Does 'Just in Time' Design Thinking Enhance Student Interest and Appreciation of Customer Needs in the Design of Machine Elements?

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SESSION C5: Systems perspectives on engineering education

CONTEXT Design thinking which is becoming important in business and related disciplines has also begun to be engaged in engineering. This paper investigates the relevance and impact of student awareness of design thinking and customer needs prior to the onset of the gearbox design project assignment which is part of the course "design of machine elements" of the mechanical engineering program. This was implemented by providing students with 'Just-in-Time Teaching (JiTT)' of design thinking and stakeholder mindfulness into the course. The effectiveness of this intervention was assessed by conducting two surveys, one before and one after the presentation, and from focussed group discussions.

PURPOSE The research question is "Does 'just in time' design thinking enhance student interest and appreciation of customer needs in the design of the machine elements"?

APPROACH Sixty five second-year mechanical engineering students attended a presentation on design thinking with emphasis on sustainability and stakeholder needs prior to the design of machine elements (a gearbox) workshop. The students were also invited to participate in an interactive focus group discussion on design thinking one week after the presentation. Two surveys based on scores (1-5), one prior to the presentation of design thinking, and one, 6 weeks later at the end of the design assignment, were conducted to evaluate the impact of this presentation on students especially in their concept of gear design, cost, efficiency, aesthetics, safety, functionality, maintainability and sustainability.

RESULTS Compared to the first survey which was completed by 49 students, the results of the second survey which was completed by 38 students showed an overall improvement of the students' consideration of completion timelines, cost, efficiency, aesthetics, safety, maintainability and sustainability in their gear design. The most significant improvement was that their overall confidence level in the design of gears had improved by 27.2%.

CONCLUSIONS Dym et al. mentioned in their paper *Engineering Design Thinking, Teaching and Learning* in the Journal of Engineering Education (2005) that, "Design is what engineers do, and the intelligent and thoughtful design of the engineering curriculum should be the community's first allegiance". It is agreed that all engineering students need to have some element of design thinking in their curriculum. However a 'just in time' intensive mode of teaching may suffice and give the necessary outcomes.

KEYWORDS Design thinking, machine elements, mechanical design, just in time.

Introduction

According to Glegg (1969) in his book *The Design of Design*, science is about discovery and a scientist could discover a star but he will not be able to make one; an engineer could do it for him. Blumrich (1970) informed in his publication entitled “Design” in *Science*, that engineering, as a profession, is a creative process which involves the use of available knowledge, materials and other resources to solve new and existing problems. Engineering curricula have always been based on basic science with technological problems solved by applying scientific principles, and design has been said to be the core features of engineering (Simon, 1996). From the industry perspective, the design of effective solutions to meet social needs is deemed necessary in engineering programs and an attribute of an engineering graduate (Evans, McNeill, & Beakley, 1990; Sheppard, 2003). Engineering programs have also been said to lack sufficient scientific foundation (Braha & Maimon, 1997). These perceptions have led the industry to think that engineering graduates have difficulties practicing in industry. The perceptions have therefore led to industry’s recognition to support academia in good design education (Todd & Magleby, 2004).

Design and engineering have many definitions. Sheppard (2003) has put into perspective what an engineer would normally do in his work and that is “scope, generate, evaluate, and realize ideas”. In a way it is not dissimilar from the design process which to quote Sheppard is “scoping and generation, assessment, and selection (or evaluation) and the making or bringing to life (i.e., realization) of ideas”. Dym, Agogino, Eris, et al. (2005) cited that the highest priority in future resource allocation decisions for engineering in academia should be the inclusion of design pedagogy.

The nineties and beyond saw the design of products and services became a huge component in the business world and corporations were investing in becoming design leaders (Dunne & Martin, 2006). Design thinking which was becoming important in business was also featuring in engineering and architecture.

So what is design thinking? Design thinking is how designers think and learn. It is difficult to teach and, reflects the process of inquiry and learning in a systems context with the individual making decisions as they proceed, in a team based collaborative fashion (Dym et al., 2005). It also depicts the involvement of a client or customer and decisions are made through an ongoing feedback mechanism between “contractor/ engineer/ designer and client” realising in an optimum product or process. It is cross disciplinary and embraces creative thinking in offering solutions to problems. According to Parmar (2014), design thinking plays a critical role in educating a new class of engineers, and that design thinking can be integrated as a core subject in the first year via project based engineering and promotes new product development. Açar and Rother (2011) introduced the design thinking approach as a new means of systematic innovation, integrated the approach in engineering education, and reflected a complex process of inquiry and learning that merges engineering with design.

The initial intent in this study was to introduce design thinking as a course in the mechanical engineering program and to encourage students to be mindful of their stakeholders, the ecosystem and to use science, technology and design to solve problems (Chang, 2013). Several engineering programs worldwide have embedded design thinking into specific programs or as topics in specific courses/subjects. The question is whether these methods have delivered the expected outcomes?

Anecdotal feedback from colleagues in other universities and Griffith University informed that a standalone course in design thinking is time consuming, may not achieve the intended benefits as students tend not to integrate it into their core courses and their learning and decision making. Students have a very short attention span and tend to compartmentalise their thoughts. It is therefore decided that, in this study, to introduce mindful design thinking ‘just in time’ into the design of machine elements course. ‘Just-in-Time Teaching’ or JiTT (Novak, Patterson, Gavrin, et al., 1999) has a similar resemblance to the ‘Just-in-Time’

manufacturing process pioneered by Toyota in the 1970s (Monden, 1998) whereby students/ participants are introduced to a topic/process or a learning assignment just in time for its application. The main element of JiTT is active learning. Students control the learning process and this engagement between student and teacher which can be held anywhere is further enhanced with the use of electronic technologies (Marrs and Novak, 2004). Students who have difficulties in understanding a topic, could attend a pre class session to address these difficulties. JiTT allows the instructor the possibility to respond to the students difficulties when the students come to class and the students determine the discussions and lead the discussions (Mazur and Watkins, 2010; Marrs and Novak, 2004; Thomas, 2011). The student input is therefore 'just in time'. JiTT used in the teaching of science and science majors in undergraduate and postgraduate programs has shown improved student attitudes and study habits leading to interactivity and also increased retention (Marrs and Novak, 2004). It was reported that using a concept-based JiTT curriculum may encourage students to study and discuss the classroom material at deeper level (Riskowski, 2015).

Included in the following sections is an approach to providing students with JiTT mindful design thinking, the results of two student feedback surveys - one of which conducted before and the other after the presentation, the feedback from focussed group discussions, and, finally the conclusions of this study.

The Approach

In this investigation it is decided against the implementation of a full course in design or, any structured curriculum in design thinking as the curriculum was already very packed. The strategy was, to quote Knight and Wood (2005), to "teach more by lecturing less" and to use a version of JiTT to incorporate design thinking and mindfulness into the design of machine elements course. The approach was to provide the students with an interactive presentation on design thinking and mindfulness, or as it was introduced to the students 'mindful design thinking' at week four. Week four was just before the students start their design project.

The design of machine elements is a second year course in the mechanical engineering program at Griffith University. It is a course on modelling and design of power and motion transmission and control machine elements such as shafts, bearings, gears, fasteners and joints, etc., using physics, mathematics and core mechanical engineering principles (statics, dynamics, stress analysis, failure prevention, etc.). This course is delivered through a combination of specially developed lectures, design problem solving tutorials, and hands-on design projects in the design workshop. The main learning outcome is the students" acquisition of strong analytical knowledge of machine elements, their design and load carriage / or power transmission mechanics. The project activities are arranged in a way to be able to motivate each student by providing experiential, authentic, and challenging learning experiences. As many second year students have not as yet had any experience with a power transmission machine, the design of the gear box exploration and design workshop which are key hands on activities is organised into two main phases and scheduled to start from the second week of the semester. In phase one, students explore and examine a real world 3-speed gearbox used in a manual transmission car as the first project. Students form project teams with around 5-6 members. The lecture on the general theory of gears which was normally scheduled during week four. To help the students prepared for the workshop activities, a briefing on the basics of gear trains is deliberately brought forward to week one.

In phase two, students design a gearbox based on a set of assigned conditions using the knowledge they have acquired. This is organised with a specific application background, such as for a conveyor system or an industrial saw. The design team need to determine the configuration and key parameters to satisfy the project task specifications, required strength and functionality, and to create a set of engineering drawings for the gearbox. In week four, along with the briefing of the design tasks, an introduction of the design thinking and

mindfulness concept is included as an integral part for students to adopt in their design practice.

From past observations, student groups are typically keen to jump into designing the gear box and to finish the project. There is lack of discussion or preparation and also the discussion on the needs of the stakeholder (customer) are not a priority. The knowledge of design thinking which systemises the team discussion process and creates mindfulness of customer needs such as costs and sustainability would be useful.

The presentation on design thinking to 65 students of the Design of Machine Elements course was short and interactive and workshop style. It covered some basic concepts and applications of design thinking and mindfulness, and a few case studies including IKEA's success in the furniture industry. It was held at 9 am at the beginning of the class when the students are presumably "fresh and receptive". This presentation/workshop was literally 'just in time' and around 15-20 minutes. Students were then encouraged to engage in inter and intra group discussions for around 10 minutes. The teams then proceeded with their design project over the next 6 weeks with a weekly verbal reminder to use design thinking in their product design. The students were invited to participate in an interactive focus group. This discussion was conducted whilst the students were undertaking their project work within their project groups. The topic discussed was the usefulness of the JiTT presentation.

Results

Table 1. Survey questionnaire

No.	Questions
1	I am confident in carrying out stress analysis.
2	I am confident in completing engineering drawings for a typical machine element.
3	I am confident in the design of a shaft for motion and power transmission.
4	I am confident in the design of gears.
5	I am confident in the design of a full set of simple gearbox.
6	In my design, I always consider the functionality of the machines or devices.
7	In my design, I always consider the safety of the machines or devices.
8	In my design, I always consider the machinability, assemblability, and maintainability of the machines or devices.
9	In my design, I always consider the cost of the machines or devices.
10	In my design, I always consider the sustainability of the machines or devices.
11	In my design, I always consider the ecosystem related to the machines or devices.
12	In my design, I always consider the aesthetics of the machines or devices.
13	In my design, I always consider the efficiency of the machines or devices.
14	The teaching (lecturers, tutors, etc.) on this course is effective in helping me to learn.
15	What did you enjoy most about this assignment?
16	What did you enjoy least about this assignment?
17	Please provide feedback and suggestions on the arrangement of the design workshops and the course.

Two surveys were conducted in the week four and week ten respectively in the Design of Machine Elements class. The questionnaire consisted of 14 quantitative questions (No. 1-14), for which students were asked to indicate their response on a scale of 1-5, where 1=not at all; 2=very little; 3=some; 4=quite a bit; 5= very much; and also 3 qualitative questions (No.

15-17) with open-ended responses expected. The questionnaire is listed in Table 1. The results of the two surveys conducted are summarised in Table 2 for the 14 quantitative questions.

Table 2. The results of the two surveys conducted (for quantitative questions)

No.	Questions	Survey 1	Survey 2	Improvement
1	I am confident in carrying out stress analysis.	3.55	3.63	2.3%
2	I am confident in completing engineering drawings for a typical machine element.	3.47	3.39	-2.2%
3	I am confident in the design of a shaft for motion and power transmission.	3.16	3.54	11.9%
4	I am confident in the design of gears.	3.02	3.84	27.2%
5	I am confident in the design of a full set of simple gearbox.	2.84	3.42	20.6%
6	In my design, I always consider the functionality of the machines or devices.	3.96	3.84	-3.0%
7	In my design, I always consider the safety of the machines or devices.	4.00	3.95	-1.3%
8	In my design, I always consider the machinability, assemblability, and maintainability of the machines or devices.	3.67	3.87	5.3%
9	In my design, I always consider the cost of the machines or devices.	3.65	3.79	3.7%
10	In my design, I always consider the sustainability of the machines or devices.	3.67	3.84	4.6%
11	In my design, I always consider the ecosystem related to the machines or devices.	3.53	3.61	2.1%
12	In my design, I always consider the aesthetics of the machines or devices.	3.59	3.66	1.8%
13	In my design, I always consider the efficiency of the machines or devices.	3.69	3.96	7.2%
14	The teaching (lecturers, tutors, etc.) on this course is effective in helping me to learn.	3.57	3.71	3.9%

The first survey which was completed by 49 students, the results of the second survey which was completed by 38 students showed an overall improvement of the students' consideration of completion timelines, cost, efficiency, aesthetics, safety, maintainability and sustainability in their gear design. The most significant improvement was that their overall confidence level in the design of gears had improved by 27.2%, while the confidence level in the design of a full set of simple gearbox had improved by 20.6%.

As for the focussed group discussions, all 15 project groups of between 4-6 students agreed that "design thinking was useful". Three groups informed that discussions with stakeholders on their needs were extremely important and should be included in the project; however one group was concerned that this would impinge into the project time. Five groups suggested that design thinking be offered as a course in the engineering program. All groups agreed that in the scheme of things students may not use design thinking effectively as they are

always short of time and therefore they were not so sure of the usefulness of including a standalone design thinking course into the program. Two groups suggested that design thinking be used in Industry Affiliates Project (IAP). IAP is the workplace internship undertaken by students. Overall all groups agreed that the JiTT design thinking presentation was useful and interesting.

Conclusions

Dym et al. mentioned in their paper *Engineering Design Thinking, Teaching and Learning* in the Journal of Engineering Education (2005) that, "Design is what engineers do, and the intelligent and thoughtful design of the engineering curriculum should be the community's first allegiance". To quote the students interviewed in this project, there is a need to have some element of design thinking in their curriculum as well as the notion of mindfulness of the stakeholders needs. This study has given us indications that a JiTT presentation has improved students' perception of aspects which would be of interest to stakeholders/clients/ customers such as completion timelines, cost, efficiency, aesthetics, safety, maintainability and sustainability in their gear design. There would be a need to investigate further to ascertain whether there should be a standalone course in design thinking with mindfulness or whether it should be JiTT presentations. The suggestion of the incorporation of design thinking into Industry Affiliates projects is one that could be considered and could be a test bed to ascertain improvements in students' design of machine elements as well as cost benefits and customer satisfaction.

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