

# Project Based Learning in Embedded Systems: a Case Study

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## BACKGROUND

In this paper we describe our application of the principles of Project Based Learning (PBL) to a fourth year embedded electronics design course. The course is fundamental to the computer systems major and therefore crucial that students gain an in depth understanding of the concepts covered. Through the use of a reconfigurable development platform called the Nanoboard 3000, students explore digital design, embedded system development, and digital signal processing.

## PURPOSE

This paper reports on the application of PBL to increase the level of engagement and learning outcomes for students enrolled in the final year embedded electronics course.

## DESIGN/METHOD

In order to be able to apply the principles of PBL to the course “advanced embedded systems” we had to find a project that was: real world; met the education requirements of the course; was engaging to the students; and provided an avenue for self-learning. The practical component of this course provided the perfect opportunity to incorporate these principles. However, since many of the concepts taught in this course are new to the students, a series of structured laboratories are provided in the first half of the semester. During the second half of the semester, students are given the opportunity to chose any game from the 1980’s and develop it for the Nanoboard 3000.

## RESULTS

Since 2009 to present day, we have implemented the principles of PBL within the course “advanced embedded systems”. We show the positive role it has played within this course through the use of student survey results, observations of student behaviour, written feedback from the students, and distribution of grades, over the past 3 years. Results from the student survey have resulted in this course to be ranked in the top 12.5% of the courses within the university. The student survey ranks the average effectiveness of this course between 6.4 and 6.7 on the 7-point likert scale, with a standard deviation in the range of 10% to 20%. The written student feedback was extremely positive; one such comment is included below.

*Practical Applications with an extremely interesting assessment item made this a very fun and engaging course. This would be the subject I have most enjoyed over the duration of my entire degree*

The observations made of the students’ behaviour showed that the students had pride in their work and were responsible for their own learning. The grade distributions for this course show that half the class achieved more than 85% in 2010 and 2011 and less than 15% failed to met the minimum learning outcomes for the course.

## CONCLUSIONS

Our aim was to extend the principles of PBL into the course “advanced embedded systems”. We achieved this using a structured laboratory component and a game based project. During the labs students gained the confidence to complete the project and the project gave them ownership of their solution. The feedback from the students, both numerically and written showed positive support for the course. The grade distribution showed that the majority of the students met the learning outcomes of the course.

## KEYWORDS

Project based learning, Embedded Electronics, Field Programmable Gate Array

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## Introduction

Project-Based Learning plays an integral part in any Engineering program as specified by the Engineers Australia Accreditation Criteria Summary (Bradley 2011) which states that “Appropriate experiential, problem and project based learning methodologies to support structured, discovery and investigatory learning within the specified field of engineering practice.” As such its use has been widely accepted and encouraged in engineering teaching practice.

Project-based learning typically consists of a large practical exercise relying upon applying the course work material (Mills 2003). Problem-based learning contains many similarities to project-based learning (Mills 2003). However problem-based learning commonly consists of smaller and more constrained tasks without the full reliance on the coursework material (Mills 2003).

Maskell and Grabau (1998) have defined problem-based learning as an ideal approach to engineering education. They also define problem-based learning as a methodology that is centered on the students solving a problem, which has not been encountered before. It has been shown that problem-based learning has the following benefits: problem-based learning encourages self-directed independent learning (Rasul 2011); problem-based learning increases accountability for outcomes and learning (Rasul 2011); problem-based learning extends the student’s skill set (Perrenet 2000); problem-based learning improves problem solving skills (Perrenet 2000); problem-based learning increases the student’s confidence (Maskell 1998); problem-based learning develops the student’s ability to solve unfamiliar problems (Maskell 1998); problem-based learning improves flexibility in problem solving (Mills 2003); and problem-based learning improves goal-setting and planning (Rasul 2011). These are all essential skills needed by practicing engineers.

In order to apply project-based learning (PBL) to course development Savery and Duffy (2001) suggest PBL learning include the following Instructional Principles: A challenging and authentic real world problem to solve (not a synthetic problem); Student ownership of the solution to the problem; Self-reflection on the solution and experiences.

Embedded Electronics is a well established and continually growing area within the electronics industry fuelled by both technological advancements and consumer demand. Embedded electronics encompasses the areas of microprocessor/microcontroller design, digital design, and software engineering. It is therefore an important component that is taught in every nearly electronic engineering degree. PBL has been successfully applied to introductory embedded electronic courses and shown to be beneficial (Loya-Hernandez 2007, Cirstea 2003). Hence PBL was a suitable candidate for application to the advanced embedded systems course.

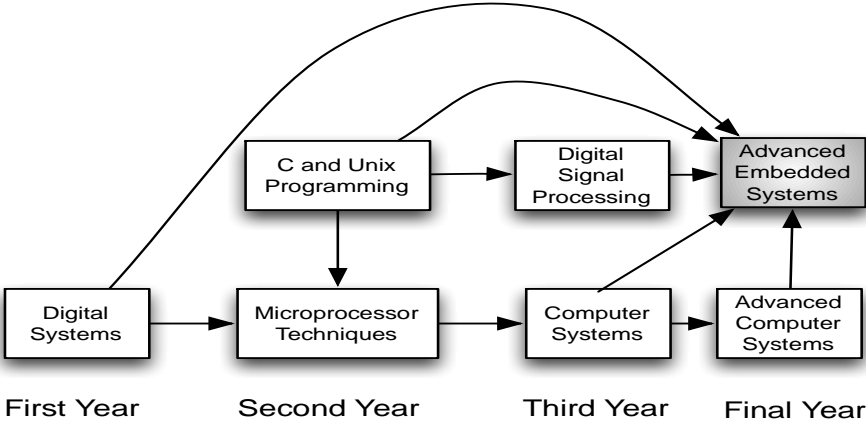
This paper aims to extend the PBL concept and apply it to a 4<sup>th</sup> year engineering advanced embedded electronics course within the engineering program at Griffith University. This course is a culmination of many of the previous courses taught prior within the degree. Therefore it is important that the students are able to holistically apply their previous knowledge and merge it with their newly gained concepts taught in this advanced course.

## Background

In this paper we describe a project based learning approach used in the course, “Advanced Embedded Systems” that has provided the students with an enjoyable motivated learning experience. “Advanced Embedded Systems” is a final year course taught within the Bachelor of Engineering in Electronics and Computer Engineering at Griffith University. The course was first created and run in 2009 and is currently running in semester 2, 2012. The course

covers concepts relating to the design and implementation of embedded systems, and is a pinnacle course that completes the computer systems major within the Electronic and Computer Engineering program. As can be seen in figure 1, the course draws upon knowledge gained in many courses from the previous years. The course extends the material taught in digital systems, microprocessor techniques, C and Unix programming, Digital Signal Processing, Computer Systems, and Advanced Computer Systems. The course covers hardware description languages, FPGA techniques and technology, signal processing implementations on FPGAs, and embedded system design concepts.

The course is taught using the standard mode of delivery consisting of both lecture and practical components. The practical component follows the lecture material and aids to reinforce the material taught in lectures. The practical component of this course is split into two distinctive parts. The first half of the course contains a series of small structured exercises based around the key concepts of FPGAs and embedded systems. The later half of the course contains a major embedded systems project.



**Figure 1: Course dependencies for the advanced embedded systems course.**

The concepts of digital design, embedded system development and digital signal processing are explored through the use of a Field Programmable Gate Array (FPGA) based development platform called the Nanoboard 3000. The FPGA is a Spartan3AN 1400, which allows digital circuits to be realized through the uses of lookup tables and programmable interconnects. This allows any digital device to be described through a hardware description language or schematic capture and synthesized onto a physical device. In the advanced embedded systems course the Altium Designer development suite is used to design, implement, synthesize, and download the digital design to the FPGA. Altium Designer is complemented by the Nanoboard 3000 which together, provide both the hardware and software needed to rapidly prototype electronic designs and get products to the market quickly.

The Nanoboard 3000 provides a flexible development platform that provides various digital and analog I/O interfaces, such as: SVGA; serial ports; mouse/keyboard connectors; a TFT touch screen display; USB ports; a high quality audio codec; SD card readers; 4 channel analog I/O; LEDs; and buttons. Figure 2 shows the Nanoboard 3000 in which the various I/O connectors and the touch screen can be clearly seen. It is possible to buy the Nanoboard 3000 with many different FPGA or CPLD devices, from manufacturers such as Xilinx, Altera, Alcatel, and Lattice. However our course focused only on the use of the smaller Xilinx Spartan 3AN, which satisfied the needs of the course.



**Figure 2: NanoBoard 3000 in desktop configuration.**

The typical approach employed in teaching embedded systems is through a project that requires the students to use the main concepts of embedded systems. An alternative approach is to use a set of small, targeted tasks that has the possibility to create an isolated understanding of the topics. Past experience in other courses has shown that students do not get the full benefit from either approach; either the level of project produced was not of the level expected from final year students or the structured labs prevented the students from exploring beyond the topics and restricted their creativity. Also past experience in other courses have shown that a lack of engagement with the project manifests itself as poor attendance in laboratories and eventually as a poor quality of final project. When the advanced embedded systems course was created, it contained both a project component and component consisting of a set of small tasks. The project was designed to incorporate the concepts of PBL. PBL has been applied to this course for the last 4 years with varying levels of success.

## **Application of PBL**

In order to apply the principles of PBL to the advanced embedded course, a project needs to be created that is real-world, engaging, and challenging. However, since the development environment and the hardware descriptive language are new to the students then they required some short problem-based learning practical exercises to reinforce the lecture content (theory) and give them the confidence and background to be able to successfully complete the project. The practical component was split into 5 structured laboratories that run in the first 6 weeks of the course and a project that runs for the last 6 weeks of the course with an oral and written defense in the final week. The structured laboratories provided a supervised environment to enable the students to become familiar with the main concepts and the project provided an avenue for self-learning and reaffirming the key concepts.

Designing a project that is both engaging and yet still meets the learning outcomes can be a difficult balancing act. A project can be more engaging if it is fun to do, however, there is a danger that the true learning value can easily be lost in the process of making the project fun. The aim of the proposed project in this course was to make it engaging, fun, and meet the instructional principles required for effective PBL. Therefore it was decided that the project would be chosen by the students themselves with the students deciding the requirements of the project within the constraints of the course. The main constraint was that the project had to be an arcade game.

The project consisted of the hardware and software design of an arcade game implemented on the NanoBoard 3000 system. This included full video, full sound and appropriate human interface. This required the development of subsystems for each of these components and

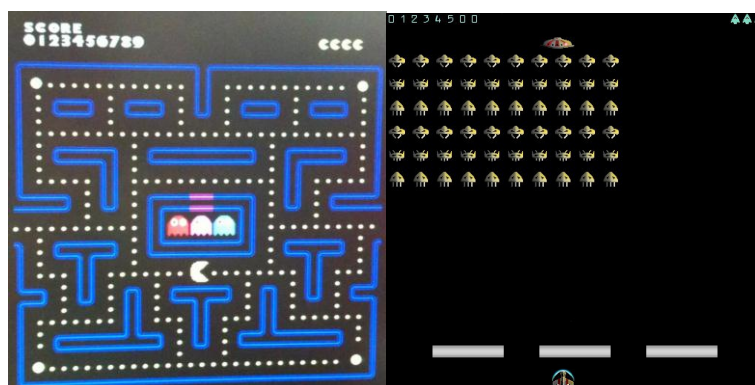
the use of a microcontroller to apply the game rules and interact with the hardware subsystems. Examples of typical arcade games developed can be seen in figure 3.

In 2009 the project consisted of an open-ended arcade game concept in which the students were able to choose any game that they wanted to implement on the Nanoboard. This was later revised due the overly complex nature of the games chosen by the students. As a result, a series of constraints were applied. The major constraint was that the students had to base their design on a game from the 1980s. Choosing this era had the benefit of ensuring the complexity of the games were at a level manageable for the students while still providing a wide range of games to chose from. The students are able to chose any game from the 1980's or develop their own based on the concept of 1980's game.

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To allow for the differing levels of students abilities, consultations were held with each student to discuss the game chosen. This enabled the teaching team to encourage the student to undertake a project suited to their strengths. For example a struggling student would be encouraged to choose a game with a lower level of complexity, such as a tile based game with a low sprite count and simple game rules. Whereas, a highly motivated well performing student may be encouraged to implement a game with a higher level of complexity, such as a sprite based game with complex game rules involving artificial intelligence.

The assessment of the project-based assignment was split into two components. These are the group based written report and an oral presentation / technical defence. The technical defence was used as a personal interview to ensure all members played an equal role in the development of the project and to give the students an opportunity to reflect upon their project. It also aided in encouraging members to participate equally in all phases of the project.





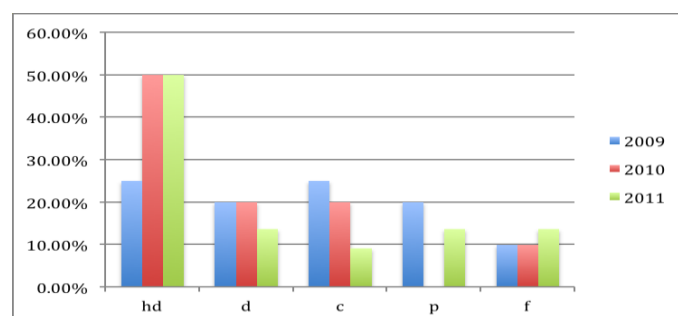
**Figure 3: Screenshots of games developed by students; shown here are PACMAN, Space Invaders, Tetris, and Duckhunt.**

### Outcomes and Survey Results

The effectiveness of the method was determined through surveying the students about the course and observing the behaviour of the students whilst they were doing the course. The surveys were taken for each year that the course ran which was from 2009-2011. The course is currently running in semester 2, 2012 and no data has yet been collected.

A selection of the screen shots of the completed games submitted by students are shown in figure 3 and the distribution in grades can be seen in figure 4. The screenshots show that the students were able to produce realistic replicas of the arcade games, which also had the added bonus of giving enjoyment to those who played the games.

The course outcomes were also determined by the grades achieved by the students. Figure 4 shows the distribution of grades for all the students who completed the course between 2009 and 2011. In 2009 and 2010 the course was available only to 4th year (final year) students. In 2011, the course was opened to both 3rd year and 4th year students, which resulted in a larger and more varied cohort. Overall, for the 3 years the failure rate has been low (<15%) which indicates the students have achieved good learning outcomes in the course. It should be noted that the grades achieved in 2009 were not as high as later years since this was the first year that the game concept was offered and many students chose games that were overly complex and so they did not perform as well as they could have. As mentioned earlier, this resulted in a tightening of the constraints of the project in the subsequent years. The improved grade distribution of P and above from 2009 to 2010 indicated that the students gained a better understanding of the material presented in the course. The failure rate did not change and was low at 10%. The slightly poorer distribution in 2011 can be attributed to the more varied cohort in that year. However, the change in the failure rate was only marginal from previous years.



**Figure 4: Distribution of grades (HD>85%, 85%>D>75%, 75%>C>65%, 65%>P>50%, F<50%).**

The survey responses are a useful method to determine the student experience of the course. Every year that the course used PBL, a survey was taken to gain an insight into the student's experience. The results of the surveys are given in table 1 and table 2 below. In 2009, the University based the responses to survey questions on the 7-point Likert scale. This was changed in subsequent years to a 5-point Likert scale with a single 7-point scale to evaluate the effectiveness of the course. The university also change the question asked of the students. Therefore table 1 shows the responses for 2009, and table 2 shows the responses post 2009. Selected written responses are also given in table 3.

Question asked	Average 2009	Std. Deviation
How effective was the course in helping you to understand why it is important to your learning? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.35	0.68
How effective was the course in making clear what you were expected to learn? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.35	0.68
How relevant was the content of this course to what you were expected to learn? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.47	0.70
How effectively did the teaching methods used in this course work together to help you to learn? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.59	0.60
How effective were the assessment tasks in this course in helping you with what you were expected to learn? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.59	0.60
Overall, how effective was this course in helping you to learn? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.47	0.61

**Table 1: Student Evaluation of Course results for 2009.**

Question asked	Average 2010	Std. Dev.	Average 2011	Std. Dev.
This course was well-organised. (1 – strongly disagree, 2 - disagree, 3 – neutral, 4 - agree, 5 – strongly agree)	4.7	0.49	4.4	1.2

The assessment was clear and fair. (1 – strongly disagree, 2 - disagree, 3 – neutral, 4 - agree, 5 – strongly agree)	4.7	0.49	4.3	1.23
I received helpful feedback on my assessment work. (1 – strongly disagree, 2 - disagree, 3 – neutral, 4 - agree, 5 – strongly agree)	4.7	0.49	4.1	1.37
This course engaged me in learning. (1 – strongly disagree, 2 - disagree, 3 – neutral, 4 - agree, 5 – strongly agree)	4.7	0.49	4.5	1.04
The teaching (lecturers, tutors, online etc) on this course was effective in helping me to learn. (1 – strongly disagree, 2 - disagree, 3 – neutral, 4 - agree, 5 – strongly agree)	4.4	0.53	4.2	1.47
Overall I am satisfied with the quality of this course. (1 – strongly disagree, 2 - disagree, 3 – neutral, 4 - agree, 5 – strongly agree)	4.7	0.49	4.4	1.2
Overall, how effective was this course in helping you to learn? (1 - unacceptable, 2 - very poor, 3 – poor, 4 - average, 5 – good, 6 – very good, 7 – excellent)	6.6	0.53	6.4	1.15

**Table 2: Student Evaluation of Course results for 2010 and 2011.**

1. Making a video game. Its fun therefore motivated me to learn
2. The practical work was enjoyable and engaging
3. Practical Applications with an extremely interesting assessment item made this a very fun and engaging course. This would be the subject I have most enjoyed over the duration of my entire degree.
4. Learning verilog and FPGA applications which are skills employers are looking for.
5. The course structure aided in helping my understanding of the subject matter.
6. Engaged in hands on experience rather than just theory.
7. The on hands part of the course enforced the material we have learnt through out the year and the material covered in the course. One of the more engaging courses in engineering.
8. Loved how interactive the course was. Made you think outside the box.
9. Great way to bring the knowledge gained from previous courses to create an enjoyable timely adventure game.



10. Hands on approach is always appreciated, as it enables learning as you go.
11. The experiments were interesting and challenging and the project was substantial and provided lots of opportunities to be creative.

**Table 3: Selected student written comments**

Although table 1 and table 2 had different questions, both tables indicated that the course was very effective in helping the students to learn with the average responses indicating that the students thought that the course was very effective. For 2009 and 2010 the standard deviation was very tight (<10%) indicating that this response was held by a majority of the students. In 2011, the standard deviation was (<20%) which still indicates that this response was held by a majority of the students. Table 2 shows that high percentage of the students felt engaged in the course. Based on the survey responses this course was rated in the top 12.5% of courses within the university in 2009, 2010, and 2011. The responses given in table 3 show that the students were engaged in the course and that the project-based structure of the course was not only engaging but also effective for their learning. Table 3 also shows the students support for this approach, as both an enjoyable and rewarding experience for them.

## Observations

The majority of the students enrolled in the class were excited about the seemingly unlimited possibilities that the FGPA platform provided when it came to digital design. Since they had never been exposed to FPGAs before the idea of a configurable platform inspired their creativity. Typically early in the semester, students would begin discussing which game they would implement, and throw around different ideas about how they would implement their project. Students also appeared to take a serious approach to the earlier structured labs since the knowledge gained in the structured labs had a direct relationship to material required for project. Generally the students who failed to complete the structured exercises within the required time would stay back in the lab and attempt to complete them. Those who performed poorly on particular exercises would request additional help and attempt to complete that laboratory even though no marks would be awarded. This is an indication of the motivation of the students to understand the fundamental concepts so that they would have the required background to successfully complete the project.

The student's connection and engagement with the course was clearly shown by the fact that many students acquired their own Nanoboard for home at their own expense. The students did this because they thought the whole FPGA concept was "cool". Furthermore they wanted to experiment with its capabilities, as well as being able to spend their free time developing the arcade game, which they appeared to enjoy.

The engagement of the students was also shown during the student's work on the project during the assigned laboratory time. It became difficult to get the students to leave the lab at the end of the lab session. Also as soon as one person in the class had their video subsystem working and some kind of character sprite displayed, everyone else was inspired to do the same. The students motivated each other and it very quickly became a competition to out-do each other. Students became bug testers for each other's systems, offered advice to each other and shared ideas (not code) amongst themselves. It was clear that the students showed a sense of pride in their work and they were eager in each laboratory session to demonstrate to all present what they had achieved. The student ownership of the project was shown by the fact that the students all put their names on their splash screens for the arcade games. The student's completed projects are displayed at the university open day each year and the participants enjoy playing them as much as the students appear to have in making the games.

Overall, the impression from the course are that the students took pride in their work, were eager to complete, and the student's could release their creativity.

## Discussions and Conclusions

The aim of this paper was to extend and apply the PBL principles to a 4th year advanced embedded systems course. The course relied upon the knowledge gained from many different courses throughout the degree. The application of PBL in an engineering program is crucial as it is a requirement for accreditation by Engineers Australia. Engineers Australia strongly recommends that PBL be applied to the engineering curricula. PBL has also been shown by the literature to provide many benefits that could greatly assist the learning outcomes of the course. A modified PBL approach was taken in the course, where the practical component of the course was designed to have a major project (PBL component) and some short laboratory problem-based learning sessions prior to the project. This enabled the students to become familiar with the course material and gain the required confidence with the newly taught concepts prior to commencing the project. The project was designed to be fun, engaging, and challenging as well as adhering to the instructional principals of PBL. The outcomes from the course were determined by the grade distribution and the student experience was determined by the Likert scale survey questions and the written student comments.

The grade distributions showed that the students gained benefit from the course as a majority of the students did very well as shown by figure 4. The figure also showed the improvement in the course outcomes when the constraints on the projects were tightened after the experience of running the course in 2009. The student surveys in table 1 and table 2 indicated that upon reflection, the students thought that the course structure was beneficial to their learning. The student's written comments gave the best indication of the student experience and highlighted that the instruction principles of PBL, namely challenging real world problems, ownership of solution, and reflection were met by the course. The students found the project to be challenging and relevant which is a key principal of PBL. The students felt engaged in the learning process and felt ownership for their solution as evidenced by the number of responses that mentioned opportunities for creativity in the solution, thinking outside the box, and learning as you go. The comments also indicated the student's self-reflection on experience of the course. A number of the known derived benefits of PBL were also shown in table 3: the self-directed learning was evident in a number of responses; accountability for the outcomes were also apparent; improved flexibility in the outcomes; and extended student's problem solving skills.

The basic concepts of this case study can be extended to other "embedded systems" courses that do not rely upon a FPGA platform. The game concept can be directly applied to microcontroller based courses through the use of an appropriate development board.

Overall, the paper has shown that PBL principles were successfully applied to an advanced embedded systems course and the results were very positive as evidenced by the student surveys and the student responses. It also showed the creativity that can be released when the student's are appropriately inspired.

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