Ministry of Education.

Bottom-up and top-down approaches have different impacts and they are both important to determine strategies and levels of change. While top-down approaches allow mobilizing and allocating resources, bottom-up approaches provide highly motivated academic staff and students to support the change.

Besides the change approaches, the PBL models described are also examples of different strategies and levels of implementation. Kolmos (Chapter 1) identifies three types of change strategies and levels of PBL implementation. They are: (i) course strategy in an add-on curriculum; (ii) integration strategy; (iii) re-building strategy. The latter strategy refers to macro-level change, including all levels of institution and aiming to a progressive and systemic integration of PBL culminating in a re-building of institution's vision, frameworks and provisions. Close to re-building strategies are Republic Polytechnic (RP), ESPRIT and Mondragon University, whereas PBL is implemented in all engineering programmes. These examples have taken a holistic approach to curriculum change; however, they do not necessarily show a more open approach to problems and critical reflection, which are core aspects of university mode (3) and re-building strategy. Furthermore, these institutions also have political drivers as main point of departure for change. On the other hand, University of Minho and Iron Range Engineering presents meso-level strategies, whereas it is at program level where PBL is implemented, relating the learning of content through courses and seminars and its use in project work. Lastly, an example of PBL implemented at course level is brought by Mohd-Yusof (Chapter 2), at UTM, where the author describes her initial motivations and experiences with PBL in the Process Control course. However, with institutional support and resources (namely for staff training) the courses become problem-based throughout the entire semester, and spread to other courses and disciplines. Figure 2 summarizes the relation between the types of approaches, strategies and levels of change based on Kolmos (Chapter 1) understanding.

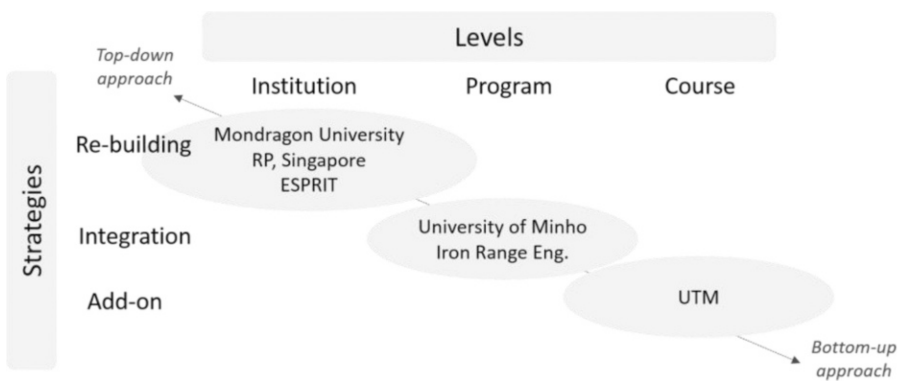

Figure 2. Relation between approach, strategy and level of curricular change and PBL implementation compiled in this book

In sum, different drivers trigger the change, leading to different approaches, strategies and levels of change. The examples described also show that, independently of the type of strategy, the PBL implementation implies deep re-structuration of courses, programs and institutions whereas: (i) new types of collaborations among academic staff, students and other stakeholders take place; and (ii) new models according to learning principles, objectives and vision of what engineering education should be are developed. In the following two sections, we refer to groups of people involved in change and the diversity of PBL models developed.

GROUPS OF PEOPLE INVOLVED

Undoubtedly, change depends on people whereas they take initiative, create opportunities, assume roles and/or support change. Change also involves different groups of people, namely students, teachers, managers, companies, alumni, and/or experts. In this section, we summarize examples of people involved in PBL implementation, the roles they assume and their relations with change approaches. In this book, the PBL models present different approaches, i.e. the point of departure and incentives for change, involving different groups of people. For example, in the bottom up approaches (i.e. UTM, University of Minho & Iron Range Engineering) the point of departure for change involved mainly educators and academic staff, who formed teams and sought support and resources to initiate the change process.

Khairiyah Mohd-Yusof (Chapter 2) states that she started by experimenting cooperative learning methodologies with a group of students in her course and later on got support from the institution management to form a task force to reform the entire course of Process Control, and train other faculty members from other disciplines at UTM. Lima et al. (Chapter 3) and Johnson and Ulseth (Chapter 4) refer to a group of teachers and educators who felt the need to change their programmes. At University of Minho, in the programme IEM, a group of teachers started the journey of implementing active learning in their courses, while the Iron Range Engineering program gathered a group of educators from across the US to develop and implement new curricular models. These two examples highlight not only the importance of forming teams to initiate change but also highlight the need to have support from management and funding as Lima et al. (Chapter 3) stated:

> The project was funded by the Rectory of the University and in March 2005, the group of teachers (authors of this study) and a number of other teachers from different departments and schools of the University of Minho got together to implement a first experience of Project-Based Learning in the second semester of the first year of the IEM program. These experiences were supported, since the beginning and during the following years, by educational researchers that also integrated the coordination team and made the difference, both in regard to the implementation and evaluation process and also the research carried out in the following years.

The above also stresses that teams' formation moves beyond the programme boundaries and might include researchers, experts and educators from other departments and even institutions – interdisciplinary teams. These teams also represent an important role in change process by validating the model through evaluation research-based activities.

While in the bottom up approaches, academic staff team-up to get top-level support and funding, in the top down approaches management nominate academic staff, form task forces and allocate resources to initiate change. Wang et al. (Chapter 5), Arana-Arexolaleiba and Zubizarreta (Chapter 6) and Bettaieb (Chapter 7) bring examples of top-down approaches to change as well as examples of the people involved. Also in these examples academic staff remains a core part of change by starting to experiment with active learning methodologies and design new curriculum models. For example, Arana-Arexolaleiba and Zubizarreta (Chapter 6) mention:

> External experts and internal teaching staff communities of practice led this first experience. This gave the teaching staff the opportunity to develop the skills needed to manage the new activities and new forms of intervention, which were very helpful when we began a thorough redesign of our educational programme.

Besides the core staff involved in initiating and developing new curricula, there are also other groups supporting and collaborating this process. These are mainly alumni and companies. In the cases here presented, these external groups of people participate in the change by providing feedback regarding the competencies needed for engineering, and real problems and contexts for students' learning.

Figure 3 summarizes groups of people involved in change and implementation of PBL as well as some of the roles assumed based on examples compiled in this book.

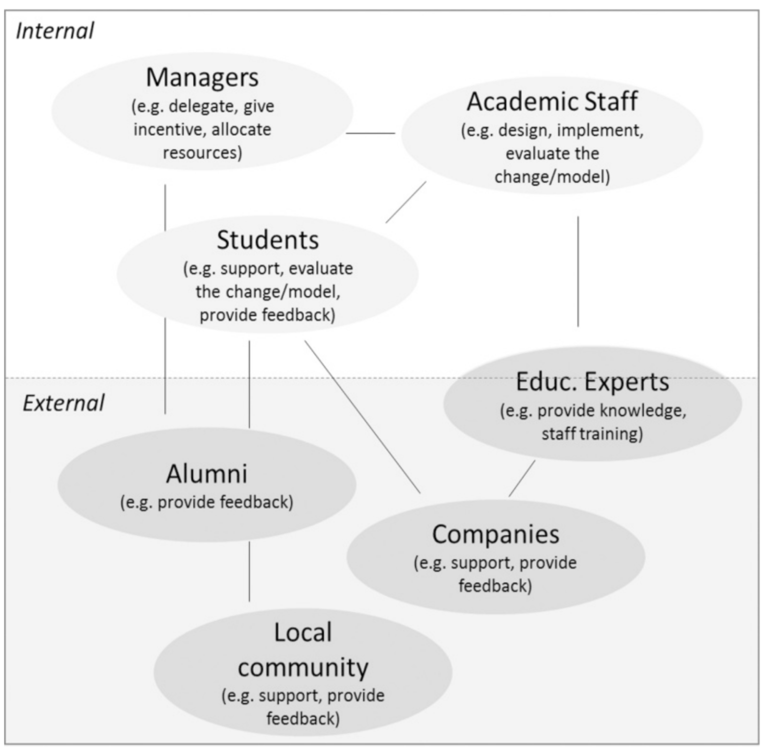

Figure 3. Relationships of people involved in change process and roles assumed (in brackets)

Based on the above, change is a collaborative process by including people from within the institution (i.e. internal collaborative processes) and from outside the institution (i.e. external collaborative processes). The main types of collaboration highlighted in the cases are: (i) interdisciplinary teams formed by teachers, students, educational researchers and experts, and (ii) collaboration with industry and alumni. Even though they have different contributions for the change process, these collaborations present important aspects for the success, legitimacy and validation of PBL models implemented by training staff, forming new communities of practice, providing students real life learning experiences and in the work place context.

DIVERSITY OF PBL MODELS

The models presented in this book are described using the alignment of curriculum elements published by Kolmos et al. (2009) as guidelines. They are:

- Objectives and knowledge;
- Type of problems, projects and lectures;
- Progression, size and duration;
- Students' learning;
- Academic staff and facilitation;
- Space and organisation;
- Assessment and evaluation.

In the present section we will not compare how the curriculum elements are used by the authors to describe their models, but rather highlight the diversity based on the learning principles, objectives and curriculum organisation they present such as:

- Cooperative Problem-Based Learning (CPBL) framework at Universiti Teknologi Malaysia, UTM (Malaysia)
- Interdisciplinary projects at IEM program, University of Minho (Portugal)
- Self-directed learning and professional development competence at Iron Range Engineering (USA)
- Problem/Project-based learning (RP-PBL) at Engineering School, Republic Polytechnic (Singapore)
- Steady increase of project work at Engineering School, Mondragon University (Spain)
- Problem situations and an integrated approach to courses and projects at Engineering School, ESPRIT (Tunisia)

The chapters highlight learning principles and objectives considered as corner stones in the models designed and fulfilment the curriculum overall aim. Furthermore these also stress the contextual aspects and meaning given to models that make them unique. In the following, we briefly address these models considering the learning principles, objectives and curriculum organisation presented.

Cooperative Problem-Based Learning (CPBL) Framework at Process Control Course, UTM (Malaysia)

Khairiyah Mohd-Yusof, in the second chapter, presents a change process at course level, at UTM (Malaysia). Her main objective is to engage and get students to form a learning community through cooperation and create a positive impact on their learning. To fulfil this purpose, Mohd-Yusof and her colleagues search, learn and design a course PBL model whereas a problem triggers the learning process and cooperative learning (CL) scaffolds it – the Cooperative Problem-Based Learning (CPBL) framework. Mohd-Yusof argues that CL allows students to receive support and feedback from their peers and develop team-based skills and do not solely rely on the facilitator.

Initially, the CPBL framework is implemented in all sections of the Process Control course in four cycles of 3–4 weeks each and involves several lecturers. In each PBL cycle, problems are designed to immerse students in different roles and to learn course learning objectives while solving a problem. Lecturers assume the role of facilitators and designers of learning environment by crafting problems. In the PBL implementation, the author highlights three elements: problems (type, role and craft), students (self-directed learners and problem solvers) and lecturers (designers of learning environment and facilitators).

Moreover, several elements of the CPBL framework can be related with contextual design and implementation. For example, CPBL is implemented at the course level and it is organized in cycles inspired in PBL medical models rather than in projects as it is commonly observed in engineering education. Another aspect is the type of problems, roles assumed by the students and the floating facilitation. In each PBL cycle, students develop problem-solving skills and assume roles with increased responsibilities demanded by the workplace (see Figure 2 in Chapter 2). Due to the number of students and facilitators the model uses the concept of a floating facilitator whereas one lecturer guides and supports the team of students in the learning process in the classroom. This process is supported by the CL principles. Besides the cooperative learning, this model also underlies other learning principles such as problem orientation, experiential and exemplary learning. The CPBL model is currently being implemented in other courses and departments in UTM, as well as in other institutions where the lecturers or teachers have been trained in implementing CPBL. Khairiyah Mohd-Yusof presents a good example of PBL implementation at the course level and proves that even though it is a challenge it is possible to make change within a teacher-centred and lectured based curriculum.

Interdisciplinary Projects at IEM Program, University of Minho (Portugal)

Interdisciplinary projects at Industrial Engineering and Management (IEM) at the School of Engineering (University of Minho, Portugal) has been implemented for more than 10 years. As the authors put it, it has been a history of resilience and continuous improvement involving students, teachers, engineering professionals and other collaborators who trust and believe in this change process (Lima et al., Chapter 3). In this model, the project works as the integrator of course knowledge and competences, which are needed to provide solutions to problems formulated in companies' context. In this interdisciplinary perspective, the disciplinary knowledge and its boundaries become blurred as the students need to learn, understand and apply knowledge from different disciplines in order to solve a problem. The course content and learning outcomes that should be incorporated in projects are defined by the course teachers and in the beginning of the semester. Lima et al. (Chapter 3) also point to other aspects, PBL is implemented in different semesters and in different years of program. PBL is implemented in the 1st and 7th semesters with a time gap of 6 semesters, i.e. 3 years. Consequently, the type of students and progression in the program is also different in the two semesters, which is reflected in the type of problems, contexts and courses integrated in the project work. This constitutes a good example of diversity of PBL models that are not only among programs and institutions but also within program where elements are adjusted to address the learning demands within the program.

Self-Directed Learning and Professional Development Competence at Iron Range Engineering (US)

Similar to the IEM model, the Iron Range Engineering model also puts emphasis on interdisciplinary projects where PBL is implemented in two semesters and students have the possibility to run company projects, however how the curriculum is organized around problems and projects is different. In this model, we take the example of the learning objectives and the authors clustered them into three groups: technical outcomes, design outcomes and professional outcomes (see Table 1 in Chapter 4). In this context, the learning experience is seen as a self-development process where the primary objective is to provide learning activities, guidance and feedback so students can become the engineers they envision. The authors address this objective in several ways such as making students' co-designers of change processes; create conditions for self-directed learning and how teams are formed. Here we highlight how the Iron Range Engineering model exemplifies the role of learning outcomes in a PBL environment and how students use them to develop knowledge, skills and competencies. The outcomes are communicated in two ways to students. Firstly, they are integrated in program syllabi and categorized in: (i) technical outcomes, (ii) design outcomes, and (iii) professional outcomes. The categorization of learning outcomes helps students to classify the value of the learning to their future career. Secondly, these outcomes are given to students in a simplified version through a model named *Being an Engineer*. In this way, the authors expect to turn the outcomes more tangible to students and easily incorporated in their daily activities and project work. In sum, the learning outcomes and how they are formulated not only calls for students' participation but also constitute a baseline of knowledge and abilities to excel and exceed. The professional learning is viewed as an individual's own development where the project provides the platform for such. Supporting students learning in this domain is the students' "professional development plan (PDP)" where students employ continuous improvements based on peer, academic staff and experts' feedback of their strategies, successes and failures along the project work. This reflective tool enables students to state goals and actions plans tackling the areas they want to develop further. The Iron Range Engineering model provides a good example of how self-direct learning and professional development are developed through PBL.

Problem/Project-Based Learning (RP-PBL) at School of Engineering, Republic Polytechnic (Singapore)

At Republic Polytechnic (RP), Singapore, PBL is implemented at the institutional level where almost all programs are problem-based or project-based. According to the authors (Wang et al., Chapter 5), RP adopted a unique implementation of PBL where the modules are organized around real-life problems or projects which may last from one day to a few weeks. The authors argue that the strength of this model lies in the solving of small bite-sized problems, during which students regularly reflect on their knowledge construction. Furthermore, PBL distinguishes itself from other active learning methodologies by intertwining fundamental concepts by means of challenges relevant for students and for their future practice, increasing their engagement in the learning process. In this model, the reader finds descriptions on two aspects of the PBL model: (1) the learning phases and (2) the key elements for students' engagement.

The PBL learning involves three phases: phase (1) students unpack and scope the problem and define information needed (i.e. learning objectives), phase (2) students outline inquiry strategies, apply the concepts/ knowledge collaboratively and test possible solutions, and phase (3) students present their solutions and answer questions from their classmates and lecturer to further refine their engagement and understanding of content. Regarding students' engagement in the learning process, the authors considered three key elements: (1) the learning environment and how it is designed (i.e. team based and classroom setting), (2) the problem statement, learning activities and how they are related (i.e. problem scope and design, scaffolding), and (3) reflection on the learning process (regular feedback from peers and supervisors highlighting skills and areas for improvement) (Wang et al., Chapter 5).

In this perspective, PBL phases and elements are well described and provide examples of relevant principles and objectives of PBL: reflection and exemplary learning. By going through PBL cycles of learning and reflecting upon the process, students develop knowledge and skills needed to solve the following problem and meet the learning outcomes needed. In this sense, students become proficient in tackling and solving real life problems.

Steady Increase of Project Work at Engineering School, Mondragon University (Spain)

In the sixth chapter, Arana-Arexolaleiba and Zubizarreta describe a PBL model implemented at the Engineering School, Mondragon University, where all programs are project based and problem oriented. The authors provide a thorough description of the model, its elements and valuable examples of how it is practiced. The main goal in implementing PBL is to equip students with transversal skills, flexibility and adaptability for the labour market. To achieve such a goal, Mondragon University used an integrative strategy whereas each semester is organized in lectures, interdisciplinary PBL and transversal competences workshops (see Figure 2 in Chapter 6). In this context, the PBL progression is done vertically with a steady increase of time allocated to project work (i.e. PBL) during every year of program. For example, time allocated to the project is around 20% each semester, and it increases every year until 100% in the last year, where students carry out their projects in companies. Furthermore, semesters are also organized in a way that the first weeks are allocated to lectures and transversal competence workshops whereas the last weeks are allocated to PBL projects. In this way, students construct the knowledge and skills needed to be used in the interdisciplinary projects later in the semester. Mondragon University presents a good example of PBL curriculum where the program moves from a focus on developing students engineering knowledge with more time allocated to course work towards a more problem-based learning in last years with 100% time allocated to interdisciplinary projects.

Integrated Approach to Courses and Projects at Engineering School, ESPRIT (Tunisia)

ESPRIT, Tunisia, just like the two above examples, implements PBL in all engineering programs. Similarly, it is also described in terms of curriculum organization, learning outcomes, progression, students' and staff, assessment and facilities (Bettaieb, Chapter 7). In this context, and similar to previous examples, the curriculum is problem oriented and organized in lectures and projects. However, aspects like how the learning is organized around problems, how the relation between lectures and projects is, and how students are prepared for PBL learning differs. The author draws our attention to three main aspects: (1) integrated projects (IP), (2) integrated courses (IC) and (3) PBL events like PBL-welcome week and PBL bash. Both IP and IC are problem based however the type of problems and how they are solved highlights the difference of learning context and progression. For example, IP has a duration of a semester and team of students address open, complex and poorly structured problems in connection with business and companies. The IC encloses several learning methodologies, from teacher centred to student centred. One learning methodology used is what the author defines as ProSit (problem situation). Here, students are presented with real life situations where a team of students needs to analyse, understand, apply knowledge and propose an effective solution. In this context, ProSit is typically carried out in three sessions, where two of them held in classroom (Chapter 7). The ESPRIT curriculum also includes two events: (1) PBL-welcome week and (2) PBL Bash. The main goal of these events is to prepare, engage and reward students, and their accomplishments, in the PBL learning environment. As other examples show (see for example, Mohd-Yusof, Chapter 2; Johnson & Ulseth, Chapter 4) it is important to prepare and engage students in change processes and PBL implementation. They are the core actors of the learning process and the purpose is to provide good educational experiences and education of quality.

All PBL examples compiled in this book use the same framework and principles to describe their models and implementation – the alignment of PBL curriculum elements (Kolmos, Graff, & Du, 2009). With the framework we expect to provide detailed descriptions of how PBL is implemented and practiced in different contexts. Nevertheless, in this section we have pointed to aspects from the different models that highlight the diversity of PBL models and the contextual nature of each one of them.

In sum, all the models have an integrative approach whereas discipline knowledge is learned, mobilized and applied in real life situations by teams of students. However, how this integration is made in the curriculum varies considerably from model to model. The reader can find a more detailed description of PBL models and how assessment, students' roles and facilitation, facilities and progression shape these models. Another aspect common to all models is the evaluation of the first PBL implementations and their continuous adjustments. Mohd-Yusof defines this as an evidence-based approach to change which helps to validate and legitimate the change.

PRESENT CHALLENGES

Even though the examples reported present successful examples of engineering curriculum change, these processes are not absent of challenges. In a change process, challenges have an on-going and continuous presence and they vary in nature and context. For example, in bottom-up approaches the lack of financial resources and support is one of the major challenges. At University of Minho (Chapter 3) and Iron Range Engineering Model (Chapter 4) the change process and PBL implementation started once funding was acquired. In this book the reader finds examples of challenges faced before the implementation process and how the different organizations/ agents addressed these challenges. Besides these initial challenges, the authors also report concrete examples of on-going challenges faced during the implementation of PBL. Table 2 summarizes the main challenges faced during the PBL implementation.

Table 2 Summary of main challenges referred to the authors

Challenges
• Resistance and reluctance to PBL (Wang et al., Chapter 5; Bettaieb, Chapter 7) • Curriculum development (Lima et al., Chapter 3; Johnson and Ulseth, Chapter 4) • Infrastructures and group rooms (Lima et al., Chapter 3; Bettaieb, Chapter 7) • Training of staff and students (Lima et al., Chapter 3; Wang et al., Chapter 5; Bettaieb, Chapter 7) • Staff recruitment (Johnson and Ulseth, Chapter 4; Wang et al., Chapter 5) • Collaborations (Lima et al., Chapter 3; Bettaieb, Chapter 7) • Economic (Johnson and Ulseth, Chapter 4; Wang et al., Chapter 5) • Drift back to traditional curriculum (Johnson and Ulseth, Chapter 4)

The challenges summarized in Table 2 are related not only with limitations of PBL curriculum elements and their practice, but also with change management and sustainability. See for example the need for more infrastructures (e.g. group rooms), the curriculum development (e.g. more PBL approaches in the curriculum), staff training, etc.

FINAL REMARKS

As Kolmos points out (Chapter 1), each change "*process will be very different depending on the context of the critical reflection and the creation of meaning*" leading to different approaches (e.g. top-down and bottom-up), strategies and levels (e.g. course and institutional level) of change. In the examples presented, the change processes imply a transformation of vision and values of what learning should be, triggering a transition from traditional learning to PBL. In this sense, PBL is also a learning philosophy and different drivers, facing diverse challenges and involving different actors, trigger its implementation. This book gathers experiences, practices and models, through which we hoped to give a grasp of the complexity, multidimensional, systemic and dynamic nature of change processes. Even though the authors shared a similar vision of what engineering education should be (i.e. quality, innovative, active, participatory, and competence-based), how they reacted to these lead to a diversity of PBL models, emphasising the constructive and contextual nature of the change process and PBL practice. Models are designed, implemented and evaluated continuously aiming their improvement and fulfilment of engineering education vision and aiming to be also a research-based and collaborative perspective to change. The authors brought several references of their previous work and the research carried out within these domains supporting their claims and hypothesis. With this book, we hope we have brought forward examples and inspiration to all of those who aim to change engineering education underlying the principle that anyone can be a change agent and provide an education of quality for the future.

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