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Author

Li, Huaizhong, Howell, Simon

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Engaging engineering students through project-based learning and industrial site visits in a mechanical design course

Huaizhong Li[a], and Simon Howell[b]
School of Engineering and Built Environment, Gold Coast campus, Griffith University, QLD 4222, Australia
Corresponding Author's Email: lihuaizhong@gmail.com ; h.li@griffith.edu.au

Introduction

In the current economic environment, some engineering graduates have experienced difficulties in finding suitable graduate roles, and graduate employability has become an important issue for educational institutions. The gap between the capability of engineering graduates and the expectations of industry might be attributed to the fact that some aspects of the engineering curriculum are overly theoretical in nature, and this leads to issues where students are unable to apply what they have learnt when they join industry (Li, Öchsner, & Hall, 2019; Male & King, 2014). This could be caused by a lack of connection and interaction between educational institutions and industry, and as a result, the curriculum frequently fails to meet the needs of the industry (Shukla & Garg, 2016). It has been suggested that engineering students should be exposed to professional engineering practice during their courses (Allen, 1996). Others (King, 2008) have also suggested students should have closer involvement with engineering practice through site visits, exposure to practicing engineers, and involvement in practical engineering project work within their courses. It has been recognised that industry engagement within engineering education can help students to increase their motivation for learning as they can better understand the context and the connections to engineering practice (Male & King, 2014). It is clear that the increased motivation is able to enhance students' engagement in learning in terms of their attention, curiosity, interest, optimism, and passion.

Design of Machine Elements is a core course for mechanical engineering students. Since this design process is deeply enshrined in established design standards/codes that all engineers should be knowledgeable of, this course has been considered as difficult and boring by many students (Li et al., 2019). According to the science of learning, learning requires the connection of the neurons in our brain, to form neural networks that embed and store our learning (Vorhauser-Smith, 2011). Active learning approaches have been shown to be effective in improving students' learning (Biggs & Tang, 2011), and it follows that courses should include a range of interesting or meaningful activities designed to motivate students and improve the learning experience. Project-based learning (PBL) offers a number of educational benefits in learning and teaching (Mills & Treagust, 2003), such as the use of real world applications with tasks closer to professional reality, higher motivation to students, and better teamwork and communication skills. It can put students into a simulated work space with some challenging design tasks so that students are able to develop effective design solutions under realistic conditions, work in a team environment, take the ownership of their learning, and improve student engagement, the educational outcomes, and their employability (Palmer & Hall, 2011).

As many undergraduate engineering students, particularly those in the earlier years of the degree, do not have any industrial experience, industry-oriented courses such as mechanical design can be very challenging for them. One potential solution for this problem is through the use of site visits, as site visits can help students match theory with practice (Eiris Pereira & Gheisari, 2019). They can motivate students and assist students to develop their understanding of how theoretical concepts are applied in a working environment. Although site visits have been widely adopted in construction education (Eiris Pereira & Gheisari, 2019), there is limited research into the use of site visits in machine design courses.

As part of a strategy to ensure graduates are job ready, not just in their technical knowledge but also in the full range of professional competencies (Howell, Tansley, Jenkins, & Hall, 2018), Griffith University has implemented a series of site visits into designated courses within the engineering program as part of a professional practice and employability skills initiative. This paper describes how PBL and a site visit have been combined in the Design of Machine Elements course, and improvement of student engagement measured by student reflection and a survey.

Planning

In the course design, a student-centred, learning-focused curriculum was developed. It aimed to actively involve students in the course, and engage students to develop and apply their knowledge and skills to solve real-world design problems. The main learning outcome of this course was the students' acquisition of strong analytical knowledge of machine elements, their design and load carriage/power transmission mechanics. In line with constructivist theory which asserts that learners construct knowledge through their own activities (Biggs & Tang, 2011), the Design of Machine Elements course was designed to be delivered through a combination of specially developed lectures, tutorials, case studies, and hands-on design projects. The teaching and learning activities and assessment tasks were carefully linked to assist students to reach the intended learning outcomes. The arrangement of the design project and design workshop was based on a holistic model of the experiential learning process (Kolb, 1984) which includes four elements: concrete experience, observation and reflection, the formation of abstract concepts and testing in new situations.

Design Project

In the design project, students were required to design a gearbox based on a set of assigned conditions using the knowledge they had learned or were learning in the course. The design project was arranged with a specific application background with practical demands from industry. Students were formed into small groups with 4-6 team members to mimic an actual engineering team in industry. They were asked to design a power transmission for an industrial application, such as a conveyer, an industrial saw to cut metal tubing, or in a vehicle. Each group was provided with different set of parameters for the drive shaft (output shaft of the transmission) rotating speed, and the minimum torque to be delivered. Specific requirements from “customers” were also listed. Students were asked to discuss the transmission configuration, select an appropriate electric motor, and determine number of teeth for each gear, distances between shafts, and length of shafts. It provided a chance for students to practise their skills in the design of shafts, gears, bearings. They were to explore different configuration and determine suitable parameters to achieve required lifetime and low cost. A stress analysis was needed to show that all parts are adequately sized and will meet all strength and life requirements. Students were required to analyse and design the shafts, select bearings, design and analyse the gears, specify key considerations for casing, lubrication and seals, complete the CAD drawings, and submit a group report. Students also had opportunities to have their designed components fabricated through 3D printing. The final project report was assessed according to the following aspects: Writing Quality, Technical content, Quality of engineering drawing, Manufacturability and assemblability, Completeness, and Teamwork.

The design implementation was guided by applying experiential learning theory. The project was arranged into a series of subtasks with some milestones within each week. For each sub-task, the lecturer firstly gave a brief review of the lecture content and related engineering theory, raised specific problems for the task, and provided specific examples to facilitate students’ design activities. Small group sessions were allocated for the group activities with about 10-15 minutes per task, and the task was then reviewed by the whole class. Students were given alternative chances to present their results and to answer questions from peers. The lecturer, as a facilitator, gave individualised feedback. In the project tasks, students were able to focus on what they learned in the course in terms of theory and procedures of machine elements design, to connect new information to what they already knew and had experienced, and to organize and structure the content and apply it to design practise. This increases the chances that students were engaged in deep learning rather than surface learning (Kember & Kwan, 2000; Ramsden, 2003).

Site visits

As part of the assessment in Design of Machine Elements, students were required to visit an engineering site relevant to the course topics. Site visits can provide students an opportunity to observe, reflect, process, assimilate, and comprehend real world situations and contexts associated with the design and manufacture of mechanical components, and thus enable the students to link their learning with real world practice. Three relevant companies in the local area, Digga Machinery, Practical Engineering, and Crown Engineering, were approached and agreed to allow small groups of engineering students to visit and tour their operations. Students were asked to choose one from the three sites to visit. Prior to the visit, students were required to do some preliminary research into the company they were due to visit, and to speculate on what they might see on the site visit. Students were required to take notes during the visit, and later had to submit a reflection on what they saw at the site, and how it links to the Design of Machine Elements course, as well as to their understanding of their future engineering careers. The total number of students enrolled in the course was 60 to 70. The acceptable group size for each site visit was discussed with the host company considering their convenience, and the group size was usually between 14 to 20 students. An academic staff was included to facilitate students in each site visit. When arrived at the site, there was one manager and/or a few engineers from the host company to guide the visit and give presentation. It usually took 2-3 hours on the site.

Implementation and Reflection

According to experiential learning theory, learners undertake four stages of learning cycling throughout the experiential learning process to construct knowledge. The four stages include concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). Immediate or concrete experience serves as the basis to observe and reflect on the occurrences. The site visits to manufacturing and engineering companies provided students a good opportunity for this experience and observation.

Observations from site visits

During the site visits, students had the following observations:

Production and manufacturing workshop

The site visit to Digga involved a tour of the production factory, and a presentation of the different CAD designs by the engineers. Digga was equipped with state-of-the-art manufacturing facilities. Many different manufacturing processes were employed, including laser/plasma cutting, folding/cutting machines, and robotic welders. The layout of the factory was in the order of the processes that the materials and product has to go through. During the visit, students were able to observe the engineering and manufacturing processes implemented throughout the production of gearboxes and heavy machinery attachments.

A students described the workshop in Digga as: *The worksite is a large-scale warehouse filled with heavy equipment. The variety of equipment that I saw in use includes: several CNC machines, several lathes and rollers, a laser cutter, a plasma cutter, and a robot laser welder. Additionally, the site had a 6-metre-tall sand-blasting machine to pre-work metal stock. The overall layout of the warehouse was one of efficiency: one side of the warehouse received metal stock, the roughing machines were next to this region, then finishing stations beyond that, and finally storage racks at the far end of the site.*

Crown Engineering primarily focuses on the development and production of different scale gearboxes and components mostly for the mining industry. In Crown Engineering, students observed different manufacturing processes. It also included an explanation of the process of residual stress building up in the gear from machining, and a lengthy annealing process involved to try and reduce these stresses. In the workshops visited, there was a chance to see a variety of machines in use. It was noted that a lot of the machines in use were from the early 20th century. They are still used in the manufacturing line as they are still as accurate as needed. However they are manually operated and take longer to machine parts.

Design practise and design for manufacturing

Students learned the importance of designing products to meet their task. Parts should only be designed for their purpose and if it is more effective to outsource a part than to manufacture in-house, then the more effective option should be taken. They realised that it is inefficient to manufacture every single part for a design. Students also learned about to set an appropriate safety factor in the design. Engineering software was used to verify the strength of the designed parts and to conduct simulation as well.

A student reflected that "*I was surprised by just how much trial and error was involved with our assignment and even more surprised again to see the same level if not more in this particular example of real world engineering. As an industrial designer doing this course I found it comforting to learn that most of the early design work was all done on Solidworks which is a program that I have become very familiar and comfortable using with through the course of my degree"*.

Team working and communication

On site of Practical Engineering, students learned that in a small company, engineers communicate directly with the client and the tradesmen. Working directly with the client enables project requirements to be efficiently met and results in high customer satisfaction. The engineers and tradesmen have mutual respect for one another. Designs are discussed between them both and simplified for manufacturing and cost reasons where possible. This effective communication is one of Practical Engineering's strengths.

Students appreciated the strengths of the site layout in a company, which enabled the engineers worked very closely with the tradesman and factory workers that built the product the engineers designed. The workers supervising these processes communicate with the other workers to ensure that the material is being processed correctly. They also seems to have very good team work and communication between different groups (project managers, engineers, boiler makers, fitters, etc.). Student reflected that *"We have found the same is true for our gearbox design assignment for our course 2505ENG, having each group member focus on a specific topic results in more in-depth work but the report as a whole is only coherent if there is open communication between all of our group members".*

Impact and influence on their study

The site visits enabled students to conduct reflective observations. These reflections were assimilated into abstract concepts about what happened, which in turn supplied additional information for further actions and active experimentation. With the new gathered information processed, the learners actively test the recent findings leading to new experiences and the renewing of the learning cycle (Kolb, 1984).

Better understanding of the role of engineers

- The role of the engineers in the company is to develop and design products, to improve and optimise the performance, by using innovative technologies. Students got a better idea about the daily working environment and activities, and the design tools used by the engineers, such as AutoDesk Innovator.

- After hearing an overview of what a day in the life of an engineer at Practical Engineering looks like, a student reflected that he was able to "*visualise myself in his position. I have always aspired to be an engineer that is able to innovate and work on new and exciting projects. I love hands on work and understanding why things are the way they are, and this is exactly what the Engineers at Practical Engineering do*".
- In the reflection, one student commented that "*My time at Crown Engineering left me with insight into possible engineering career paths, while also leaving me evaluating the end result of my degree. I find the use of modelling software and manufacturing enjoyable and interesting and as a result the site visit has left me with a positive outlook and a display of the vast opportunities within an engineering career*".

Higher motivation for course learning

- The designing that occurs at the Digga Site is very similar to the course 2505ENG Design of Machine Elements, showing examples of how CAD drawings are used in the industry as well as the long process involved in turning a design into a finished product.
- "*Visiting Digga has definitely broadened my knowledge on the scope of this industry. Before the visit I would never have realised many components go into mass producing a single product, from designing to production, to the importance of the site layout to the types of machines used. The site visit hasn't affected my career goals, only made me more intrigued at the complexity of different production processes and engineering projects.*"
- *In visiting Practical Engineering, a project was presented about designing lifting beams. An innovation in the design improved safety and students found that they were able to relate the work done in 2505ENG Design of Machine Elements to the work at Practical Engineering as they used the design process to implement ideas into workable solutions, just as they have innovated a usable gearbox for an electric saw this trimester.*
- *Throughout the tour, topics and fields we have studied within courses such as 2505ENG Design of Machine Elements were constantly present. Shaft design and gear trains are an enormous aspect of Crown Engineering's work. Discussion of Spur and Helical gears within the industry of manufacturing was provided from our guide. It was also very interesting to see aspects of our main assessment piece (the design of a transmission system) being applied. Seeing shafts in their raw state with rough surface finishes next to the finished products with different diameters, smooth surface finishes, fillet radius, and teeth cut into the material was very refreshing and showed a strong link between our main assessment piece and the real world.*
- *An evaluation of the links between DIGGA and Design of Machine Elements are numerous. First off, DIGGA is a manufacturer and supplier of machine elements. They turn raw metal stock into gears, shafts, augers, and gearboxes. Seeing how these items are made at an engineering site gives me a lot of insight into what types of parts could and should be designed by myself as an engineer. A point that stuck with me after the visit was one that several DIGGA staff pointed out: all parts had to be "designed to be manufactured." If a part couldn't be easily made, then it simply wouldn't get made, from a practical business perspective. This is the same lesson that our lecturer has been instilling in the engineering cohort throughout the course.*

Clearer target for future career development

- The site visit helped to give students an insight into where a recently graduated designer may start. "*As a designer, I now have a better idea as to what will be required of me in the workforce and the necessary skills needed to be competent*". "*Since the visit I am more able to understand the potential career pathways available to me after graduation*."

- Students realised that “a career in engineering meant continuous learning, it doesn't just stop once you get that certificate”. It was also interesting for students to learn about the similarities and differences between university life and industry life. *The similarities are that teamwork will always be important, reports and deadlines, and critical thinking and problem solving are integral. The difference is that in a real industry, it is more about practical solution, as it is what the costumers want and also because there much be more variables in real life when working on engineering projects.*
- *As an Industrial Designer, it is fundamental to have a knowledge of HOW and WHY products are produced- not only to converse with engineers in the supply chain of manufacturing and producing products but also expand design opportunities/career paths- this visit affirmed this aspect of my future career.*
- *In relation to my career goals, I plan to seek an opportunity to intern with a manufacturing company similar to DIGGA within the next 12 months. I feel that there is a lot that I can learn from working with designers and manufacturers, a lot of “on-the-ground” knowledge that would be otherwise difficult to acquire*.

Influences on the design project outcomes

It was observed that the site visits generated a positive influence on students which resulted in a better engagement and improved quality of the design project outcomes. Students demonstrated a higher motivation to do a better job in the design. More questions were asked to the lecturer and tutor related to further details of the machine elements under design. Students paid more attention to the machinability of the components they designed. A group of students sought opportunities to work in the workshop of the school and worked out a full set of physical prototype of the gearbox they designed.

Overall the average mark of the final project report in 2018 was improved to 79.5% from 68.4% in 2017. There was also a clear improvement with the Student Experience of Course (SEC). The overall satisfaction rate with the quality of this course in the SEC surveys was increased to 4.1/5 in 2018 from 3.5/5 in 2017. Student comments included that the “course taught relatable topics to industrial careers, making it extremely relevant. Coupled together with site visits during employability week, this course offered a lot of useful knowledge”, “This course was the best course among my courses this semester because of the way it was set out”, and “the hands-on project based learning is a very effective way of delivering this content”. Meanwhile, it should also be mentioned that organising the site visits was time consuming. It can be more challenging for a course with higher enrolment number.

Conclusions

The addition of a hands-on project has been shown to be a very effective way of delivering the content of the design course. The site visits have also allowed students to observe the engineering and manufacturing processes implemented throughout the production of mechanical components. These visits have helped students better see the links between their studies and the industry they hope to join in the future, and resulted in a better motivation for students to study harder in the course as indicated in their reflections. The implementation of the project-based learning approach and inclusion of site visits has been demonstrated as an effective approach to engage the students. The SEC results also show that overall satisfaction with the course has increased by 17%.

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