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THE CHALLENGES OF TEACHING DESIGN IN THE 21ST CENTURY, THE AGE OF THE FOURTH INDUSTRIAL REVOLUTION

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ABSTRACT
There is an ever-growing demand from industry for qualified design engineers. Many of these design engineers are trained at universities and colleges. This paper will explore how to keep this training as up to date and relevant as possible. It will look at the modern techniques and methods used by world-leading industries during the 21st Century. This century, known also as the Fourth Industrial Revolution, or the Information Technology Revolution. It will show how these techniques and methods can be applied in academia. A challenge is also highlighted, how to get students to design to industry standards but at the same time make it possible to assess their work to satisfy the needs of academia and awarding bodies. These modern techniques and methods will be applied to actual university students and an assessment made of the results. Use of group working will be explored and an algorithm developed to grade the completed group work. What do students need now to equip them to become competent designers, and what will they need soon?

Keywords: Design, knowledge, teaching, skills, peer assessment, future, Industry 4.0

1 INTRODUCTION

Before manufacture, a product needs to be designed. To design requires a specialist engineer, a design engineer, to develop an idea from conception and take it through to manufacture and production. Because of the importance of design to a company, it has been described as a core practice in engineering [1]. The Design Council, the United Kingdom's (UK) national strategic body for design has built up a solid body of evidence over a ten-year period. They looked at UK quoted companies which had been identified as effective users of design, the evidence showed these companies out-performed companies listed on the Financial Times Stock Exchange (FTSE) 100 by 200%. They also show, that for every £100 a business spent on design, their turnover increased by £225 [2]. According to the Association of German Engineers, about 75-80% of the total cost of a product is determined by design [3]. The latest forecast for the UK is that engineering employers need to recruit 182,000 people with engineering skills each year until 2022 [4]. A significant number of these engineers will be design engineers.

Design engineers have been found especially difficult to find and recruit [5]. Industry is looking for graduates with core skills of science, technology, engineering and mathematics (STEM) enhanced with a firm grounding in the engineering design process [6]. Where will the engineering sector find these engineers?

Universities and colleges have traditionally been a source of engineering graduates. Many graduates think that their university education did not prepare them for their current job [7][8] or it was found that graduates required extra training once employed. How can universities and colleges teach design engineers so that they are better prepared for their future role? What can universities and colleges learn from industry that can be used to aid their teaching? What are the needs of a modern design engineer in the 21st Century?

2 DESIGN THROUGH THE AGES

During the Industrial Revolution technological changes included new materials; new energy sources; new machines; work was organized into factories; new transportation; and increasing application of science by industry [9]. During this period designers and engineers produced some of the world's greatest inventions. The steam engine, telegraph, steam locomotive, the submarine, the telephone, the steamboat, transatlantic cable, the airplane, and the light bulb [10].

The first Industrial Revolution, in the 18th Century started with the introduction of the steam engine which made many manual jobs, mechanized. This was followed by the second Industrial Revolution in the 20th Century which was driven primarily by electricity. Design during the first and second revolutions was an in-house affair, each company having their own, small design departments. The third revolution, which we are still in, but which is ending, was due to the use of electronics and computer technology for automation in manufacturing. Design during the third revolution began with much larger design departments with hundreds of designer's working on more and more complex designs. With the introduction of computers, the design departments became small, but the complexity of designs has increased. We are now entering the fourth Industrial Revolution, also known as Industry 4.0, which uses advanced manufacturing and engineering. The speed of this revolution is unprecedented. Previous revolutions evolved linearly, the fourth is evolving exponentially. The breadth and depth of change will transform entire systems of design, and manufacture [11]. This revolution has heralded the design and manufacture of things never even imagined. The mobile telephone with instant internet access, automated factories, commercial aircraft, communication satellites, self-driving automobiles, and global positioning systems, are just a few of the benefits from the fourth revolution [12].

3 THE FOURTH REVOLUTION

How are products designed in the fourth revolution? The Design Council, which is an independent charity and the UK's government's advisor on design carried out a benchmarking study to inform UK businesses' understanding of the design process and specifically the processes used in companies deemed to be leading users of design [13]. Lego, British Telecom, Virgin Atlantic Airways, and Whirlpool were reviewed. Here is a summary of their findings:

- Modern design requires a team approach due to the number of skills and specialism required. No one person can have the necessary skills required to design the complex products we expect as consumers. Sometimes, on large design projects, sub-teams may be used which often would consists of specialist small and medium-sized enterprises (SME's). the total design team personnel could be into the thousands.
- Teams do not have to be in the same physical location, due to modern technology based around computers, the internet and software. Designers can be located internationally and use a central server to access all the data and research required. Conferencing software makes communicating as effective as if the participants were in the same room. Physical meetings are still recommended at crucial points in the design process.
- Close links are maintained between the design teams and the customer. This is achieved by regular meetings and presentations where a two-way dialogue can take place. As per the previous point, these meetings do not necessarily need to be physically in the same place.
- Most companies use an informal design process. To be too prescriptive, especially in the early stages of the design process could stifle creativity. As the designs develop more formal systems are employed.
- Sharing of ideas is encouraged within a company. The design process, at all stages is open to scrutiny which prevents designers from drifting away from the original design brief.
- Many specialist design companies are employed by larger companies as and when the design process demands.

As the fourth revolution continues to develop, and at a speed never witnessed, it is important that pedagogical methods keep pace as close as possible with industry. Working in teams, using conferencing software, developing relationships online, sharing of ideas across groups are all skills required by a modern design engineer and can be applied in academia. This will make the modern design engineer almost immediately useful to a company, ready to join the workforce and immediately be of value to the company, with a minimum in-house training required.

4 A MODERN CHALLENGE

The challenge for academics is this; future mechanical engineers need to be taught the skills, methods and understanding to make them good design engineers in the 21st Century, and so useful to industry.

At the same time, they need to be able to assess a student's abilities and determine if they have met the standard to pass the course they are studying on.
The dilemma is that the needs of industry will never completely match the needs of academia. Industry knows that no matter how good a design functions, no matter how good a design looks, no matter how economic a design may appear, no matter how innovative a design may be, at the end of the day it is the user who will decide if it is a good design [14]. If the users like it, they will tell others who will buy it. If the user does not like it then the opposite will happen, sales will drop and eventually the manufacture of the product will eventually stop. The user is the final arbiter of whether a design is good or bad.
Academia does not have the advantage of user input when assessing a design. Their assessment cannot be based solely on the product and how "good" or "bad" it may be perceived by others. They are required to assess the ability of an individual student who is required to demonstrate several skills such as group working, research, problem solving, material selection, application of engineering science, modelling, manufacturing technology, and costing.

5 LOGISTICAL APPLICATION

Students on the BEng (Hons) Mechanical Engineering programme at the University of Derby, approximately 120 students, during the 2018-19 academic year have just completed the final year design module. This module has been updated since academic year 2016-17 to bring it closer to 21st Century methods.
The task set for the students was to design either a car jack for use by Autosport teams or a screw jack for use in a mechanical engineering workshop. Specifications on loading, maximum size and required extension were set. A detailed report explaining all decisions made on literature review, material selection, hand calculations, assembly, Finite Element Analysis (FEA), cost, and manufacture was prepared along with a fully functioning model using SolidWorks. The model includes parametric design, optimization, movie showing operation, 2D drawings, and Finite Element Analysis (FEA). The report was handed in during semester week 12.
The students formed into groups of up to four. Each group planned their weekly work schedule and decided on the task's individuals would perform. The assignment was kept open-ended to allow the student's the greatest possible scope to develop their designs. On week 5 of a 12-week semester, each group gave a presentation to the rest of the class. The class could then ask questions. This encouraged the sharing of ideas to all the class.
Each week the lesson would start with a lecture. This would be based on material uploaded the previous week to the universities Virtual Learning Environment (VLE). This gave the students the opportunity to view the material in advance of the lesson. A timetable, produced before the semester began, was followed, its aim was to support the students through each stage of the design process, from earliest ideas through to a completed product. As the semester progressed, other topics raised by the students were added to these lectures to make the lecture as subject specific as possible. The lecture was followed by a tutorial. This allowed the students to test their knowledge and understanding with the lecturer assisting where required. During the second half of the lesson, the students formed into their groups and was student led with the lecturer in support. Most groups used social media to contact each other, to provide support and the sharing of information. This helped overcome geographical differences and more efficient use of time.
When a design group is formed in industry it is rare that an individual gets to choose which group or group's they are to be a part of. The selection is usually carried out by a manager and would be based on individual strengths, knowledge and experience. This would make a possible weakness in one team member be offset by the strength of another. The whole can be greater than the sum of its parts. In academia, to introduce group working, it was decided to allow students to form their own groups. The reasons for this were: timetabling required that groups be divided between part time and full-time classes as part time students only attend university one day a week; a significant number of students are direct entry into year 3 and so their previous knowledge, strengths, experience, and weaknesses were not known; the bonds between students, built up over their years of study would help support each other.
As expected, after the groups were formed most were made up of members that knew each other. Also included in most groups were a significant number of "unknown" members. These "unknown" members were to add an element of uncertainty to the groups. The final groups were very diverse, which according to Dieter and Schmidt [15] should result in a knowledge base that is broader and often more creative than a single individual. This is because of different educations and life experiences.

Verification of the above changes would be through industry feedback from design engineers, publication of peer reviewed papers, and review of student grades. Industry feedback will also be used once students have joined a company. The feedback will be on their ability to integrate into the design workforce with minimum in-house training required.

6 ASSESSING GROUP WORK

The most difficult part of this process and the one that caused the students most concern was the grading of the assignment for individuals, when the work had been carried out as a group. They want a fair grading for the quantity and quality of the work they, as individuals have done. Assessment is, generally, a complex process and when encountered within a group activity it may become even more complicated and difficult to manage [16].

In class, a lecturer would need to be with the group for all activities, which is not possible as there will be more than one group and a large proportion of the work will be completed away from the lecturer's view, in the student's own time. Those in the best position to assess the work of individuals students are the students themselves. This involves peer assessment.

Peer assessment is an arrangement in which individuals consider the amount, level, value, worth, quality, or success of the products or outcomes of learning peers of similar status [17]. A large amount of research has been carried out on peer assessment and this paper does not plan to add to it, only to apply it.

An important decision was whether peer assessment was to be anonymous or not? Lan [18] carried out an experimental study which indicated that a group of students who practiced anonymity in peer assessment outperformed their peers who practiced peer assessment while knowing the identity of each member of the group. However, the aim of this research is to align the teaching of design to closer resemble design in industry. Improving student grades is usually a good thing and would normally satisfy the requirements of academia. In this instance the requirements of academia come second to those of aligning with industry. The peer assessment would be carried out without anonymity. Each member of the group would know and be part of the assessment process.

If problems occurred within a group, then the weekly peer review and the final individual survey should highlight them. Students were also encouraged to E-mail their lecturer if any problems occurred. Thus, a strong body of evidence should be available to the lecturer so that any necessary adjustment of marks can be made.

7 GRADING ALGORITHMS

At the end of the semester, each group handed in their design model in a final group report and model. Each member of the group would initially receive the same grade.

On week 5 of the semester, the groups gave a presentation to their peers. At the end of the presentations and after questions had been answered by the group, each individual member received a grade based on their presentation skills. The individual grade was added to the initial grade from the report and design model that the group received.

In the weekly peer reviews, students gave an assessment of the work completed by each group member. This was signed by each group member and handed in. At the end of the semester, the average individual assessment was calculated. Students with the highest assessment received a weighted grade of 100%. Students with a lower grade received a lower weighted grade relative to the highest assessment. This was used to adjust the initial grade from the report and design model after it had the presentation grade added. The grading algorithm is shown in equation 1:

$$\left(\begin{bmatrix} Each\ group\ member \\ receives\ same\ grade\ from \\ Report\ and\ Design\ Model \end{bmatrix} + \begin{bmatrix} Individual\ grade \\ from \\ Presentation \end{bmatrix}\right) \times \begin{pmatrix} Individual\ student\ work \\ from\ Weekly\ Peer \\ Review \end{pmatrix} \qquad (1)$$

8 GROUP WORK PEER ASSESSMENT

Three times during the semester students were asked to complete a survey specifically on the dynamics of group work. A concern raised by many students at the beginning of the semester was the equal contribution made by each group member. Of 318 responses, 213 stated the contribution was "Always contributes; quality of contribution was exceptional"; 68 stated "Usually contributes; quality of

contribution is solid”. Individual contribution did not appear to be a major issue. This was backed by the survey question on Preparation. Of 309 responses, 203 stated the preparation was “Always completes assignment; always comes to team sessions with necessary documents and materials; does additional research, reading, writing, designing, implementing”; 77 stated “Typically completes assignments; typically comes to team sessions with necessary documents and materials”.
The student’s assessment grade profile for academic year 2018-19 is shown in Table 1.

Table 1. Academic Year 2018-19 % Grade Profile

Grade Range	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
No	0	0	0	3	7	18	46	26	15	1

Previous years (2015 - 2018) had a large proportion of students failing their first attempt and being capped at 40% in their second attempt. Compared to previous years the grades for 2018-19 are higher and follow the normal curve with standard deviation much closer.

9 STUDENT SUPPORT – NOW AND FUTURE

This paper suggest that group work is a requirement for designers. Students, especially full-time students will not have experience in industry. Group working requires skills such as organizing and planning, problem solving, communication, persuasion and influencing, feedback, chairing meetings, and people management. Some of the above can be covered in lectures/tutorials but practical examples can be provided by the lecturer when they meet with each group. This paper has dwelt primarily on the design process during the final year of a BEng (Hons) Mechanical Engineering. It is crucial that before reaching the final year, students are taught the required skill set they will need in the future.
The fourth revolution with its advanced manufacturing and engineering has been built on the back of the computer and the World Wide Web. This will naturally be the first-place students will look for information. The sources of information available to students is vast. How can students be reasonably certain that the Web pages they are using are from appropriate sources. Students need to be equipped to make this determination. University of Derby suggest their students use the following acronym, SMALLCAPS (Table 2).

Table 2. Information Source Acronym

S	Look for sites from **Secure** institutions.
M	Avoid **Mind-set** or bias.
A	Check the **Age**.
L	Consider the sites **Look**.
L	Check the **Links**.
C	Steer clear of **Commercial** sites.
A	Avoid anonymous **Authors**.
P	Avoid **Purchased** sites.
S	Look for sites that are **Specialists** in their field

10 CONCLUSIONS

By looking in detail at the design process of multi-national, successful companies it was possible to determine several important techniques and methods that assist their design process. Working in groups to utilize the strengths of individual, using social media so that individuals do not need to be in the same physical location, presentations to share information to others not in the design group. By implementing these processes in the teaching of design at universities and colleges it has been possible to close the gap between industry design and training in academia.
An algorithm to assess students group work was developed and applied successfully to several university classes with excellent results. The algorithm is in its early stages of development and requires refining to allow for different group size and quantity of work by individuals with the groups.
Students are still learning and so require support during their studies. This paper looked at a couple methods to provide support. First, how to work successfully as part of a group and second, to assist

students to determine appropriate sources of information from the vast amount of information available from the World Wide Web.

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