Introduction

Problem and Project Based Learning (PBL) tries to emulate the environment encountered by professional engineers in the field with the intention of increasing engagement and improving the practical and applied skills of engineering students. Theoretically, by making the classroom more reminiscent of the 'real-world', students are encouraged to behave, respond to, and solve problems *like* engineers rather than simply *knowing* how others have solved them in the past (although the activation of this prior knowledge is critical in solving a 'new' problem). If, momentarily, we put aside the frequent debates surrounding the contradistinctions of these constructivist approaches to learning and their suitability to differing disciplines (e.g., Savery 2006 or Perrenet, Bouhuijs, and Smits, 2000), we can see both PBL approaches afford students the opportunity to collaborate with peers, develop interpersonal, communication, reporting, presentation as well as problem-solving and critical thinking skills (Schmidt, van Der Molen, te Winkel and Wijnen 2009). The very same skills are required for accreditation as an engineer by peak professional bodies like Engineers Australia (EA) and demanded by industry. Whilst the debate over the nature, implementation, and impact of PBL within engineering faculties and accreditation bodies worldwide reaches a high point, it is interesting to explore and report on the perceptions held by current high school Science, Technology, Engineering and Mathematics (STEM) students and Alumni graduates on the impact of PBL on their learning in a secondary school and university context as well as its suitability to an engineering education and attainment of professional accreditation.

Constructivist Pedagogies utilised at Parramatta Marist High (PMH)

Constructivism, as a theory of learning, posits the basis of knowledge construction is derived from the learner's experiences, their activation of prior knowledge and the resultant creation of 'new' understandings from engagement with these varied stimuli (including other human beings). PBL, as a learning 'philosophy' within a constructivist theoretical framework, places the student at the centre of an active, collaborative, scaffolded, and, in the 21st Century, blended learning environment with a strong emphasis on skill acquisition as well as formal and informal assessment – with the learning being driven by a 'problem' or 'project'. Parramatta Marist High (PMH), a comprehensive Catholic systemic all boys high school in Western Sydney, New South Wales, initiated significant whole school change in 2008. As of 2015, three constructivist approaches to learning are deployed across the school curriculum to meet the challenges of various NSW Board of Studies, Teaching and Educational Standards (BOSTES) *stages* as students' progress through their secondary education (the Flipped Classroom approach in year 12 is not discussed in this paper). All approaches integrate technology with content delivered online through various learning management systems to student owned devices. The first 'PBL' trained students graduated with the NSW Higher School Certificate (HSC) in 2011. For this paper, a brief summary of the two PBL approaches and the tailoring of STEM subjects within stages 4 and 5 (Years 7 – 11) of learning are discussed below.

Project Based Learning in STEM courses at PMH (Years 7 – 10)

Project Based Learning has been utilised throughout the junior and middle school curriculum since 2008. Subjects with related content skills (like STEM) are grouped together in a rotation and often formed into integrated projects when learning outcomes and intentions align. Students are assessed individually (formative) and collectively in their groups (summative). Groups usually comprise 3 to 5 members of mixed ability and projects generally last anywhere from 3 – 10 weeks (Mathematics being the exception as it utilises a

Problem based approach and is streamed and accelerated from Year 9 onwards). In Years 9 and 10, *all* students undertake *Information and Software Technology* (IST), which is normally an elective course in other secondary settings. In addition, students may elect to do *Design and Technology*, *Elective Science* or *iSTEM* - a newly created school-developed, BOSTES endorsed course. The school is a member of the *New Tech Network*, a not-for-profit organisation with over 180 Project Based Learning schools across the United States and students across Years 7 – 10 use their purpose-built learning management system.

Problem Based Learning in STEM courses at PMH (Year 11)

In 2010, a Problem Based Learning approach was adopted throughout all Year 11 Preliminary HSC courses. Modelled on the 'One Day, One Problem' approach pioneered at Republic Polytechnic, Singapore (see Rotgans, O'Grady, and Alwis 2011), this variant has been coined '1-5-1'; a term which denotes the hourly break up of class time within a two week timetable cycle. Students participate in pre-learning activities in the first hour class on one day; engage with a 'problem' and present a solution at the end of a full 5 hour school day (in groups of 5 selected on differing basis); and, participate in post-testing and extension activities in the subsequent one hour class. Subjects are not integrated given the syllabus requirements leading into the Year 12 HSC courses, however, and given these courses' individual requirements, there is great scope for variation within this model. In some ways, the nuanced approaches taken are very reminiscent at times of the Danish model and 'three types of project work' undertaken at Aalborg University as described in detail by Kolmos (1996). Besides traditional Science and Mathematics courses, students in the senior school can elect to do STEM-related courses like *Engineering Studies*; *Software Design Development (SDD)*; *Industrial Technology (IT)*; *Information Processes and Technology (IPT)*; and *Design and Technology (D&T)*.

Methodology

This preliminary study has been designed to collect, identify and report on recurrent 'themes' or 'trends' in the data to be explored and analysed in greater depth and sophistication in subsequent studies. To collect these initial perceptions of high school students and recent graduates taught in a PBL environment, this study utilised two online surveys incorporating questions with a 5-point likert scale (ranging from *Not true at all for me* to *Very true for me*), 'checklist' style and open questions followed by interviews (face-to-face and over the phone) with selected students and alumni to help clarify elements of their responses e.g. understanding of the possible meaning of the competencies and their impact on their learning (see Male, Bush, and Chapman 2010). One survey with 26 items was designed for current students in Years 9 – 10 who have *elected* to undertake a STEM course including 6 items designed to measure individual (dispositional) interest of participants. Years 7 and 8 students were not included in this study given their *mandatory* participation in a curriculum set by BOSTES. A second (related) survey with 15 items was designed for alumni presently studying a degree in engineering or related STEM area at university (no individual interest measures were required given their choice of degree). A simplistic single item self-efficacy measure also asked alumni whether the skills developed in PBL environment *can* help them achieve the 'Professional and Personal Attributes' competencies required by Engineers Australia (this measure being supported by in-depth discussions with selected respondents). For the sake of brevity, not every survey item or its responses are included in this paper (particularly answers to the open questions) but where possible, mention is made if a contribution to an overall theme or trend is apparent. The sample size (at present) is 145 current students and 35 alumni (studying engineering courses) from PBL graduating classes of 2011 to 2014 - a reasonable sample size from within an overall small population (that is, Australian high school students who are or have been educated in a predominantly PBL environment).

Results and Discussion

Perceived and reported impacts of PBL on student learning

Of the 145 current students surveyed, there was a significant level of individual interest in relation to STEM. For the two most critical items (of 6 items), concerning present interest and potential future employment in a STEM area, students' responses were largely in the range of 'true for me' to 'very true for me' (see Table 1). Given these students have elected to undertake these courses, it was expected they would have higher levels of interest than if compelled to study these courses. Additionally, current students perceived PBL was only marginally better suited to their STEM subjects compared with their other subjects. Both current students and the 35 alumni PBL graduates were also surveyed regarding their perceptions of their *enjoyment* of learning in a PBL environment at school and its *benefit to* their learning. Interestingly, in both cases, alumni rated higher levels of 'enjoyment' in learning in a PBL environment and perceived 'benefits' than current students (see Table 2).

Table 1 – Overall ratings from 145 current PBL STEM students regarding dispositional interest and enjoyment and benefits of PBL

Questions:	Rating (/5)
I am very interested in Science, Technology, Engineering and Maths (STEM) subjects.	4.4
Later in life I want to get a STEM-related job.	4.0
Compared to my other subjects, I feel PBL is better suited to my STEM-related subjects.	3.4
Project/Problem Based Learning (PBL) is beneficial to my learning.	3.8
I enjoy learning in a PBL environment.	3.7

Table 2 – Overall rating from 35 Alumni PBL graduates studying engineering on enjoyment and benefits of PBL

Questions:	Rating (/5)
Project/Problem Based Learning (PBL) was beneficial to my learning at school.	4.3
I enjoyed learning in a PBL environment at school.	4.2

Whilst current students somewhat enjoy learning in a PBL environment and believe there is some apparent benefit in doing so, alumni studying engineering reported higher levels of both enjoyment and perceived benefits. This increase may be nostalgic, developed with maturity or upon reflection, however, it may also be linked to the skills development afforded them at school and deployed at university in a setting and discipline that requires greater and independent usage of those skills – that is, the benefits to their 'learning' from school are ongoing (this perception was confirmed by selected alumni subsequently interviewed).

Conversely, it is possible that other alumni studying within other disciplines and not surveyed in this study, may not rate the benefits of their PBL secondary school experience as highly given its associated skills may not be valued or emphasised in their tertiary context or by an accrediting body in the same way as engineering. Moreover, despite its reported benefits, current students are *compelled* to learn in a PBL environment and must deal with issues not encountered in other settings on a more regular basis. This may account for their lessened enjoyment. For example, when asked to write a response to the *least* enjoyable aspect of learning in a PBL environment, students and alumni overwhelmingly indicated 'lazy or disengaged group members' as their greatest frustration. However, numerous alumni indicated that being within a PBL environment helped them build skills to deal with such a situation – again, possibly accounting for their higher rating as to PBL's benefits.

Perceived and reported impacts of PBL on STEM-related education and degrees at University

As noted over a decade ago by Mills and Treagust (2003), engineering educators, researchers and accrediting bodies worldwide studied the technical and personal qualities required of engineers within industry. Collectively, these studies concluded that:

> *Today's engineering graduates need to have strong communication and teamwork skills, but they don't. They need to have a broader perspective of the issues that concern their profession such as social, environmental and economic issues, but they haven't. Finally, they are graduating with good knowledge of fundamental engineering science and computer literacy, but they don't know how to apply that in practice.*

Since that time, peak professional bodies worldwide have included and/or increased the importance of non-technical competencies within their accreditation process – with Engineers Australia placing 'Professional and Personal Attributes' on an equal footing with 'Knowledge and Skills Base' and 'Engineering Application Ability'. Importantly, a subsequent Australian study, Male, Bush and Chapman (2011), demonstrated that rather than being viewed as imposed from above, experienced engineers valued this development and:

> *non-technical and attitudinal competencies were rated as especially important by engineers for their work. This result supports the trends in programme accreditation in Australia, and internationally, to broaden engineering curricula beyond technical knowledge and skills.*

The recognition of the equal importance of 'soft' skills with more tangible (or 'hard') skills is reflective of a more general trend within education itself with the Australian Curriculum, Assessment and Reporting Authority (ACARA), for example, enshrining them as 'general capabilities' in the new national curriculum. In government and industry circles these so-called 'employability' skills are highly sought after as illustrated in a recent occasional paper from the Australian Government's Office of the Chief Scientist entitled '*Stem skills in the workforce: what do employers want?'* (Prinsley and Baranyai 2015). Of the 13 skills included, 1065 employers rated (in order) *Active learning* (i.e. learning on the job); *Critical thinking*, *Complex problem-solving*; *Creative problem-solving;* and *Interpersonal skills* the most important. It is noteworthy too, that employers, when asked to list additional skills they considered important in their workplace, "overwhelmingly" identified 'communication'. Consequently, how do current PBL trained students and alumni perceive these soft skills in relation to STEM-related tertiary education? The following sample feedback in Tables 3 and 4 are indicative of responses to an open question on the perceived (current students) and reported (alumni) benefits of PBL to a STEM related tertiary education:

Table 3 - Sample feedback from 145 current PBL STEM students

Question: In what ways might studying in a PBL school environment benefit you when studying a STEM-related degree at university?	
Student 1	*PBL allows for teamwork, and an effective working environment for solving problems. It also prepares students for an environment where working with others to achieve a common goal is just as important as understanding the content.* - **Yr 11 Engineering Studies student**
Student 2	*PBL encourages collaboration, which is an essential tool to studying most STEM subjects at university. Subjects such as engineering require heavy teamwork making it more essential to utilise PBL at school.* - **Yr 11 Engineering Studies student**

Student 3	It would benefit me as I would be exposed to situations in which I would need to apply my knowledge of the subject. The problems in PBL taught me how to work together as a group and to effectively create a solution to the problem presented - **Yr 12 SDD student**
Student 4	*Studying in a PBL school environment might benefit me when I study a STEM degree at university because most of the areas of STEM require teamwork. They require teamwork to utilise skills and work together to produce end solutions. Therefore, PBL will help me work in a team and also help me prepare for studying at university so I can work with others and so I can produce end products with others in courses if I have to.* - **Yr 9 iSTEM student**

Both current student and alumni responses were mostly focused on 'soft' skills (particularly teamwork and communication) and recognised their importance as being commensurate with 'hard' skills (content and knowledge) in the resolution of a problem or completion of a project with the depth and sophistication of responses between survey groups the only key difference. This is an interesting development given "communication is the competency that features most frequently as a deficiency in Australian surveys" (Male, Bush & Chapman 2010). These responses also add weight to the idea that the stated benefits of learning in PBL environment at a secondary level (a key factor in convincing school stakeholders to initiate change) are being confirmed and reinforced when students move into tertiary education. Furthermore, alumni rated highly the impact of skills developed within a PBL environment in potentially helping them attain Engineers Australia's (EA) 'Professional and Personal Attributes' work-related competencies (see Table 5). Although warranting further investigation, this rating (4.4/5) points towards a positive impact on the self-efficacy beliefs of PBL graduates; an impression supported by the confidence in skills reported in the sample feedback in Table 4. These beliefs would likely be enhanced in professions like engineering whose accreditation requirements are in greater alignment with those of PBL.

Table 4 - Sample feedback from 35 Alumni PBL graduates studying Engineering at Uni.

Question: In what ways has the experience of studying in Project and Problem Based Learning at school benefitted you at university?	
Alumnus 1	*At university you constantly find yourself working in teams trying to break down complex problems, particularly in engineering. In terms of understanding team dynamics and the optimal way to run certain teams, I believe that I definitely had an advantage over other students and more often than not I find myself leading my work teams, because I am not shy to speak up, offer suggestions and to help other members. I certainly see now that PBL instilled me with a lot of confidence to work with people to whom I do not necessarily know. Also, I learned the importance of not judging or generalizing people and focus more on using their strengths to the team's advantage. My team based assessments at university are my most successful assessment components and they are often based on extensive and lengthy problems/projects. I also find that I give presentations with a lot more ease and I can express myself very clearly. I believe this was a result of consistent practice.* - **2011 Graduate; 3rd year Civil Engineering & Project Management student**
Alumnus 2	*Through Project and Problem Based Learning, I have been able to better engage with the content and look for different ways to interpret and understand the content presented. I use some techniques picked up through high school and PBL to organise notes and ensure that study for subjects is seamless and highly productive and beneficial.* - **2013 Graduate; 2nd year Civil Engineering & Business Marketing student**
Alumnus 3	*Through working in groups in university projects, I already have the experience of looking at problems, assessing what needs to be done, creating a solution and assigning roles in*

	accordance with strengths of individuals. Hence, I am able to get through group work easily with fewer problems - **2013 Graduate; 2nd year Civil & Environmental Engineering student**
Alumnus 4	*PBL has been a very valuable resource in my development as it has allowed me to interact with individuals in a professional and firm manner. Furthermore, it has allowed team/group activities to be fairly easy when compared to other people with little to no prior experience in group work.* - **2014 Graduate; 1st year Civil Engineering (Hons)/Commerce student**
Alumnus 5	*It has been extremely beneficial thus far. All my units have employed group work to some degree, and a few to a significant degree. I believe the skills developed in PBL have been essential to my work and have allowed me to be far more comfortable than I otherwise would be.* - **2014 Graduate; 1st year Engineering (Naval Architecture) student**

Table 5 – Alumni on PBL's contribution to potential EA accreditation (self-efficacy item)

Question:	**Rating (/5)**
Skills developed in a PBL environment can help me achieve the 'Professional and Personal Attributes' competencies required for accreditation as an engineer by Engineers Australia (EA's competencies shown above)	4.4

Perceived and reported usage of PBL within Universities

Another interesting perception identified from the survey data was the disparity between current students' notions of the usage of PBL at universities domestically and internationally with those held by alumni as shown in Table 6. Current students believed its usage was predominant (despite their earlier rating that PBL was only marginally more suited to STEM subjects), however, following a focus group discussion, students thought PBL much more appropriate for 'engineering' alone (believing this to the be the focus of the question). Similarly, following discussions with alumni respondents, their lower rating was a direct result of their occasional or limited experience of PBL in their present course at university as revealed in the sample feedback in Table 7; merely extrapolating these experiences to foreign universities.

Table 6 – Comparison of perceptions of current and past students regarding the use of PBL in Australian and foreign universities

Question:	**Current %**	**Alumni %**
What percentage of Australian universities do you estimate use PBL in their STEM-related degree programs?	65	35
What percentage of foreign universities do you estimate use PBL in their STEM-related degree programs?	58	38

Table 7 – Sample feedback from alumni regarding use of PBL in their degree at university.

Question: As far as you are aware, does your university use Project or Problem Based Learning in any STEM related degrees/faculties?	
Alumnus 1	Yes. One of my units (Engineering design & communication) employed PBL.

Alumnus 2	Yes, both engineering mechanics and computations use the PBL formats.
Alumnus 3	'PBL' has not been encountered within my degree as of yet but it is bound to come up in the future.
Alumnus 4	The Engineering course is structured very similarly to a PBL project.
Alumnus 5	No, but I did do a 'flipped classroom' course in electrical engineering. This was pretty good, but required a lot of work to watch all the resources and the long video lectures were a bit dull.

Emanating from discussions with alumni, one perceived impediment to the wider use of PBL at university was concerns over plagiarism from faculty and students leading to the discouragement of (formalised) peer collaboration in assessment tasks.

Limitations

Understandably, the difficulty with measuring the effects of PBL on soft skill acquisition, levels of engagement, enjoyment, efficacy beliefs and other 'perceptions', is that they are not always easy to ascertain (quantitatively speaking). Consequently, reliance on qualitative data acquired through student and alumni artefacts like surveys and interviews are relatively high. The results of this basic study, whilst crude, are both interesting and somewhat reassuring when attempting to understand the (perceived) benefits of PBL. Of course, it is important to recognise that other factors not addressed in this paper can still influence student perceptions (e.g. teacher quality). However, this study's most significant outcome is the direction it provides for future research into those areas identified above. Whilst this study cannot be used to draw broad or more definitive conclusions, particularly in this case given how few students are currently taught in a PBL environment in Australian secondary schools, there is still merit in this (very) preliminary and subsequent small-scale studies as noted by Xiangyun, de Graaff and Kolmos (2009).

Implications

This initial (largely qualitative) study into the perceptions of PBL educated students regarding the nature of STEM (specifically engineering) education has revealed some interesting insights and implications for schools, universities and the engineering profession. To date, the focus of engineering education, naturally, has been on the quality, intention and products of tertiary programs, however, growing interest and implementation of Project and Problem Based Learning at secondary level, particularly in STEM education, might help and hasten its wider introduction at a tertiary level. Moreover, as noted by Male, Bush, and Chapman (2010): "*increased opportunities for project based learning could have contributed to improvement in the development of practical engineering competencies".* Additionally, the greater alignment of competencies and educational outcomes from secondary and tertiary education, accreditation/professional bodies and industry may better help to address the omnipresent 'STEM skills shortage' - progressing, hopefully, towards articulation agreements between secondary schools practicing PBL and engineering faculties at universities; and, the encouraging of talented STEM students into early entry for their engineering degrees. Furthermore, this study will hopefully lead to more in-depth research providing more concrete conclusions and recommendations in the future.

Conclusions

Whilst possibly holding rather naïve ideas of the nature of tertiary STEM education, current students identified a correlation between the engineering profession and their current mode(s) of learning; specifically, how the skills central to the PBL pedagogies align well with the engineering profession and its accreditation processes (with these perceptions being reconfirmed by Alumni). Current students also held higher expectations than alumni (who are more aware of the reality) of the use of PBL in a tertiary setting here and abroad. PBL-educated alumni (graduating from 2011 onwards) are developing greater positive self-efficacy towards Engineers Australia's (EA) accreditation process which recognises the importance of work-related competencies that are very similar to the soft skills targeted in a PBL environment. Furthermore, and in a wider sense, the findings of this study are supportive of the notion that constructivist approaches to learning might be better able to meet the growing demands from government, industry and peak professional bodies for the teaching and learning of fundamental 21st century 'employability' skills.

Future Research

To facilitate future research (and a possible longitudinal study) on alumni perceptions on the post-school effects of PBL, the ex-students' association collected personal contact details from the 2011 to 2015 HSC cohorts. To date, 665 ex-students from these classes have agreed to receive surveys and other materials related to future research in this area.

References

Australian National Curriculum General Capabilities, Retrieved August 1, 2015, from Australian Curriculum, Assessment and Reporting Authority (ACARA) www.acara.edu.au

Bandura, A., (2006) Guide for constructing self-efficacy scales, *Self Efficacy Beliefs of Adolescents*, Information Age Publishing 307-337

Engineers Australia, (2012) Stage 1 Competency Standards for Professional Engineer. Retrieved June 16, 2015 from: http://www.engineersaustralia.org.au/sites/default/files/shado/Education/Program%20Accreditation/130607_stage_1_pe_2013_approved.pdf

Kolmos, A., (1996) Reflections on Project Work and Problem-based Learning, *European Journal of Engineering Education, Vol. 21, No. 2, 1996, 141 - 148*

Male, S.A., Bush, M.B., & Chapman, E.S., (2010) Perceptions of competency deficiencies in engineering graduates, *Australasian Journal of Engineering Education*, Vol. 16 No 1 55-68

Male, S.A., Bush, M.B., & Chapman, E.S., (2011) An Australian study of generic competencies required by engineers, *European Journal of Engineering Education*, 36:2, 151-163

Mills, J.E. & Treagust, D.F., (2003) Engineering Education – Is Problem-Based or Project-Based Learning the answer? *Australasian J. of Engng. Educ., online publication 2003-04* http://www.aaee.com.au/journal/2003/mills_treagust03.pdf

Perrenet, J.C., Bouhuijs, P.A.J. & Smits, J.G.M.M., (2000) The Suitability of Problem-Based Learning for Engineering Education: Theory and Practice, *Teaching in Higher Education,* Vol. 5, No. 3

Prinsley, R. & Baranyai, K., (2015) Stem Skills in the Workforce: What do Employers Want? *Occasional Paper Series Issue 9, March 2015, Office of the Chief Scientist, Australian Government*

Rotgans, J.I., O'Grady, G. & Alwis, W. A. M. (2011) Introduction: Studies on the learning process in the one-day, one-problem approach to problem-based learning. *Advances in Health Sciences Education,* 15, (4), 443-448

Savery, J.R., (2006), Overview of Problem Based Learning: Definitions and Distinctions, *Interdisciplinary Journal of Problem-based Learning,* 1(1)

Schmidt, H.G., van der Molen, H.T., te Winkel, W.W.R. & Wijnen, W.H.F.W., (2009), Constructivist, Problem-Based Learning Does Work: A met-analysis of Curricular Comparisons Involving a Single Medical School, *Educational Pstchologist,* 44:4, 227-249

Xiangyun, D., de Graaf, E., & Kolmos, A. (eds.) (2009), *Research on PBL Practice in Engineering Education.* Sense Publishers, Rotterdam

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