The Crazy Machine: a PBL approach in third year embedded systems laboratories

Cesar Ortega-Sanchez and Clive Maynard
Curtin University, Electrical and Computer Engineering Dept.
Corresponding Author: c.ortega@curtin.edu.au

Structured abstract

BACKGROUND

Engineers are first and foremost problem solvers. Industry is demanding graduating engineers to possess not only discipline knowledge, but also a complex set of professional skills that will allow them to contribute to the position from day one (Wagner, 2013). Demanded skills include, but are not limited to: ability to effectively work and communicate in interdisciplinary teams, life-long learning, disposition to embrace the company's ethos and work ethics, problem-solving incorporating innovation, creativity and discipline rigour. To respond to this demand some universities are transforming the way engineering is taught (CDIO, 2013).
This paper describes the laboratory work offered in two third-year units at the Electrical and Computer Engineering Department, Curtin University. The units involved are Embedded Software Engineering 302 (ESE 302) and Advanced Digital Design 320 (ADD 320). These units are taken by third year Computer, Mechatronic, Electronic and Telecommunication student engineers. Both units have separate lectures but share part of their laboratory work.

PURPOSE

The authors wanted to increase and evaluate student engagement in the embedded systems laboratory so they devised a Project-Based Learning (PBL) activity entitled the "Crazy Machine Project". The project component of the two units was reviewed and changed to support these aims. Changes included not just what students did in the laboratory, but also the way the work was monitored and assessed.

DESIGN/METHOD

The shared part of the laboratory experience followed a PBL approach. In semester two, 2012, students were separated into eight teams and were asked to Conceive, Design, Implement and Operate (CDIO) a module of a machine. The final machine, aptly named the Crazy Machine Project (CMP), was made with the modules presented by each of the eight teams. The objective of each module was to move a steel ball in an entertaining way for up to one minute. Students had to work with their team, negotiate with other teams the giving and receiving of the steel ball and apply their knowledge of embedded systems to design their part of the Crazy Machine. These learning activities and the corresponding assessments are aligned with the unit learning outcomes of both units.
At the end of semester students were asked to reflect on their learning experience in an interview carried out by an independent researcher. All students very enthusiastically expressed how much they have learnt by developing their Crazy Machines. They recognised the learning of discipline content, and also the development of important graduate skills like teamwork and time management.

RESULTS

In interviews students stated that they liked the Crazy Machine Project because it was challenging and fun. All wanted to see their machines working. Reflecting on his learning one student declared he had learnt more about engineering during the Crazy Machine Project than in his three years of university. Even though students spent long hours working on their machines, workload did not appear to be an issue. This demonstrates that students will engage if they can associate the task at hand to a bigger purpose and if the task is enjoyable.

CONCLUSIONS

- Students will work longer and more effectively if the right task is given to them.
- For PBL to work well clear documentation and assessment criteria are crucial.
- This research will continue with a new edition of the Crazy Machine Project in 2013.

KEYWORDS
Problem-based learning, CDIO framework, student engagement, practical skills development

Introduction

Problem-based learning

Problem based learning (PBL) is an approach to learning through the use of classroom problems that are chosen to lead students to the realisation that there is new knowledge necessary to solve the problem and it is intended to bring about responsive learning. Students use technology and inquiry to engage with the issues and questions that are relevant to the solution. These classroom problems are used to involve the student in active learning and to assess the students' subject matter competence on completion.

PBL has been successfully applied since the late 1960s to a variety of disciplines (Karpe & Maynard, 2009). The PBL approach used in the context of team-based projects appears to work well in the development of Computer Engineering courses. At Curtin the Computer Engineering course has been developed to follow the required content from widely recognised curriculum guidelines (IEEE/ACM, 2004) and a number of units have been identified as suitable for implementation under the CDIO (Conceive, Design, Implement, Operate) framework (Crawley et al, 2007).

The units involved

The Crazy Machine Project was part of the laboratory component of two third year units: Embedded Software Engineering 302 (ESE 302) and Advanced Digital Design 320 (ADD 320). The Unit Learning Outcomes for both units are shown in Table 1.

Table 1: Unit learning outcomes

ESE 302	ADD 320
• Analyse the principles of Hardware-software co-design. • Apply the basic techniques of project management including quality assurance issues. • Structure real-time system software for efficient implementation. • Analyse the differences between uniprocessor and multiprocessor in concurrent configurations	• Explain the importance of field-programmable logic devices (FPLD) in the context of modern, digital electronic design. • Apply relevant selection criteria to choose the FPLD technology that best matches a particular problem. • Explain and apply the Universal Design Methodology. • Describe and implement digital systems using the VHDL language. • Use commercial FPLD development tools to implement embedded systems. • Work as part of a group to develop a project. • Report your experiences in an effective way.

Table 1 shows that there are two common elements between the units. In ESE 302 a microcontroller is used to learn embedded software development. In ADD 320 a Field-Programmable Gate Array (FPGA) is used to implement embedded systems. This commonality led to the idea of creating a laboratory experience that could be used in both units. In previous versions of these units each had small, less challenging projects.

In 2012 15 students did ESE 302 and 16 students did ADD 320. Six students did both units. For students doing both units a common laboratory represented a significant advantage because they could focus on one single project to meet the requirements of the two units. The unit coordinators decided that one project, lasting throughout the semester, would suffice to demonstrate achievement of equivalent learning outcomes. The level of difficulty for students undertaking both units was slightly higher to compensate for this.

The Crazy Machine Project

In their professional lives engineers solve problems on a daily basis. To solve a problem, engineers need to make the best use of available resources. More often than not, problems are vaguely stated, resources (people, time, money and equipment) are limited, and information is incomplete. A good engineer knows how to deal with all this uncertainty to produce an effective solution. The Crazy Machine is an open-ended problem; i.e. there is not a unique solution for it. Radically different solutions can satisfy the requirements. In 2012 the problem statement was presented to students as follows:

A technology museum is looking for a new display for its embedded systems section. The curator of the museum visited Switzerland during his holidays and saw the machine shown in the following video: http://youtu.be/a61dY3mrpJA

Your team's job is to create one section of a machine that moves a steel (or glass) ball in original ways. Your machine must satisfy the following requirements:

1. *The dimensions of the machine should be 180 x 90 cm; divided into 8 modules of 45 x 45 cm. Teams will be allocated one module at the beginning of the project.*
2. *Modules should pass the ball to each another. Teams will have to negotiate entry and delivery points with neighbouring modules.*
3. *Every module must keep the ball in motion for a minimum of 30 seconds and a maximum of 1 minute. Alternatively, the ball may trigger the activation of a moving mechanism that must operate for the same time. Once the mechanism finishes its operation, the ball must be delivered to the next module with no human intervention.*
4. *The ball's trajectory may span for more than one module; in that case teams need to negotiate use of system real estate so that modules do not interfere with each other.*
5. *Every module must use at least two different sensors and two different actuators. Available sensors are: touch switches, tilt sensors, infrared proximity sensors, pressure sensors and current sensors. Available actuators are: servo motors, DC motors with H-bridge controller, LEDs, and small speakers. Other sensors and actuators may be used, but they will have to be sourced by the design team.*
6. *Materials for the machine will be sourced by the design team. Cost must be minimum, hence the use of recycled materials is highly recommended. (How many uses can a plastic bottle have?)*
7. *The machine will be powered with a single 5V power supply.*
8. *Every module should be controlled by an independent processor (microcontroller or FPGA).*
9. *Teams doing both units (ESE and ADD) must use three different sensors, three different actuators, the microprocessor and the FPGA.*

Resources available to students

Students worked in teams to conceive, design, implement and operate their machines. Unit coordinators used a questionnaire to obtain information about students: Interests/hobbies, skills, gender, ancestry and cultural affiliation, course weighted average (CWA), and time availability. This information was used to form highly diverse teams of three to four students with, for example, balance of gender and cultural diversity in mind.

A Blackboard site was created to make information about the Crazy Machine Project available to students. The site was available to students in Bentley and Sarawak, Malaysia campuses. In Blackboard students could find documentation about the project, rubrics for assessments, a discussion board, a file sharing facility for their group and their grades.

Giving clear and timely information to students is essential in Problem-Based Learning. The unit coordinators ensured that students had all the information needed to achieve their goals. Available documents included: Research Project Information Sheet, Weekly Deliverables, Guide to Effective Teamwork and List of Sensors and Actuators.

Students had 24/7 access to the "Embedded Systems Laboratory" with regularly scheduled tutor supported sessions. Health and Safety rules were clearly stated for access to the laboratory e.g. at least two students should be present at all times.

Assessment

To obtain marks students produced several deliverables. Most assessment items were produced in groups. Only the logbook was individual. Figure 1 shows the breakdown of marks for the Crazy Machine Project as part of the laboratory component of each unit. Rubrics for all assessment components were available in Blackboard.

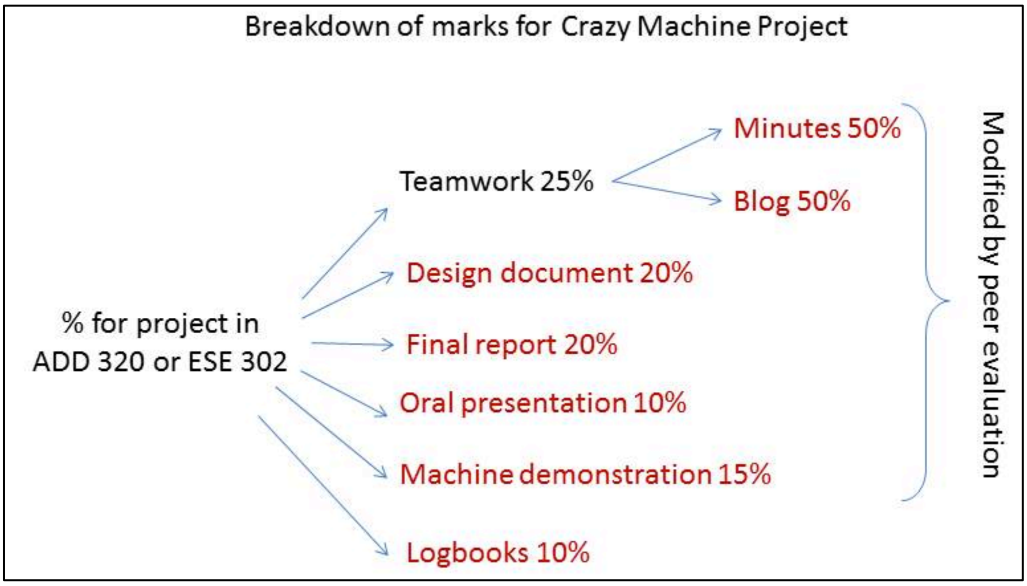

Figure 1: Breakdown of mark for the Crazy Machine Project

For ESE 302 the project comprised 50% of the final mark and for ADD 320 it was 30% matching the appropriate learning outcomes.

At the end of semester students completed a peer assessment form where each team member evaluated other members' participation as well as their own. The peer assessment form was adapted from (Wicks & Stribling, 1991).

Outcomes

To make the experience as authentic as possible; i.e. resembling a real-life situation, students had to keep minutes of all their meetings. A list of actions was generated on every meeting and reviewed in the next. One team created a Facebook page to communicate.

Before implementation, students prepared a design document where they described their machines and outlined its specifications. In this document teams presented a plan and an estimate of required resources. The documents were marked using a rubric which provided the students with feedback that was used in preparing their final reports.

To build their machines students had to come to the laboratory because all the machines were physically located on the same mounting structure. Toward the end of semester they spent long hours working on their machines. Some teams even worked night sessions and weekends. Contrary to what was expected, students did not express any complaints about workload. They were very motivated and invested their time willingly.

Figure 2 shows some of the machines implemented by students in 2012.

Figure 2: Some modules of the Crazy Machine in 2012

On the last laboratory session of the semester all machines were demonstrated. Four machines out of eight worked according to specifications. Three worked partially or intermittently, and one team did not present a machine. Feedback was provided during the demonstrations. Additionally, students prepared a 15-minute oral presentation in which they shared their designs and experiences.

Unbeknown to students the unit coordinators decided to award two prizes: the people's choice award and the first penguin award inspired by (Michel, 2013). For the first, students voted for their favourite machine and the machine with more votes won. The first penguin award was presented to the team that proposed the most ambitious machine, even if it did not operate fully.

Analysing the student experience

To capture students' perceptions two evaluation instruments were utilised: a survey and an interview. The survey was applied to the whole cohort (n=25) and responses were kept anonymous. For the interviews, an independent researcher interviewed one volunteer representative from each team.

The survey

In the survey students were asked to use a Likert-type scale to express their level of agreement with some statements. Table 2 shows the results for the survey.

Table 2: Survey results

Item	SA	A	N	D	SD
1. Before this project I had significant experience in team working	5	9	10	1	0
2. My team always completed tasks in time	6	9	3	6	1

3. All members of my team contributed equally	3	12	4	4	2
4. All members of my team were initially enthusiastic about the project	9	14	2	0	0
5. The level of enthusiasm in my team increased as the project progressed	4	8	7	6	0
6. It was worth investing my time for the amount of learning I achieved	7	15	2	1	0
7. Inter-team communication was a crucial element for the success of our project	13	7	4	0	1
8. My knowledge of embedded systems grew substantially during this unit	12	8	5	0	0
9. The Crazy Machine Project provided me with opportunities to develop professional skills	11	13	1	0	0
10. There was an element of fun in the project that made my learning easier	12	9	4	0	0
11. I wish I had the opportunity to develop project like the Crazy Machine in the laboratories of other units	13	6	5	1	0
Key: SA=Strongly Agree A=Agree N=Neutral D=Disagree SD=Strongly Disagree					

Table 2 shows that students had a good overall experience during the Crazy Machine Project. Item 9 (professional skills) received the highest agreement. This indicates that the learning outcomes were clearly stated and students knew they were learning not just about embedded systems, but also about the way engineers work. In item 4 (initial enthusiasm) students indicated that practically everyone was enthusiastic about the project. However, item 5 (maintaining enthusiasm) shows that not all students could achieve the same level of enthusiasm throughout the project. The interviews provided some explanation for this behaviour. Most students manifested agreement with the rest of the items.

Interviews

To capture other elements of the student experience an independent researcher interviewed five students each from a different team. All interviewees were asked ten questions and the interviews were recorded and transcribed for analysis. A brief analysis of the answers for the questions together with a selection of representative answers (in italics) is presented. Answers have been edited for publication.

1. What was your first reaction to the Crazy Machine Project?

The reactions were varied from apprehension to an expectation that it would be too easy but some felt that the specification was too open and the end product ill defined. These reactions are to be expected when an engineer is introduced to a new system design specification. In this regard the project met the lecturers’ expectations for authenticity.

> *Probably a bit apprehensive, we were given quite a big project and some of the things they required I didn’t know if we’d be able to achieve the required skills in time, so probably a bit of worry that we wouldn’t get it done.*

> *I thought it was going to be too easy. But as the semester went out things didn’t quite seem as easy as they looked in the first impressions.*

2. How do you feel about the Crazy Machine now that the project is completed?

The students reflected on the professional skills they developed and their learning achievements. Some were relieved that it had been completed but most appreciated the process and the fun of working in teams to solve a significant problem.

I really enjoyed it because I have developed so many different things like technical skills or working with a team or spending time problem-solving things so yeah. It was a really good project all around.

3. How did your team work?

Students highlighted the importance of cooperation and assignment of roles.

Most teams performed well and developed a good rapport, however, one team failed to establish their process and did not complete the machine. This problem was not raised by the team nor noticed by supervisors until too late. Measures have since been taken to detect and facilitate team roles to minimise risk.

It worked pretty well. Everything was very well distributed and there wasn't really much conflict that I can think of.

I think the team worked pretty well. There were a couple of issues with a member attending meetings and on time and that sort of thing but um... I don't think that had too much of an overall problem.

4. What would you change about the project?

Students provided valuable and generally positive feedback which has been incorporated into the current version of the project.

I liked the idea of the rubrics. The rubric makes things very clear but being me I would have liked another document that said more about what was expected......or maybe and example.

5. What aspects do you think went well?

Students valued the emphasis on independent learning with ongoing support to achieve the project objectives. It is clear from the student responses that open access to the working space was a critical condition for their success.

I guess the one that went well was actually the objective to let us have independent learning during the process. I guess that aspect went pretty well for most of us.

Trying to develop skills on our own like accessing information by ourselves without having to need to approach a lecturer.

6. What problems did you experience?

A recurring theme in the answers was the need for good time management and intra-team communication.

I guess the main problem was my own time and time management between everyone.

7. Was the project supervision appropriate?

The general response was very positive with many appreciating the level of staff availability and their support style.

The lecturer had a method to lead you into thinking, so sometimes that actually helped us do the independent thinking part. This is actually how we were supported: you have a lecturer who is supervising your independent learning and then you have a lab supervisor who gives you a hand when you're stuck, so I guess we had a good combination between those two

8. If one day you get the chance to run or coordinate this project what would you keep and what would you change?

The general response was that students liked the overall structure of the project and the way it was run. Many felt that the breadth of the project and limited time resulted in most building the skills they were already confident in but they would have liked to be encouraged to become involved in activities outside of their comfort zone.

It was a good learning experience but I felt some people may have missed out a little bit on learning about some of the technical things. So may be if there was a way to make sure the learning was available for everyone in every aspect. I don't know how to encourage that though.

I definitely keep the demonstration and the documentation that we had to submit.

9. What was your most valuable lesson from the project?

Time management was highlighted in most students' responses particularly in the context of planning for problems. The general assumption was that they would succeed in their originally estimated time when in reality this is rarely the case.

> *Maybe time management and work ethics would be the biggest things. I definitely have to leave time to count for things going wrong and spending the time working through problems and researching.*

10. Is there anything else you would like to add?

> *It was quite interesting. It's a really enjoyable feeling to see your project running on top. It was a pretty exciting feeling to actually make something because previously we knew about sensors, we knew about the motors and stuff, but we didn't know how to control them, so being able to apply them made us actually relate pretty close to electronics.*

> *I would give future students the following advice: Make sure you know what you want to do for the project, make sure you get that organised cause you don't want that in the way. And once you start actually doing things like building, don't underestimate it, it's going to take a lot more time than what you expected, and it's going to be a lot of issues. Yes, organisation and time management are very important.*

Final reflections

The project specification, online support for the teams, assessment processes and supporting rubrics required considerable effort by the two academics involved in the establishment of the CMP. Interview responses confirmed that students react positively to challenging activities if they can perceive the didactic purpose and relationship with the professional practice. That effort has established a solid basis for continuing usage.

The ongoing support during the progress of the CMP essentially consisted in ensuring that there was enough staff availability to help the teams' progress. This was handled by providing fixed periods of direct support in the laboratory for the students. Monitoring of associated learning/understanding of the students' progress together with responding to concerns and questions as soon as possible within the normal working week was also a priority. In retrospect, team performance and success needs closer monitoring. One team had considerable difficulties that if detected early enough could have been handled.

Conclusions and future work

PBL and the CDIO framework has been shown to have considerable value in a Computer Systems Engineering degree provided it is introduced with sufficient resource support both in terms of staff support and documentation resources. If students find that the work is interesting and rewarding they will commit to it. A critical resource is assessment documentation. By ensuring that the students understand what they are being assessed on and how that will be judged they can approach a new learning environment with a fair degree of equanimity and comfort.

The Crazy Machine Project is running again in semester 2, 2013. Feedback from students has been incorporated, resulting in a slightly modified problem statement. Also, all rubrics and documents have been made available to students from week 1. The survey and interviews will be repeated and results contrasted with those obtained in 2012.

References

CDIO. (2013). History of the worldwide CDIO initiative. Retrieved 12 June, 2013, from http://www.cdio.org/cdio-history

Crawley E., Malmqvist J., Östlund S., & Brodeur D. (2007). *Rethinking engineering education: The CDIO approach*. Springer.

IEEE/ACM. (2004). Computer Engineering 2004: Curriculum Guidelines for Undergraduate Degree Programs in Computer Engineering. Retrieved October 17, 2013 from http://www.computer.org/portal/c/document_library/get_file?p_l_id=2814020&folderId=3111026&name=DLFE-57612.pdf.

Karpe R., & Maynard N. (2009). Teaching Risk Management by using PBL – a risky approach? Paper presented at SEFI conference.

Michel G.J. (2013). Be the First Penguin – 5 Questions To Ask About Taking Risks. General Leadership. Retrieved August 28, 2013, from http://generalleadership.com/leadership/be-the-first-penguin/

Wagner A. (2013). Change leadership: Transforming education for the 21st century. Retrieved 12 June, 2013, from http://www.tonywagner.com

Wicks B., & Stribling J. (1991). The use of peer reviews for evaluation of individual student performance in group projects. *Schole: A journal of leisure studies and recreation education*.

Copyright statement