Introduction

The importance of hands on education for the learning process of engineering students is well documented (Gibbs and Simpson, 2005). In the first semester of the engineering curriculum at The University of Queensland (UQ), students enrol in a project-based course: Engineering Design (ENGG1100). The course offers four different projects from which students elect one to enrol in. They cover all engineering disciplines taught at UQ. One of these projects is a mining project, which incorporates mechanical and electrical elements to produce a prototype of a piece of mining machinery. For many years, The Mining Project focused on theoretical design independent of any real practical context. Poor student performance and feedback indicated a low level of engagement and interest in the project. In 2011, the course was significantly restructured to resolve the issues related to student learning and address students' feedback. Since then, The Mining Project has put equal emphasis on research, design, build and operation of the prototype to reinforce student engagement and the hands-on learning experience. The Mining Project has included the production of a scale-model Dragline in 2012, a Bucket Wheel Excavator in 2013 and an Electric Mining Shovel in 2014 (Figure 1).

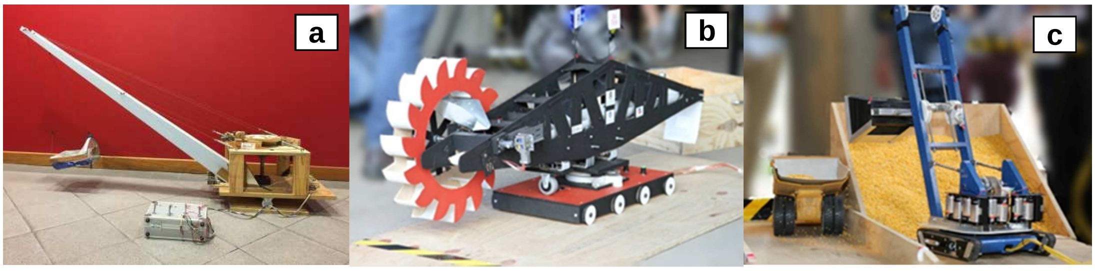

Figure 1: (a) Dragline -2012 (b) Bucket Wheel Excavator-2013 and (c) Electric Mining Shovel-2014

In 2015, The Mining Project involved students carrying out initial research, design, construction and operation of a Load Haul Dump (LHD) machine (Figure 2). The LHD machine is a key piece of equipment used in underground metalliferous mining for both development and production. These machines load broken ore or waste into a large bucket and haul it to the ore or waste pass where it is dumped from the bucket. LHDs can be driven by an on-board operator, operated remotely by an operator standing nearby in safety, or fully autonomous where the functions are repetitive – e.g. hauling from a draw point and delivering broken ore to an ore pass through the same drive every time. The machine is designed to operate in an underground environment with limited headroom and drive width. Consequently it is articulated but compact.

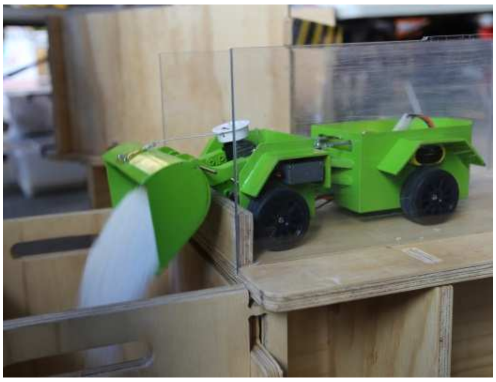

Figure 2: Load Haul Dump (LHD) machine-2015

This paper presents the journey of this project and the reasoning behind the methodologies that were put into place in order to promote deeper learning and provide a unique engineering educational experience.

Background

The Mining Project is structured such that continuous monitoring takes place through well designed assessment items that are aimed to encourage students to progressively reach important milestones in a timely manner on their project throughout the semester. Since it is the assessment that will most capture student attention, educators must leverage this to make as best use of it as possible (Craddock and Mathias, 2009). Assessment should be aligned to the aims, objectives, learning outcomes and course content (Hargreaves, 1997).

In its basic form, learning (and the continuous monitoring and assessment that enables educators to measure this) can be structured in such a way so that students work together (collaboratively), on their own (individualistically) or, by competing with each other (competitively). These are not mutually exclusive and can occur concurrently. The individualistic approach tends to be the more traditional, in the sense that students are expected to absorb from their teacher or textbook and then reproduce this. The merits of working collaboratively are well publicised by authors including Johnson and Johnson (1995) and Johnson et al. (1995) as this utilises the social constructivism transmission model of learning. The notion that better decisions are made when working collaboratively by avoiding one another's mistakes is extensively discussed by Awerbuch (2008) within a computer sciences setting. The Mining Project utilises all three basic forms of learning so that these complement each other to encourage deeper learning. Continuous monitoring of individual and group performance to provide formative feedback was carried out on a weekly basis with tutors meeting with their respective teams during project sessions.

Continuous evaluation throughout the semester also enabled numerous opportunities for students to receive formal constructive feedback. The importance of continuous evaluation (assessment) in higher education to allow regular feedback has been well documented. Gibbs and Simpson (2005) provides a discussion around 8 key conditions under which assessment supports student's learning. Interestingly, 5 of the 8 conditions in some way relate to feedback and the way this is given to students. To further show the importance of feedback, Ramsden's (1991) study of student course evaluations shows that the most common distinguishing factor between the best and worst courses was whether or not students received helpful feedback on how they were progressing. Rapid and quality feedback in promoting deeper learning has been well established and can also provide students with additional motivation to push their learning further. It is important for students to know if the direction they are taking is appropriate. Rapid feedback allows them to clearly define the gap between their current level of knowledge and their desired level of knowledge (Sadler, 1989). This empowers them to take ownership of their learning. Students were required to submit progressive assessment (individual, cooperative and competitive) on a continuous basis throughout the semester.

During their time in ENGG1100, students not only attend their designated project sessions, but also a series of workshops and lectures that are run for the entire course. These sessions provide the basic framework of the course that enables students to participate and achieve within their chosen project. Topics covered include, but are not limited to:

- Safety in engineering;
- Project management;
- Data presentation;
- Sustainability;
- Failure mode analysis and effects; and,
- Engineering decision making.

Through these lectures and project sessions, eight learning outcomes are aimed to be achieved, these are the ability to:

1. Approach a complex and realistic engineering design task;
2. Locate, evaluate, use and cite information from a variety of sources;
3. Communicate through professional standard written, oral and graphical mediums;
4. Use basic project management processes, tools, and record keeping;
5. Work effectively in an engineering team, including critical evaluation of personal and peer contributions;
6. Demonstrate competence in interpreting sustainability concepts, and incorporating them in the engineering design process;
7. Demonstrate personal development, such as time management, ownership of learning and critical reflection of personal professional development; and,
8. Demonstrate professional development, such as adhering to the responsibilities of a professional engineer through critical reflection of engineering ethics, ability to meet deadlines, and incorporation of risk management, as well as health and safety aspects in design.

While the lectures and workshops cover the theory of many concepts that contribute to the learning objectives, students actively put them into practice in the project sessions with help from tutors and project leaders as required. The combination of lectures, workshops and project sessions provide the pedagogical framework to achieve the desired learning outcomes.

The Mining Project has been offered in ENGG1100 for many years, and repeatedly proves popular with students, achieving the highest project scores during the end of semester course evaluations, significantly ahead of the other projects. As this project is taught with an emphasis on interactive and hands on learning, students are continuously using engineering practices to complete the task. While this project provides a clear introduction to both the mining industry and mining systems, the learning outcomes can be extended into any strand of available engineering degrees at UQ, and further into the student's professional career.

Project Description

At the beginning of the first semester in 2015, students were provided with the project brief that outlined the learning objectives, details of the projects and set of tasks as well as providing a series of constraints that they should consider in their design (e.g. dimensions, budget, and limited number of motors). The project brief included the working space in which the designed and built LHD machine must operate (Figure 3).

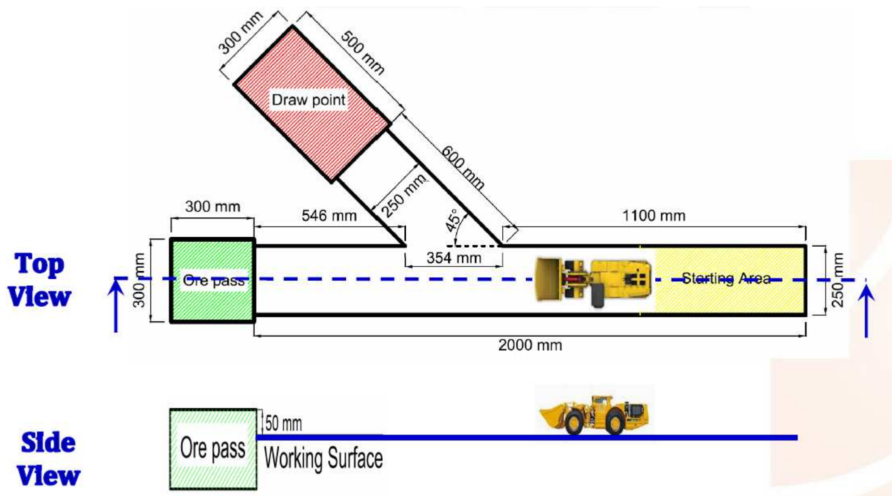

Figure 3: Working space for the LHD project.

The working space had the following specifications:

- The draw point is bounded by a wooden box (height=200 mm, width=300 mm);
- A wooden box with (height=350 mm, width=300 mm) bounds the ore pass;
- The roadway has a rectangular cross section (height=200 mm, width=250 mm);
- The entire working area except the starting area, draw point and ore pass has a roof;
- The sides and roof of the tunnel are made of clear Perspex to allow for vision; and
- The tunnel roof is removable in order to allow for cleaning and removal of machines.

Students' prototypes were required to achieve the following four motions (Figure 4):

1. Propulsion (travelling of the whole machine both forwards and backwards);
2. Articulation (steering);
3. Raising and lowering of bucket; and,
4. Tip and level the bucket.

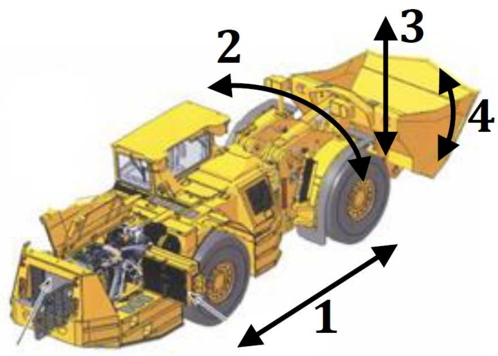

Figure 4: Primary motions of an LHD

The full operating cycle to be demonstrated included the following steps:

- The LHD is initially positioned in the allocated starting area;
- The LHD travels to the ore pile;
- The LHD digs into and collects material from the ore pile;
- The LHD travels to the dump location;
- The LHD dumps the load into the dumping area; and
- The LHD repeats this process for the allowed time (5 minutes).

The LHD had to comply with the following design guidelines:

- The fully assembled length is in the range of 0.3-0.5 m;
- The assembly includes only one bucket;
- No more than four motors can be used;
- Power is supplied by batteries. Battery location is optional (on-board, or external);
- Control philosophy is at the discretion of each team as is the number of operators; and
- The LHD is able to dump over a 50 mm raised ledge into the ore pass.

Learning Pathway

Overview

With the project brief provided, students followed a well-developed learning pathway. This pathway started with a comprehensive review (research) of prior developments relating to the project, followed by the design, construction and operation of the prototype machine, as depicted in Figure 5. Students attended weekly workshops during the semester, which consisted of three weeks of individual research and preliminary design (weeks 1-3), four weeks of group work on conceptual design and critical evaluation (weeks 4-7), four weeks of group work on prototyping, building, trailing and revision (weeks 8-11) and two weeks of group work on testing, operation and demonstration (weeks 12-13). This learning pathway introduced the first year students to the engineering practices and processes that would be used throughout the rest of their academic and professional careers.

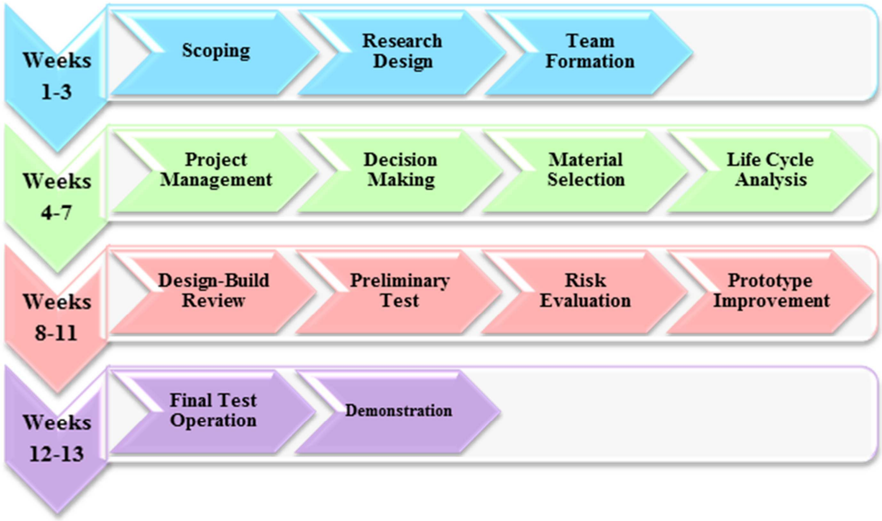

Figure 5: Learning Pathway

Weeks 1-3

During the research stage of the project, students conduct a comprehensive review of existing LHD technologies, manufacturers, applications and new developments. Experts in the field and professionals from LHD manufacturers such as Joy Global, Sandvik and Hastings Deering were invited to present workshops to the students. These sessions ranged from how and where LHD machines are used in mining, the physical components of an LHD, to challenges in maintaining such machines in underground conditions. Students were provided with essential background knowledge to both the mining industry, and to the project at hand while working on their preliminary investigation reports. After three weeks of individual research and investigation, students submitted their reports which contained their individual findings on existing solutions to the problem to be overcome, as well as some initial design work that could be shared with their team. This initial report was submitted, marked and handed back to students within seven days in order for feedback to be given before they progressed further into the project.

Weeks 4-7

After students completed their preliminary investigation reports, they were sorted into the 28 teams of five or six that they worked in for the remainder of the semester. These teams were formed by the course coordinator based on the students' Belbin team role system results (BELBIN, 2103). To do this, each individuals two highest scoring roles were identified, then groups were composed such that between the five to six people, each of the nine roles in the

Belbin team role system were represented. Teams were required to produce a team charter outlining who was responsible for handling various aspects of the project, as well as outlining meeting times, communication methods and team structure. As well as students being put into teams, the tutoring team was each assigned groups that they were responsible for. This provided each group with a first point of contact for any subject related matters, and allowed the tutor to provide continual feedback to both the groups, and the individuals within them. During this phase of the project, students shared designs from their initial research and combined elements of each to form the initial design of their LHD machine (Figure 6). Students refined their designs as they deemed necessary in order to meet all constraints and criteria. Once elements of the machines were finalised, students were able to begin construction.

Weeks 8-11

Facilities were provided for students on campus that had all basic hand tools and some power tools. This allowed students to construct their prototypes after appropriate training had taken place, and under competent supervision. Some students chose to build their prototypes off campus as they had access to other technologies. For example, some students used 3D printing to manufacture the LHD frame and bucket. During week 9 of the semester, in the construction phase, teams presented a build milestone (Figure 7) that showcased what sections of their prototype were complete and functioning, as well as ideas to move forward with the rest of construction. This build milestone provided an opportunity for the project leaders, tutors and other students to ask questions and to learn from other groups.

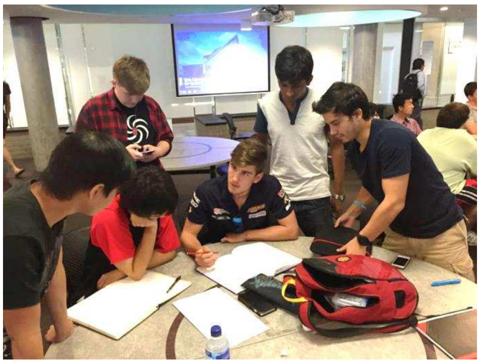

Figure 6: Students reviewing potential design options

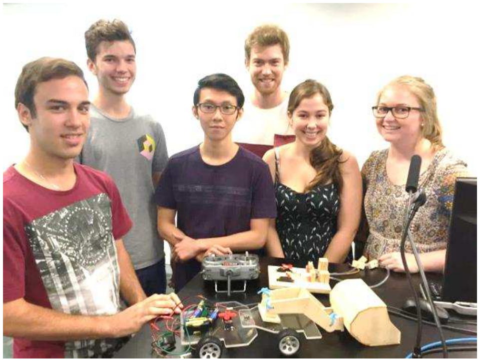

Figure 7: Students showcasing their building progress

Weeks 12-13

During the last two weeks of the semester, students finalised the construction of their model, examined the operational features of their LHD and made the final revisions to the structure. On the last Friday of semester one 2015, all teams in The Mining Project demonstrated their prototypes in three sessions starting from 9 am and finishing at 5 pm (Figure 8).

Figure 8: Students demonstrating their LHD prototype on demonstration day

In addition to the assessment carried out by the course staff, several industry professionals were invited to judge each machine on its creativity, robustness, innovation and simplicity.

Each team's prototype was measured and scrutinised to ensure that they met all the design criteria, and were within all constraints. In addition to this assessment of the prototype, the productivity of each teams unit was ranked against every other team in the project. This competitive assessment was what encouraged teams to produce the best prototype that they could in order to achieve the highest mark possible.

The industry judges also sponsored prizes for many of the top placed teams, as well as a barbeque lunch for all involved. The main value of this engagement was the exposure of students to industry that involved experienced engineers from Sandvik, Anglo American, Joy Global and Hastings Deering.

Learning Support

Social media was used to provide a platform for interactive discussions between students, tutors, project leaders and lecturers outside of the classroom. Students were also provided with a document that contained approximately 100 frequently asked questions that were related to project sessions, team issues, online resources, preliminary investigation report, design, build, logbook, library access, final report, and demonstration day.

Evaluation of Project

In order to maintain ongoing quality assurance, UQ conducts routine course and teaching evaluations which gives students the opportunity to voluntarily and anonymously rate and provide feedback. The success of The Mining Project is demonstrated by consistently positive evaluation scores from students since 2012 (Table 1). In 2015, The Mining Project received a student evaluation score of 4.0 out of 5.0 which was higher than the student evaluation scores obtained by other projects. As the course evolves there is an ever increasing student demand that must be satisfied to maintain consistently high evaluation scores. Each year these demands have been met by The Mining Project, which is a differentiating factor from the other projects.

Table 1: Student evaluation score (out of 5.0)

Year	**Mining Project**	**Other Projects**		
		A	**B**	**C**
2012	4.0	4.1	3.7	3.4
2013	4.0	4.0	3.7	3.9
2014	3.9	3.6	3.9	3.5
2015	4.0	3.5	3.9	3.8

The Facebook initiative to promote student interaction was introduced in 2011 by The Mining Project and has been positively received by students (Table 2). This approach has also been adopted by other project leaders since 2013.

Table 2: Student feedback on the use of social media in the project (out of 5.0)

Student Feedback	**Mining Project**	**Other Projects**		
		A	**B**	**C**
Facebook was helpful for getting answers	4.6	4.5	4.4	4.2

The project has continually received industry support and attracted funding to support students and prizes for winning projects.

> *"It was my pleasure to be involved and thank you very much for the invitation. It was a great day. There was excellent energy within the teams and some great work completed. All of the students should be proud of their achievements and I would like for you to pass on my congratulations to them all, and to you and the tutors for the sound guidance they have provided. Universities are crucial to the sustainability of not only our industry but to the community at large. People such as yourself should be lauded as heroes as you are nurturing innovation and fostering a lifelong love of learning amongst some of the best young brains in the country."* (Principal Engineer, Anglo American, 2015)

It is not only students completing The Mining Project and industry representatives participating in it that appreciate its merits. Later year students who completed the project several years prior are also still recognising the implications of the project in seeking employment or working as a graduate engineer as evidenced in the following quote:

> *"Applying for scholarships in my first year of study was difficult as they ask you for examples of when you have displayed various qualities. With only high school and a few months of university as experience, I felt my responses would be limited. I was greatly rewarded however, when I was able to give numerous examples of my ability to work in a team, problem solve, time manage, communicate with my peers and staff and complete my goals all as a result of ENGG1100. Whenever I had the opportunity to tell these stories in an interview or during an application, the employer had positive responses as this evidence of qualities I say I have is invaluable now that I have examples. There are very few other opportunities through the curriculum at university to develop all of these skills and in this way I think ENGG1100 has helped me enormously on my journey to becoming a qualified engineer."* (ENGG1100 Student, 2012)

Reflections

The most important aspect is the quality of the project team in The Mining Project. Students need to see a team (particularly tutors) that are enthusiastic, dedicated and approachable and that also understand the journey from start to finish. A diverse tutor team ensured a balanced mix of experienced and new tutors. The more experienced tutors were able to guide the newer team members. None of the achievements of The Mining Project would have been possible without tutors and project leaders that are committed to making this an enjoyable experience for all.

Another vital aspect has been continued project renewal. Some other projects within the ENGG1100 course fell into the trap of recycling projects from past years without significant change. Students immediately notice this and begin questioning the dedication of the project team. Developing a completely new project each and every year is an extensive and time consuming task; it, however, maintains a higher level of alertness within the project team. Using a new project each year provides an opportunity for the project team and other academic staff to work collaboratively in the development of the project, by sharing their individual areas of research and expertise. While the structures and processes in producing the prototypes are largely known, having just enough unknown elements within the project ensures that the project team is undertaking the journey together with the students.

Facebook was also integral to the success of the project. This provided a platform that facilitated easy and direct communication between students themselves as well as students and the project team. This did however require regular attention which can be time consuming. In some circumstances students tended to revert to asking questions on Facebook rather than undertaking some important research themselves. It was thus vital to distinguish between these circumstances and to provide the appropriate level of guidance. As with any larger project team, it is imperative that all members are consistence in answering student questions, marking assessment and providing feedback. Any major discrepancies between what one tutor and another say can lead to confusion and ambiguity and thus be detrimental to the overall experience. In order to minimise inconsistencies wherever possible it is vital all team members attend regular meetings throughout the semester, moderate all assessment and maintain clear and open communication channels.

Conclusion

The Mining Project has confirmed the effectiveness of combining three modes of learning: Individualistic, collaborative, and competitive. Not only has this learning pathway proven highly successful over several years, it continues to be popular with students. The Mining Project incorporates a wide range of learning experiences. As such, it is inspirational for most students seeking to settle into a life-long commitment to the engineering profession. Working in a group of peers with whom they may have never met is in itself a broadening experience that introduces and reinforces essential life skills. This experience also exposes students to working in a multi-cultural learning environment.

A valuable learning experience not at first evident involves the tutors. These are all students themselves from second, third and fourth year engineering, so the processes of group and project management for which they are responsible add greatly to their personal and professional growth. During the course of the project, interaction with mature industry personnel, and their factual presentations, ensures a formative understanding of industry realities and fundamental knowledge for aspiring engineers.

References

Awerbuch, B., and Kleinberg, R. (2008). Competitive collaborative learning, Journal of Computer and System Sciences, (74) 1271–1288.

BELBIN (2013). Method, Reliability & Validity, Statistics & Research: A Comprehensive Review of Belbin Team Roles. Retrieved August 21, 2015, from http://www.belbin.com/content/page/5599/BELBIN(uk)-2013-A%20Comprehensive%20Review.pdf

Craddock, D., and Mathias, H. (2009). Assessment options in higher education. *Assessment and Evaluation in Higher Education*, 34 (2) 127-140.

Gibbs, G., and Simpson, C. (2005). Conditions under which assessment supports students' learning. *Learning and Teaching in Higher Education,* (1) 3-31.

Hargreaves, D. J. (1997). Student learning and assessment are inextricably linked. *European Journal of Engineering Education*, 22 (4) 401-409.

Johnson D. W., and Johnson, R. T. (1995). Teaching students to be peacemakers. Edina, MN: Interaction.

Johnson, D., Johnson, R., and Smith, K. (1995). Cooperative learning and individual student achievement in secondary schools, in Secondary Schools and Cooperative Learning, J. E. Pedersen, Ed. New York: Garland 3–54.

Ramsden, P. (1991). A performance indicator of teaching quality in higher education: the course experience questionnaire, *Studies in Higher Education*, (16) 129-150.

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science*, (18) 119–144.