HOW TO TEACH MECHANICAL ENGINEERING DESIGN USING INDUSTRY METHODS WHILE STILL ASSESSING TO UNIVERSITY CRITERIA

PhD Thesis (Version 11)

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ABSTRACT

There is a growing demand from industry for qualified design engineers. Many design engineers are trained in industry at vast expense in time and money, while many more are trained at universities and colleges. This thesis will explore how to maintain the training by universities and colleges to be as up to date and relevant as possible. It will look at the modern techniques and methods such as design teams, use of computer software, communication, use of the internet, and methods to solve design problems. All these techniques and methods are used by world-leading industries during the 21st century; this century, known also as the Third Industrial Revolution, or the Information Technology Revolution. It will show how appropriate techniques and methods can be applied in academia. A challenge is highlighted, and a solution found, how to get students to design to modern industry standards but at the same time make it possible to assess their work to satisfy the needs of academia and achieve the awarding criteria. Modern techniques and methods will be applied to university students and an assessment made of the results. Use of group working will be explored, and an algorithm developed to grade the completed work. What do students need now, to equip them to become competent designers, and how do lecturers support these students in these new methods?

A knowledge gap between full-time students and part-time students in their final year of a degree programme was identified. This gap was reduced by reviewing the curriculum from earlier years and specifically targeting improving the student's knowledge. To reduce the gap further, the development of a new teaching theory based on reverse engineering and a reversed application of Bloom's Taxonomy was developed. This new teaching theory was applied to engineering student in their final year of a BEng (Hons) Mechanical Engineering Degree.

The above methods and theories were validated by experienced industry design engineers from world leading companies.

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ACRONYMS

AHEP	Accreditation of Higher Education Programmes
AI	Artificial Intelligence
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacture
CE	Conformite Europeenne
CFD	Computational Fluid Dynamics
CPD	Continual Professional Development
EU	European Union
FEA	Finite Element Analysis
HEI	Higher Education Institution
IATF	International Automotive Task Force
R&D	Research and Development
UK	United Kingdom
VDA	Verband Der Automobilindustrie
WWW	World Wide Web

CHAPTER 1

INTRODUCTION

1.0 Introduction

The mechanical engineering industry, within the European Union (EU) is set to grow by 3.8% over the next 10 years (from 2016), with an estimated 3 million people directly employed in that sector (Growth, 2017). According to the Career Transition Partnership – Industry Sector Guide, 2017, the United Kingdom's (UK) engineering sector employs 5.5 million people in a variety of roles. These roles include mechanical engineers, electrical engineers, and civil engineers. Engineering UK, (2019), projects for the UK over the next 10 years, an annual demand of 124,000 engineers and technicians with core engineering skills across the economy, and an additional requirement for 79,000 related roles requiring a mixed application of engineering knowledge skills and other skill sets.

The growth recorded above was forecast before the UK left the EU on the 31st of January 2020 (Brexit) and before the first two cases of COVID-19 were confirmed in the UK on 30th January 2020 leading eventually to full lockdowns. Research is not complete, and the effect of Brexit and COVID-19 are still difficult to differentiate from each other, so a definitive statement of their effect is not possible, but some trends have begun to emerge.

- Prior to COVID-19 the mechanical and electrical sectors were under pressure from the investment delays associated with Brexit. The impact of COVID-19 was rapid and strong but the recovery of much of the mechanical and electrical market has been equally swift (Leggett, 2021).

- Brexit has two main affects; First, administrative barriers to trade (custom formalities or proving rules-of-origin requirements) and their accompanying costs; Second, disruption of labour flow directly affecting some manufacturing sectors and indirectly harming manufacturing by damaging service sectors such as logistics that support it (Bailey, 2022).

- Student enrolments for a first degree are little changed. There has been a steady increase every year since academic year 2012/13. Academic year 2020/21 saw an 8% increase over the previous year. The number of qualifications obtained during academic year 2019/20 decreased (-2%).

Academic year 2020/21 saw an increase of 6%. The decrease in the number of qualifications previously mentioned for academic year 2019/20 is explained by a significant number of qualifications awarded in the academic year not being reported until the following academic year 2020/21. This is likely to be linked to the impact on examinations and awards resulting from COVID-19 (HESA, 2022).

- International student recruitment up to March 2022 show 466,611 study visas granted. This is the highest annual number of study visas on record and represents a recovery from the lower number of visas granted during the COVID-19 pandemic but also an increase on pre-pandemic levels. The previous record was 307,394 for year ending June 2010, which is an increase of 52% (Universities UK, 2022).

Long-term, the effect of Brexit and COVID-19 on industry and education still has many unknowns. Most commentaries hope that long-term the UK will equal or better its position pre-COVID and pre-Brexit, but few are willing to try and forecast the future. Student numbers look unaffected. The number of qualifications dipped for one year but have now returned to their expected growth. International recruitment looks very healthy even when compared to pre-Brexit and pre-COVID. With more university places being taken by international students, and overall student numbers being unaffected, the future difficulty may be in keeping design engineers in the UK. The necessity to train future design engineers in the skills required to work in an international market have increased, especially in areas such as teamwork and communication via the internet.

Design has been known as the aristocracy of the engineering profession. A mechanical design engineer over 40 years ago was considered highly technically qualified, literate, numerate and a creative individual (Vesma, 1980). Today, the skills required of a mechanical design engineer have increased to keep pace with technological changes. A good understanding of the design and manufacturing process, a multidisciplinary, system perspective with product focus, and an awareness of the boundaries of one's knowledge are required (Mourtos, 2012). The Design Council – the UK's national strategic body for design has built up a solid body of evidence that over a ten-year period, UK quoted companies identified as effective users of design out-performed the Financial Times Stock Exchange100 by 200%. They also show that for every £100 a business spent on design, their turnover increased by £225 (Designing Demand, 2007).

For many years industry has supplied qualified engineers through training and apprenticeship schemes. Another area of supply is academia, through colleges and universities who train around 46,000 graduate engineers each year (Gibney, 2012). The increase in student numbers enrolling on an engineering and technology course in Higher Education can be seen in Table 1.

Table 1 Engineering and Technology Students Number over Time (HESA, 2022)

Engineering and Technology Students		
Year	Number	Change over 1 year (%)
2009/10	156,985	-
2010/11	160,885	2
2011/12	162,020	1
2012/13	158,115	-2
2013/14	159,010	1
2014/15	161,445	2
2015/16	163,255	1
2016/17	165,155	1.2
2017/18	164,975	-0.1
2018/19	165,180	0.1
2019/20	175,145	6
2020/21	183,160	4

In academic year 2009/10 there were 156,985 students which increased to 183,160 by academic year 2020/21. Data after 31st January 2020 is difficult to understand due to the UK leaving the EU. Since the 2016 referendum to leave, almost 11,000 academics have left the UK and 40% of students between the ages of 15 to 17 indicate that they were less likely to study in the UK (Engineering UK, 2020). Table 1 indicates that rather than student numbers declining, the opposite has happened, and they have increased. For industry to receive maximum benefit from theses graduates, it is important that the education they receive is attuned to the skills and knowledge they will use in industry.

Mechanical engineering design has grown in complexity. Single components have now been replaced with many different components connected or related to each other in a complicated way. The interaction of forces acting on this design also becomes complex requiring more advanced equations to understand them (Brad, 2008) (Collins, 2023). A complex design requires assembling all the components in the correct order, either manually, automatically or a combination of both. Deciding which method to use involves investigating the cost, efficiency, accuracy, quality, flexibility and scalability. Due to the number of variables, there are numerous references on how the best method can be determined (AMN Quality Solutions, 2023).

A major factor driving change in the design of complex mechanical components is the internet. For the last few years Generation Z or GenZ has been starting work or attending universities and colleges. The exact definition for Generation Z varies but is generally agreed to be the generation born in late 1990s and early 2000s (Warren, 2022). They are the first generation not to know a world without the internet. The 'norm' they experience as children is a world that operated at speed, scale, and scope. They develop an early facility with powerful digital tools that allow them to be self-reliant as well as collaborative (Witte, 2022).

It is important to define the internet in the context Generation Z and for this thesis. When the Internet is referred to, it will include some or all the following:

- Artificial Intelligence (AI) is a major category of the internet and computers, with a myriad subset (Fig.1). Machine learning, according to International Business Machines researcher Arthur Samuel who coined the term by saying it is the 'field of study that gives computers the ability to learn without being explicitly programmed'.

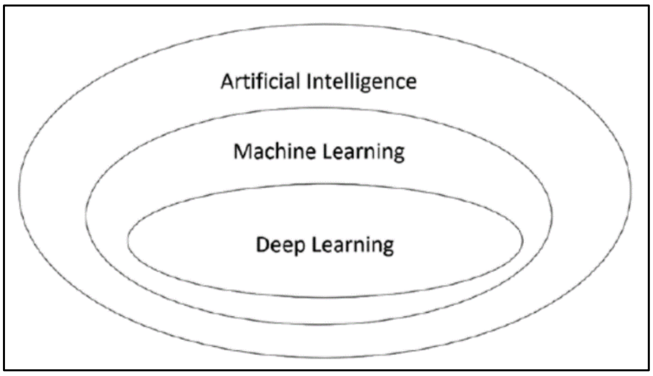

Figure 1 High-Level View of the Key Components of AI (Taulli, 2020)

Deep learning excels at identifying patterns in unstructured data, enterprises can use it to unlock the value of data they already have, revealing patterns they can use to create or improve products and services (Taulli, 2020).

- Modern networking has developed into the Internet of Things allowing for interconnection via the internet of computing devices embedded in everyday objects. Enabling them to send and receive data faster. This will empower the connected things with new capabilities (Li *et al*, 2015).

- Virtual reality, Augmented Reality, Mixed Reality, and Extended Reality all immerse the user in a virtual world by allowing digital objects to appear within material spaces (Fig. 2). An example could be in combining images from the camera of a mobile phone with a 3D digital model so that you can view how seats look in the interior of an aircraft cabin (Jones & Osborne, 2022).

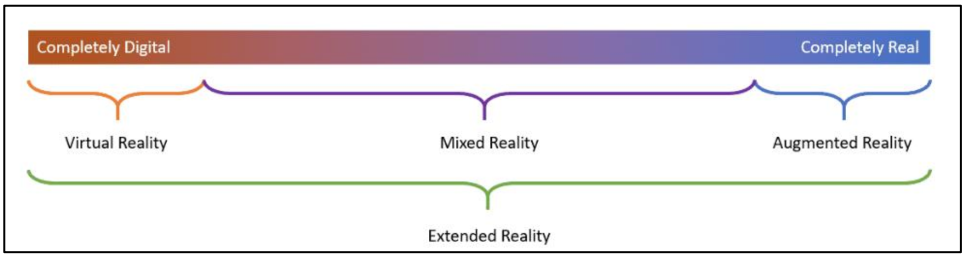

Figure 2 Reality - Virtuality Spectrum (Aniwaa, 2022)

- Cloud computing is on-demand access, via the internet, to computing resources and applications, servers (physical and virtual), data storage, development tools, and networking capabilities. These are hosted at a remote data centre managed by a Cloud Service Provider.

Design is an international collaboration of engineers with many different specialities. The research carried out in this thesis was from many different international sources, especially peer reviewed journal papers. The application of the research to meet the thesis aim was carried out in small steps and applied to student classes studying a BEng (Hons) Mechanical Engineering at The University of Derby (UK). Research was carried out in other Higher Education Institutions (HEI's) in the UK to determine if their methods and data differed in any significant way to that of The University of Derby (UK). As no significant differences were found, it would be safe to predict that any changes to The University of Derby's (UK) methods and any data used can also be applied to other HEI's.

The scope of this thesis will be limited to post 1992 HEI's. During this year the Further and Higher Education Act was approved by the UK government. This Act fundamentally changed the way Higher Education was taught in the UK and paved the way for the system of funding and organisation used today. Many HEI's prior to 1992 either didn't exist or existed as a college or polytechnic.

1.1 Research Rational

The rationale for performing this research study is:

- Prior to Brexit and COVID-19 the mechanical engineering sector required, annually 124,000 engineers and technicians (Engineering UK, 2019). The indications are that student recruitment is stronger than before Brexit and COVID-19 and could continue to grow, creating a greater demand for qualified design engineers (Universities UK, 2022) (HESA, 2022).

- The importance of engineering design to the performance and turnover of a company is shown in Fig. 3. This shows the impact of design, manufacturing processes, raw materials, management, and marketing on the overall product costs. The impacts are measured by the percentage of overall product cost affected by the activities in a certain category. Even though the minimal percentage of the actual cost is related to the design activities, they mainly affect the overall product cost. Because design has the greatest effect on product costs it is important that a company employ the best skilled designers as possible. This puts the emphasis on colleges and universities to train the best possible design engineers, ready to work in industry (Zhuming & Xiaoqin, 2020).

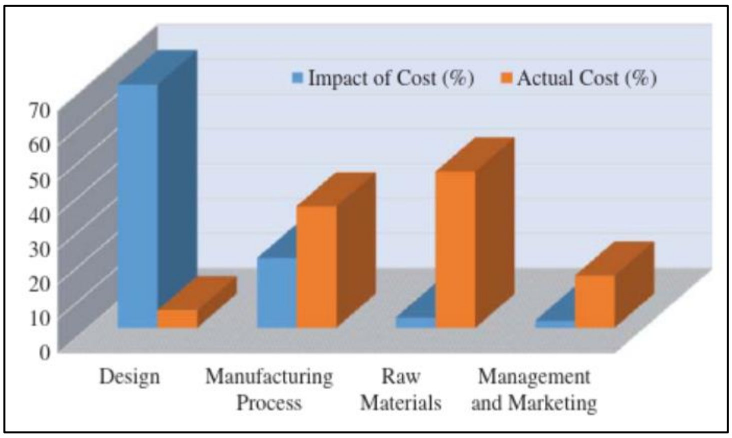

Figure 3 Significant Impact of Design Activities on Overall Product Costs (Zhuming & Xiaoquin, 2020)

- With changing technology, especially based on computer systems and the internet, it is important that academia keeps up to date and adjusts the teaching of students to fully encompass the changes (Hoidn & Klemencic, 2021).

- Organisation and planning of complex designs, working in teams, and using the latest technology encompasses softer skills that are important for students to have gained so that they can work alongside industry specialists (Volchenkova & Zhezhera, 2021). Academia and industry are on a journey. Each, in turn takes the lead with new methods and techniques to produce new designs. This journey has no end. At present, industry leads, and academia needs to catch up.

1.2 Aim and Objectives

1.2.1 Aim

The aim of this research is to narrow the difference between the requirements of mechanical engineering designers leaving colleges and universities and the requirements of modern industry, while at the same time making an accurate assessment of a student's abilities based on the criteria set out in Programme and Module documents.

1.2.2 Objectives

1. Carry out a literature review on the methods to teach design in colleges and universities to gain a comprehensive understanding of this area. A summary of main findings will be used to identify any gaps in knowledge.

2. Research the organisation and methods used by small, medium and large enterprises in the mechanical engineering industry sector to design single components up to complex parts and systems. Summarise the main findings that could apply to teaching design in academia.

3. Prepare a research methodology to address any gaps in knowledge identified in the literature review and any required future research.

4. Provide a reference section on the generally accepted design process used by industry. This to be used as a baseline of accepted methods.

5. Carry out interviews of design specialists in Higher Education Establishments to establish the methods and logistics of teaching design and if there are any major differences in their methods and those used at The University of Derby (UK).

6. Introduction into live student classes on a mechanical engineering degree programme the logistics and methods used by the mechanical engineering industry sector. Determine any support students may require using the new methods. Assess the benefits of applying these methods.

7. Review if further research is required into areas of teaching mechanical engineering design which cause student difficulties and that require support.

8. Further develop, if required, the organisation and methods of teaching design to mechanical engineering students based on the methods used in the mechanical engineering sector.

9. Once the new organisation and methods have been proven practical in live classes, validate the organisation and methods by peer review of conference and journal papers.

10. Continue the validation process of the organisation and methods from industry by requesting industry specialists to review the changes made and request comments on their benefits and appropriateness to meet the needs of industry.

11. Review the gaps in knowledge, and if those gaps have been addressed and validated to an accepted level.

12. Complete the PhD thesis and prepare to defend its findings in a Viva.

1.3 Gap in Knowledge

A thorough literature review was carried out (see chapter 2) on existing knowledge of teaching mechanical engineering design in colleges and universities and the requirements of modern industry when designing a complex component from new or through modification.

The review will focus on relevant academic literature from recognised experts in their fields. Published journal papers, appropriate internet web pages, books, trade literature, and video will all be read or watched, disseminated and where appropriate added to this literature review.

Two areas or gaps in knowledge from the literature review were identified for further research:

1.3.1 The methods used by industry to design complex mechanical engineering components making full use of the latest tools, many of which are a part of the internet (see introduction for definition of internet in the context of this thesis) such as, 3D modelling, virtual simulation, conferencing software etc.

1.3.2 Research the specific knowledge students require when learning to design complex mechanical engineering components and research the effect any changes made to teaching mechanical engineering design have on the students experience and achievement.

The two areas or gaps in knowledge identified above will be researched and become the basis of this thesis. The research methodology is detailed in chapter 3 and the industry design methods used detailed in chapter 6.

1.4 Chapter Summary

The mechanical engineering sector is growing and requires thousands of skilled engineers over the next 10 years (from 2016) to make this growth continue. The economic benefits to a company of skilled design engineers are clear. Those that were effective users of design significantly improved their performance and turnover. Even though industry and academia are producing many thousands of design engineers, a shortfall is expected. This shortfall will significantly reduce the performance of UK companies. The UK leaving the EU and COVID-19 has probably made things more difficult for industry and academia in terms of recruiting students and skilled mechanical engineers. Their effect is not clear yet and will take a few years to fully understand.

A major factor driving change in the mechanical engineering design of complex mechanical components and systems is the internet. In the context of this thesis, the internet was defined and will just be referred as the internet through the rest of this thesis.

A rationale for proposed research of two identified gaps in knowledge required by design engineers was explained in detail. The aim of this thesis was made clear and the objectives to achieve the aim laid out.

CHAPTER 2

LITERATURE REVIEW

(Objective 1 section 1.2.2)

2.0 Introduction

The aim and objectives of this thesis were given in chapter 1. At the conclusion of each section of the literature review, a summary will be given followed by signposting the literature review findings to the aims and objectives.

Lasher, (2008) highlights the challenge between industry and education as “the biggest priority for learning was to align it with business strategy”. To achieve this, it is necessary to “predict the needs of the user (industry) and move swiftly to select the most useful content and delivery techniques”. Specialist companies use many different methods to try and predict future trends. These can be divided into two main categories 1) quantitative – moving averages, regression analysis, exponential smoothing, adaptive smoothing, graphical methods. 2) Qualitative – Delphi method, Expert opinions, market research, focus groups, historical analogy (Zip Forecasting, 2020). Knowledge transfer between universities and industry, in the form of research is not new. This literature review will look further than knowledge transfer and will research industry methods that can be applied to teaching design (Berbegal-Mirabent *et al,* 2020). This literature review is a summary of the existing knowledge about teaching mechanical engineering design in colleges and universities and the requirements of modern industry when designing a component either from new or through modification. It will be based on secondary sources and is not trying to discover new knowledge or information but will set the direction of this thesis in-order to make it possible to find such knowledge and thus add to the depth of knowledge in this subject area.

This review will focus on relevant academic literature from recognised experts in their fields. Published journal papers, appropriate internet web pages, books, trade literature, and video will all be read and watched, disseminated and where appropriate added to this literature review. The relevant academic literature will be the most up to date available but will also include older literature to provide an historical perspective as even a few years can see large changes in methods and equipment.

2.1 Methodology

An initial literature review will be carried out by looking at the abstract and conclusions of appropriate published journals papers. Appropriate internet web pages will be reviewed to determine their applicability to the aim of this thesis. Preface and contents page of books and trade articles will also be reviewed. It is expected that many articles reviewed at this stage will be rejected due to the subject matter not being applicable.

Those sources of information that pass the initial literature review will be studied in more detail to ascertain their detailed relevancy or not. If relevant they will be categorised. After categorisation, each category will be considered and placed in the literature review that follows. The literature review methodology is shown in Fig.4.

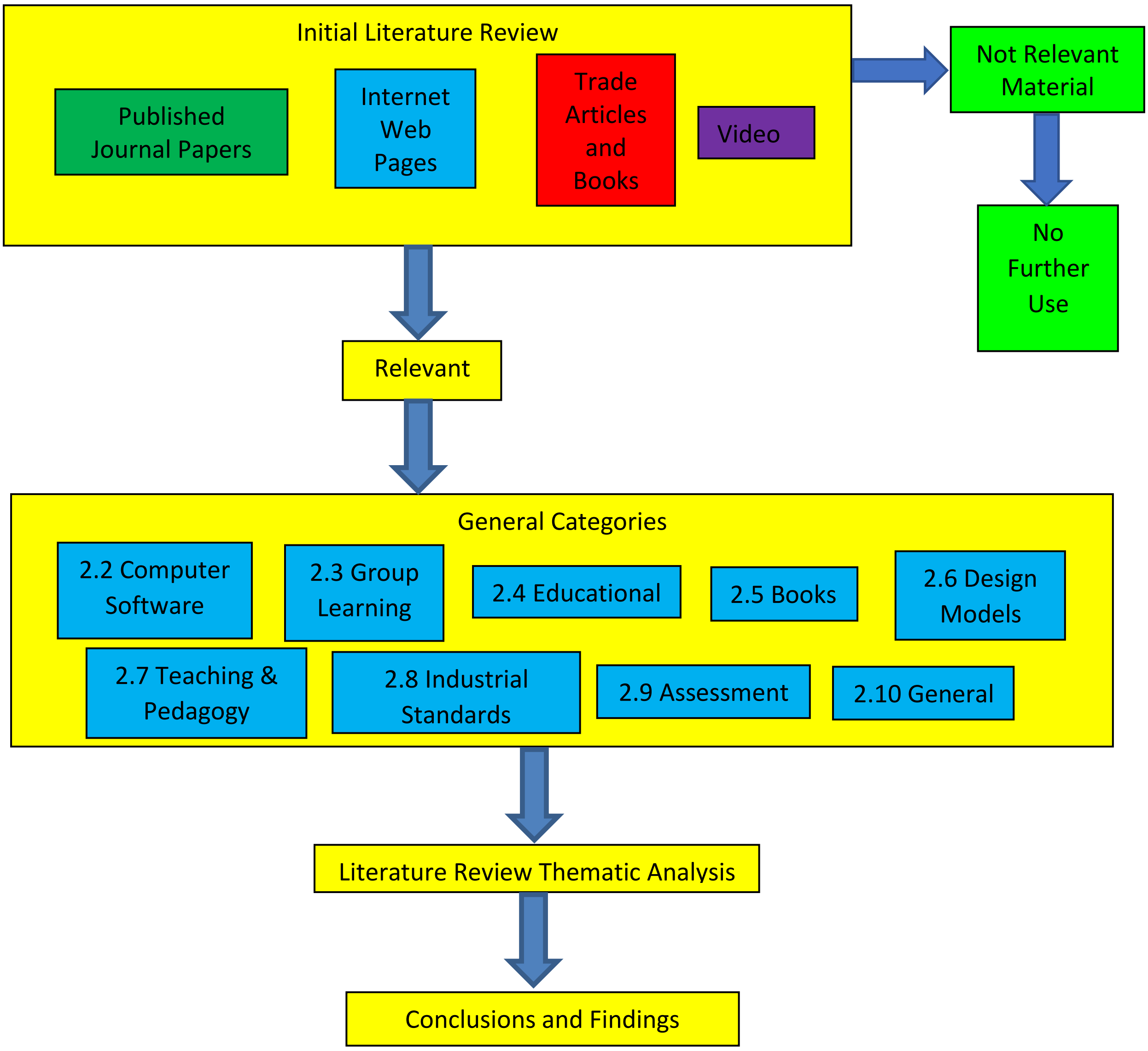

Figure 4 Literature Review Methodology (Sole, 2023)

2.2 Computer Software

Very few mechanical engineering designers in the modern world would consider designing a component without using 3D design modelling software. Due to this demand a vast range of software is available. Examples of 3D modelling software are, Catia, Solid Edge, Turbocad Designer, SolidWorks, and Autodesk Digital Prototyping. Other software such as Matlab, Ansys and Fems are used to support a designer allowing simulation, analysis and programming (Hooper, 2017) (Shakoor, 2020). These 3D software programs are for use on a high specification personal computer allowing users to access the system wherever they happen to be. 3D modelling can increase many-fold in complexity and cost until, at the extreme end of the market they become simulators which simulate dynamic movement, for example, an aircraft simulator used to train pilots. These simulators combine the virtual and physical worlds. There are similarities with these complex systems and 3D software programs combined with 3D printing systems. These will be discussed later in this section (Marlow, 1985). An opposite view was put forward by Elverum & Welo, (2014) who researched the early stages in the design process of seven automotive companies. The early stages were selected because, as most researchers agree that "the most substantial impact on the innovation outcome lies in the execution of the early phases". Case studies were looked at and prototypes were identified to play an important role regarding 1) enabled the team to explore various concepts and reduce mainly technical uncertainty, 2) communicating and gaining financial support from internal decision makers and 3) providing detailed characteristics to gain a deeper understanding of the product requirements. The research showed that using prototypes in the early stages of design was just as important as using them in the latter stages. The early stages of the design process, also known as the 'front-end' of design was graphically highlighted by Rodriguez-Calero, (2022) in Fig. 5. Starting with the Front-end design question in the centre, the question can be answered by going direct to the stakeholder specialist or to a prototype.

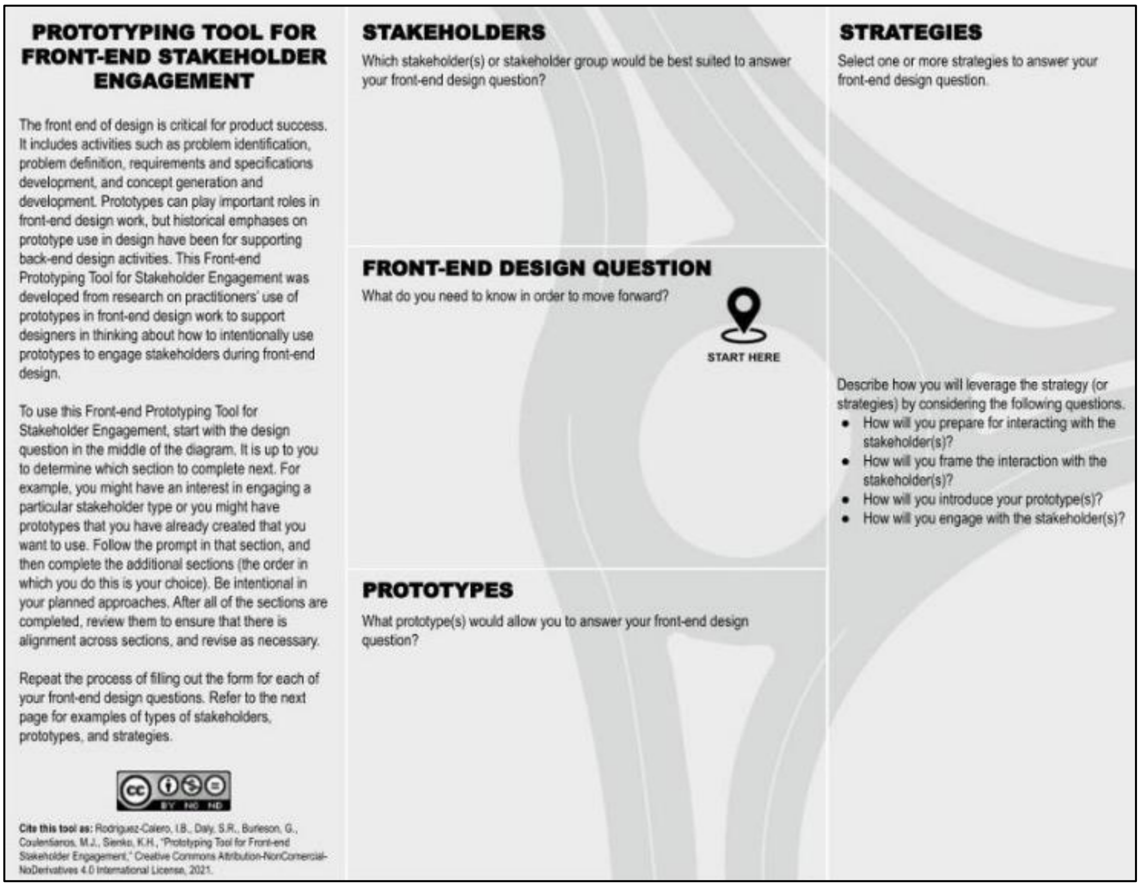

Figure 5 Front End Design – Prototypes (Rodriguez-Calero, 2022)

Visual and audio tools make a far greater impression on learners, registering learning outcomes in their memory better than the passive teaching of lectures. As educators we must make full use of all the modern tools available to us. Dramatic changes in technology have increased the variety and accessibility of information tools. Some of the latest information tools are: Online Google Apps, presentation software's, desktops and palm devices, course management tools, clickers, and lecture capture tools, even flipping the classroom. The difficulty is keeping up to date. Information technology changes daily, even hourly. This is illustrated well in Fig. 6. The benefits of an image in getting the message across, but also the importance of keeping up to date with the information presented in class (Scripavithra *et al,* 2022).

Figure 6 A Clear Message - Is it Up to Date? (Scripavithra *et al*, 2022)

Dormido, (2002) & Johnson *et al,* (2016) explain the problem well. “Educators must have an open attitude toward new technologies. They should sensibly incorporate new technological development to avoid the risk of teaching the students of today, how to solve the problems of tomorrow, with the tools from yesterday.” The need to teach modern techniques and technologies is highlighted. The important word here is “sensibly”. As will be seen in this literature review, there is a vast amount of research on the design process and the use of computers to help and support the design engineer. Indeed, much research has been carried out on the benefits or not of incorporating computer software in the education of mechanical engineers (Hassouny *et al,* 2013). School age students have been found to achieve lower marks when using computers when compared to those who never use computers (Karlsson, 2022). Some software will be useful, some not. A sensible decision on software selection needs to be made.

Modern Computer Aided Engineering (CAE) technology allows the integration of 3D modelling systems and production systems. This was foretold by Chaharbaghi, (1990) who’s vision was of whole production systems being modelled using computers. Today, this integration is a reality as detailed by Samadhiya *et al,* (2022). This highlights the strength of 3D modelling software. Single components can be designed, combined with other components to produce a complex system or assembly, the complex system or assembly is combined to produce a production system. The above systems are produced under the umbrella of designing for sustainability. Design engineers, according to Modler *et al,* (2020) and Sriraman and

DeLeon, (2001) typically design for function. It is accepted that as functionality increase, so does complexity (Fig. 7).

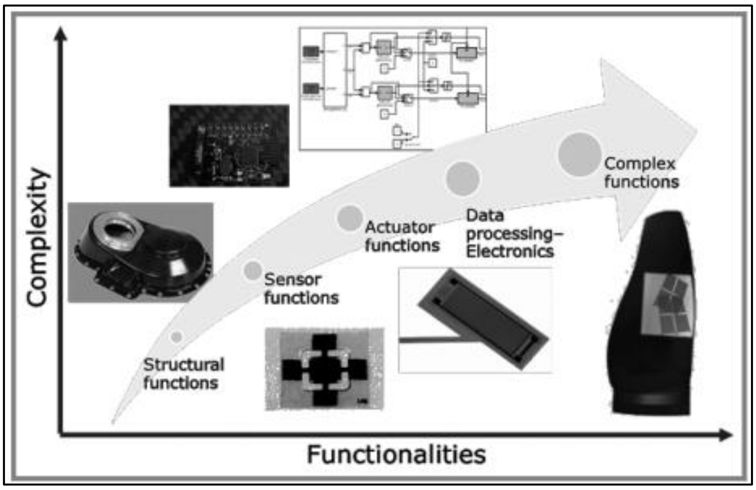

Figure 7 Functionality v Complexity (DeLeon, 2001)

Here is an example of a vacuum cleaner. The design engineer will attempt to achieve the best suction, and hence the most efficient cleaning possible. To a lesser extent, a design engineer may Design for Manufacture and Assembly (DFMA). The design of the vacuum cleaner achieves the desired function so the design engineer can now consider ways to make the manufacture easier; would a radius rather than a sharp corner facilitate the machining? Another example from the Douglas Aircraft Company helps to understand the benefits of apply DFMA. By identifying the optimal part design, material choice, and assembly and fabrication operations they produced an efficient and cost-effective product. The redesign of the Ram-air door assembly in their MD-11 airliner gave a 36% decrease in parts (from 2172 to 1383), a 34% decrease in the number of assembly operations (from 4038 to 2649) and the elimination of 107 pounds in weight. The redesigned door was also significantly more reliable and easier to maintain (Ashley, 1995) (Barbosa & Carvalho. 2014).

Rarely does the design engineer consider the assembly process even though it is estimated that 50% of the manufacturing costs are tied up in the assembly process. Modern modelling software allows the user to assemble the parts, very little attention is spent on how the parts are assembled. It is possible to carry out various analysis such as design for assembly, kinematic, dynamic and tolerance analysis. This paper (Sriraman & DeLeon, 2001) suggests that students should be provided with 'Design for Assembly' guidelines and the design process split into two programs; the first, how to produce parametric components, the second would concentrate on assembly and testing previously mentioned. A similar system was propounded by Swift, (1983) who describes a computer system that uses AI to try and advise a non-expert engineer regarding design for assembly and manufacture. The AI tries to determine whether manual assembly only, or assembly with some form of automation should be considered. The paper is not clear who this system is meant for. It describes its use by a non-expert engineer, which is not a clear definition, and later it says the application requires the user has expertise in the field of assembly. After Design for Assembly, Soh *et al,* (2016) takes the subject to the next stage by discussing 'Design for Disassembly'. This paper presents a methodology of applying 'Design for Assembly' and 'Design for Disassembly' from the remanufacturing perspective. Practical considerations, such as part accessibility and disassembly complexity, will be considered to determine the optimal disassembly sequence.

3D modelling software, as foretold by Medland, (1995) will allow the creation of products in reduced time and with fewer problems by addressing uncertainty of functionality faced by the designer at the earliest possible stage. This is true as 3D modelling has allowed the rapid development of virtual prototypes, which can be produced in hours and days as compared with manufactured prototypes which could take weeks or months or even years. Aroma, (2015) moves the development of 3D modelling software into a different area of evaluating rapid prototyping to support 'Human Factors/Ergonomics Evaluation' during the design phase. The conclusion provides an in-site into the degree of complexity when producing a 3D model. According to Aroma, it is not important to produce a model with high fidelity, of more import is the need to provide a 3D model with just enough detail to make good design decisions. Becker *et al,* (2005) was written twelve years ago but the development of 3D printing is explained in some detail. At the time of writing the paper, 3D printing was only used for basic components and prototypes, but the prediction was for their use in production manufacturing. Different raw materials will be used such as powder which provides the greatest flexibility; endless wire which can be used to create parts and add and repair them; liquid raw material in a bath in which parts are hardened by an energy beam; liquid raw materials in the form of ink can be used to produce micro and Nano structures, for example, human skin. Due to these emerging technologies, the point of production and the point of design can be a great distance away from each other. Good design can greatly reduce this journey time (Das *et al,* 2016).

Why is 3D software considered so important? Flatworld Solutions, (2017) lists nine advantages (Table 2).

Table 2 Nine Advantages of 3D Sofware

1	Improves the quality of the design
2	Increases the productivity of the designer
3	Easy documentation production and editing
4	Compatible with international standards
5	Automatic redrawing of design
6	Reduces design time
7	Better visualisation for clients by producing orthographic views
8	Saving of data and drawings
9	Saves costs due to the reduced time

To achieve the advantages just mentioned it is necessary to know the software well. Adding to the cost of purchasing the software is the cost for training. Both can be substantial. Once trained, modelling software can provide the advantages already mentioned. Generally, modelling software is accepted as accurately displaying simple through to complex physical systems (Satyandra *et al,* 2001). Allowing designers to produce single components, assemble them together, redesign, improve the design, consideration of assembly and production. The purchase cost of commercial 3D modelling software can be mitigated by using Free and Open-Source Software. Donato & Abita, (2019) compares Freecad with commercial software by providing a single case study of a steel canopy which was designed for the urban renewal of an open space in Teramo, Italy.

Modelling software has advanced features that provide the design engineer with some very powerful tools. One such feature is the use of parametric modelling, also known as parametric variational, and constraint-based modelling. Parametric modelling is a feature where the geometry of a model can be controlled by a set of parameters which can automatically change dimensions such as length, angles, and radii. The engineer is required to design a part and at the same time set up the parametric constraints. Once set, the model geometry will be changed just by entering one or two control values which will then change the model geometry based on the parameters set by the design engineer. Chua & Lye, (1998) provide a parametric example of the modelling of drinking bottles. Using parametric design, they create a library of parametric bottle parts which can also be parametrically joined to give a large database of possible designs. The final parametric design can be used by Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems. A great amount of time can be saved using parametric design, especially if the final configuration of a component is not known. The operation flow chart for the drinking bottle is shown in Fig. 8.

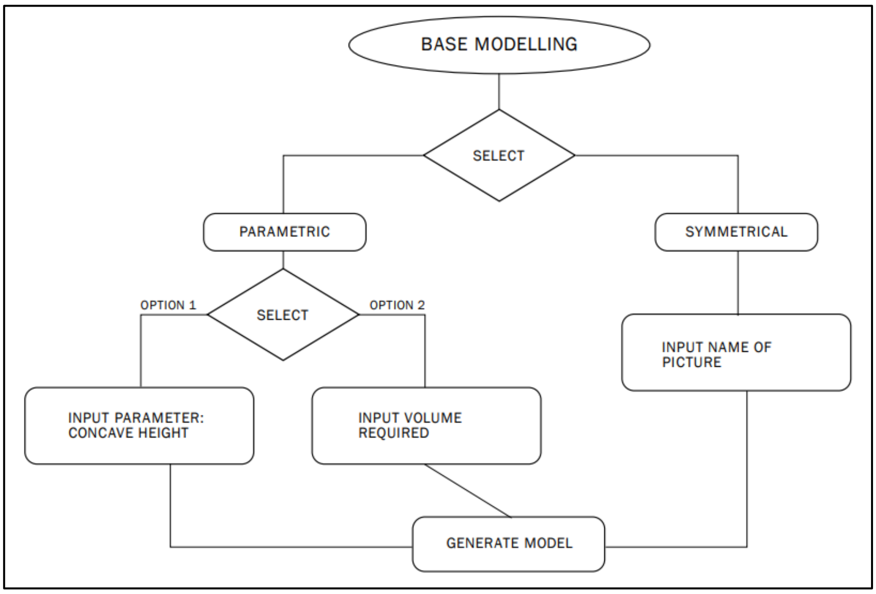

Figure 8 Operation Flow Chart for Parametric Design (Chua & Lye, 1998)

The left-hand side of the flowchart shows that in this example, parametric is used to adjust either the concave height or the volume. By changing one or both, parametric will redraw the model based on the control values. In 1998 when this paper was written, parametric design was limited by the computational power of the computer systems. Today's systems basically work on the same principles but can achieve much more due to the increase in computer speed and memory, allowing for software with increased analytical power. Sanchez *et al,* (2021) looks at improving aircraft design through parametric CAD modellers. Fig. 9 shows how parametric design can be used in a model's shape (geometry), size (subsystems within a system), place (positioning in the aircraft model), and other undefined parameters. These variables can all be analysed using parametric to achieve different outcomes such as thermal risk, maintenance, and electromagnetic compatibility.

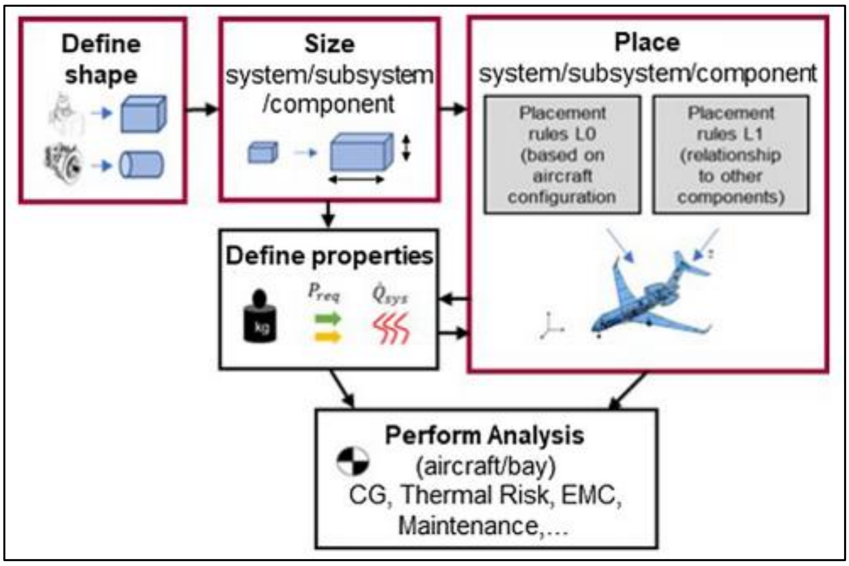

Figure 9 Operational Flowchart for Parametric Design (Sanchez *et al,* 2021)

An important step along the design process is the processing from CAD systems to CAM systems. Kyratsis *et al,* (2020) and Chen & Wu, (1994) looked at ways these two systems can be integrated closer. Previous methods used a system based on a model's surface or volume. The proposed system uses a model's shell which can incorporate both volume and surface. Their system allows the user to set geometric tolerancing, costing, fixture planning and Numerical Control programming which can all be achieved easier and quicker. This suggestion, if true, will benefit the manufacturing design process and would be something a design engineer would need to consider. The best of designs, if they cannot economically be manufactured are just a waste of time and energy. Foteinopoulos *et al,* (2016) produced a paper with a similar argument. An optimisation strategy for the design and manufacture of parts, combining hybrids of composites and metals. The strategy reduces the time for a successful design procedure by simplifying the often-complex process due to the many design parameters that must be defined. Novak *et al,* (2015) is along the same line of argument. Design of simulation models and their integration into industrial automation systems requires knowledge from several data sources and tools. The integration of tools and data is time consuming and error prone. The paper explores methods to integrate data sources and tools effectively and efficiently as a knowledge basis to support dynamic simulation for industrial plant. Reducing time and costs in the design phase of a product's life is important, especially in industry. This importance and the need to consider manufacture difficulties must be given consideration when teaching the design process.

An interesting and natural link suggested by Huang, (2016) is to link 3D modelling with 3D printing. No matter how well written 3D software is, no matter how high the quality of the 3D graphics, no matter how accurate the 3D simulation, there is still a difference between the virtual and real worlds. By linking 3D modelling and 3D printing the virtual model can become something that is tactile, real. This ability to produce a tactile real component will only improve as 3D printing improves. Maybe one day, complete complex machines will be 3D printed as prototypes. According to Huang, (2016) 3D printing is moving into 4D printing where the printed object possess smart behaviour such as self-sensing, self-actuating and shape changing. For a designer to use 3D modelling software to produce a prototype which will allow the design(s) to be verified in two worlds, virtual and reality is exactly what a designer requires. A quick and cheap way to design and verify their designs. 3D printing of houses has been accomplished for some years, showing that size of a component is not a limit in the design process. Kafle *et al,* (2021) shows the difference between 3D to 4D printing graphically (Fig. 10). Essentially, 4D printing means the 3D printing of smart materials. A smart material is a material that responds to external stimuli such as heat, PH, magnetic/electrical fields etc. The addition of stimuli makes a static structure into a dynamic one. An example is of a material that can change its shape when subjected to an external stimulus.

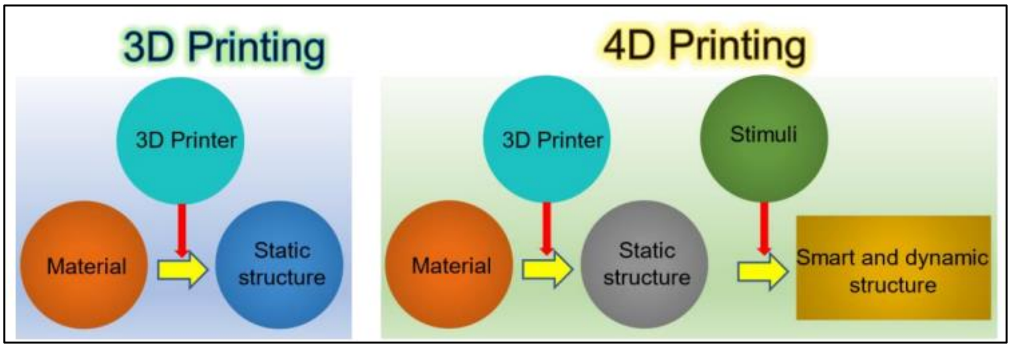

Figure 10 3D to 4D Printing (Kafle *et al*, 2021)

Another link suggested by Pan, (2014) is between CAD systems and CAE. The proposed combined system is known as Computer Aided Design While Engineering. Several commercial CAD systems are available such as NX, CATIA, Pro Engineering and SolidWorks. CAE is often applied to computer-based engineering analysis tools and methodologies such as Finite Element Analysis (FEA). SolidWorks already combine CAD and CAE, and this relationship is set to grow as computer's become more powerful and cheaper to purchase. CAE can have many variations. Ghaleeh *et al,* (2022) uses the term Computer-Aided Analysis when referring to a 3D model that undergoes a Finite Element Method to determine the stresses in a component.

If a designer does not have the necessary skills to produce a program for a 3D printer, their designs may be limited. It is now possible to purchase open access 3D models from the internet. Research on the type and range of 3D models available was carried out by Groenendyk, (2016). As the number of models increases, the need to preserve and curate them also increases. The validity and accuracy of these models must be ascertained and recorded.

It's not all good news for 3D modelling software. Some complex physical systems are not fully understood by computer logic. Maybe this is an area for future development of AI. One example highlighting the problem was provided by Answer & Mathieu, (2016) who discussed reverse engineering of components into 3D models. Reverse engineering is defined as the process of developing a set of specifications for a complex hardware system by an orderly examination of specimens of that system. 3D modelling software can have difficulties in interpreting the geometric shape of components especially when the geometric shape has been digitised. The software can miss-read this data and so provide an inaccurate geometric shape. Shapes are digitised because they are complex. By its very nature, a complex shape is difficult to check for accuracy.

For 3D simulation to be possible the complex system (materials, geometric shapes, loading, contact surfaces etc.) need to be mapped mathematically. This mapping is not possible unless the system is fully understood. An example was researched by Shimoda *et al,* (2016). A structure may need high temperature resistance in one part, toughness, or wear resistance in another location. This structure would require the modelling of composite materials and then possibly optimisation (Fig. 11).

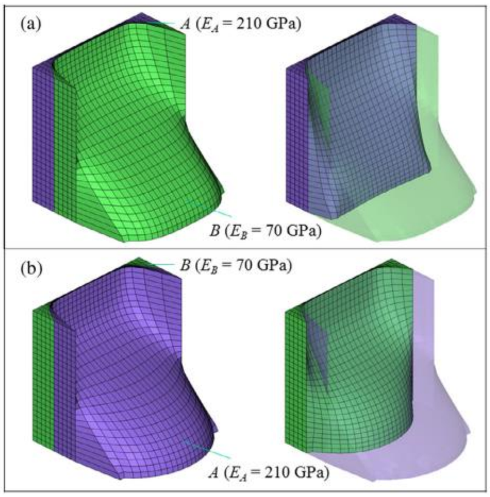

Figure 11 Optimisation of Composite Structure (Shimoda *et al*, 2016)

To manufacture such a structure would require the development of adhesive techniques. The adhesive when combined with the parent material would create a composite material which also needs to be modelled. Shimoda suggests using a freeform optimisation method to create the shapes which would include the interface where the adhesive would be found. The use of physical prototypes has not ended with the use of 3D modelling software. The formula already used by the software may not accurately reflect the system it is simulating. Very large amounts of processor time are required for complex systems to be simulated (GCE ICT, 2017).

Due to competition throughout the world, it is necessary to design and manufacture a new product as quickly as possible. It is at the design stage that manufacturing costs are largely determined. The assembly process is the single most important process contributing to both manufacturing costs and labour requirements. When productivity improvements are sought, design for ease of assembly must be given the highest priority (Boothroyd & Dewhurst, 1984). New Product Design stage, according to Relish, (2022) can reduce the time to launch a new product, provide greater product variation, and reduce materials and energy consumption. The New Product Design process is one of the most important issues in today's businesses.

Unfortunately, due to the size and complexity of some products, it can take years to bring them to market. An example is the Boeing 777 (Fig. 12) commercial airliner.

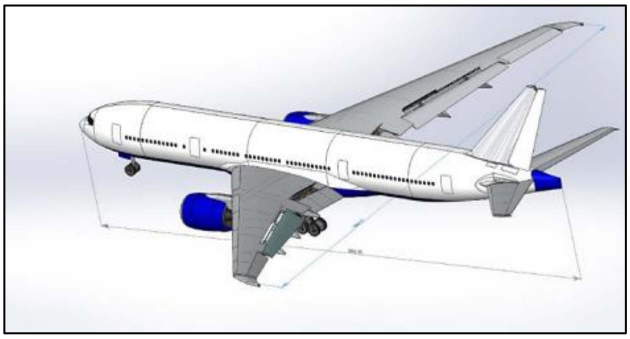

Figure 12 Boeing 777 CAD (Kuprikov *et al*, 2021)

From the first component to be designed, until the first flight, was over 16 years. To try and reduce this time the concept of concurrent engineering was applied. This had been used in other engineering projects, but never on a project with such complexity (McDonald *et al,* 2021). In the case of the Boeing 777, concurrent manufacture began while parts of the aircraft were still being designed. The shorter time to market reduced the development costs (Sabbagh, 1996). To achieve concurrent engineering which includes the design, the original organisational structure of companies needs to be replaced. Due to the complex nature of the new structure, computer systems were developed to help in the organisation. The integration of people and software was necessary. Chen & Wu, (1994) introduce a system which uses an axiomatic approach. This approach involves the continuous processing in four domains: consumer needs are established; these needs are then formalised in the functional domain; the functional domain is mapped to the physical domain which shows how we will achieve them; the three previous domains lead to the final domain, process, how the product will be made. This is another example of trying to formalise the design process which could affect the creativity and freedom of the designer (Stewart *et al,* 2020). The formalised approach to design will be looked at in greater detail in section 2.6 Design Models.

2.2.1 E-Learning

All designs begin with the designer understanding the requirements of the component or system. To get this understanding, knowledge is required. This is wide ranging knowledge which could include but is not limited to the following: material for manufacture, dimensions, stresses, thermal attributes, standard parts, fatigue characteristics, strength, component life, environmental footprint, mass, cost, surface finish, and manufacture (Stacey & Eckert, 2022) (Science Buddies, 2017).

Keckstein *et al,* (2015) suggests the use of electronic study materials. An example is provided of the description, design, calculation, and construction of a universal centre lathe. A lack of appropriate knowledge is identified, and the solution suggested is to provide better quality study materials. To provide the better-quality study materials, careful preparation, and research of related issues is required. A set of rules, methods, and techniques were developed before the design process was begun. The electronic study materials worked well but were too specific to a universal lathe. For this suggested system to work for most designs the study material cannot be specific but must be general which would defeat the object of producing the study aids. One very good suggestion is the necessity of dealing with real projects from technical practice instead of theoretical examples. Often in design, the use of real products, prototypes rather than virtual cannot be emphasised enough.

Cloud technology has made it possible for users to use the internet and smart handheld devices to perform various tasks. E-books and Apps are a couple of the results. Are these devices useful in engineering courses in a classroom setting? An extension to this thinking, can these devices be used in the design process? Jou *et al,* (2015) has carried out an empirical investigation on a mechanical engineering drawing course to determine whether E-books or Apps are beneficial.

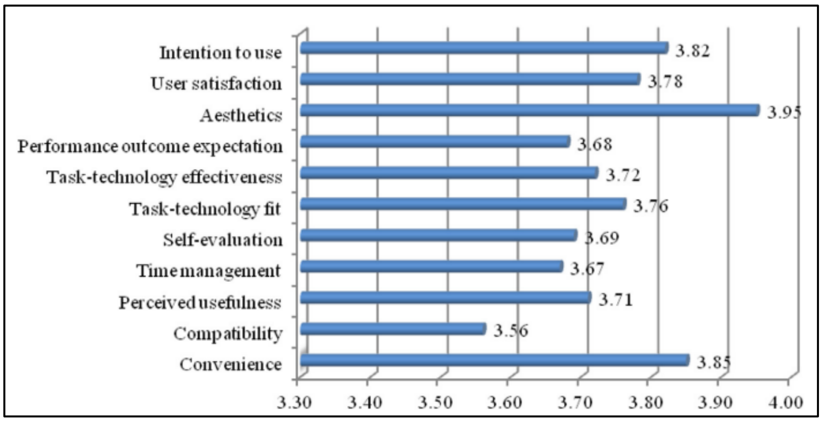

Figure 13 E-Book Usability (Jou *et al,* 2015)

The conclusion of the study was that both E-books and Apps are recommended to be used if they are written to suit the students different learning styles. If an individual has their own device, and most do, then E-books and Apps could be used to help fill the knowledge gap students have when designing, if the information source suits the students preferred style of learning. A survey of students on a mechanical engineering drawing course (Fig. 13) identified aesthetics, convenience, intention to use, and user satisfaction as the four highest usability score.

With the ability of the internet to share information with millions, it is only natural to extend this ability using social media tools. Gopsill *et al,* (2014) suggests a system called ‘PartBook’ (Fig. 14). As previously stated, in the early part of a design, design engineers will spend a significant amount of time searching for information from many differing sources. Gopsill *et al,* (2014) suggests social media can be used to fill in any gaps of knowledge in the process. Many complex design problems involve designers working in teams requiring close collaboration and hence communication. Tenopir & King, (2004) estimate that engineers spend from 40% to 60% of their time communicating, and this can go as high as 75%. This communication can be in many forms, reports, prototypes, parts, assemblies, notes, result files, Computer Aided Design files, engineering drawings and the product itself. Communication is also used in the coordination of tasks between engineers and project management. To encourage and control this communication, a bespoke Social Media tool known as ‘PartBook’ was created. This guides the design engineers in communicating with each other by categorising the different types of communication. For small to medium size parts this system could be good. For large complex parts or systems, too many categories may be formed making control of the communication difficult.

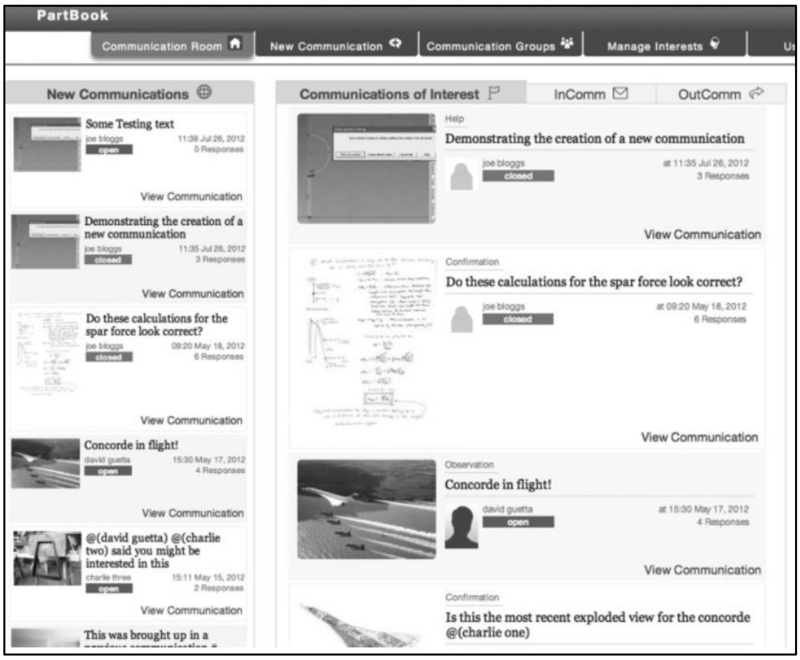

Figure 14 PartBook Screenshot (Tenopir & King, 2004)

2.2.2 Virtual World

The argument is, do we need real teachers or can they be replaced by virtual teachers. This subject was broached by Plantec, (2004) and Moodley, (2019). Making use of software already available, such as the WhatsApp platform to create an online social media network. The advantages could be many; they can teach any subject; they can automatically adapt their teaching style to suit each student's needs; easy to change personalities, language, student profiles, updating coursework. The virtual teacher could lead to remote course management or virtual learning systems. This article was written in 2004, so why have we not seen this change? Plantec, in his discussion inadvertently provides the answer. People learn in a carefully contrived learning environment replete with precise conditioned reinforces and variable schedules of reinforcement. Computer systems cannot provide the variable conditions that humans need to learn. Designers need the variation of imagination that computers just do not have.

Conversely, keep the teacher and make the course a virtual reality course (Hafner *et al,* 2013). This idea does have merit as industry makes more and more use of virtual reality simulation. Making a practical lesson a virtual practical simulation would help students use simulations and so make the transition from the classroom to industry easier. This paper aims to use virtual reality to simulate a practical engineering problem, along with teamwork, working in groups and time management. Students have an opportunity to learn from their mistakes which is expensive for industry to allow. Okutsu *et al,* (2012) tests this theory of virtual reality on a group of 135 second year university students. Their conclusion was that virtual worlds warrant further investigation for their efficacy in higher education offerings. The use of virtual reality can only improve as computers and software improve. A method for the future that cannot be ignored.

EmonaFrances & Wilkinson, (2001) provide an interesting perception to the design of a virtual classroom by comparing the design of an effective learning environment used for library instruction. The ergonomics of an electronic classroom was researched. The classroom size and layout, workstation design, and environment factors all can affect the virtual classroom. Students who enrol at university are usually computer literate but not necessarily information literate. Instruction in how to use a library helps, but most important was the physical (not virtual) environment. 25% of learning is dependent on the effects of the physical environment. The virtual world may have some benefits but these need to be balanced with the benefits from the physical world (Redner *et al,* 2020).

2.2.3 E-Laboratories

Why is it important that trainee engineers are allocated time in engineering laboratories? A student must learn whether their theoretical calculations lead to practical results. Students recognise the importance of laboratory work. At the National University of Juliaca, a survey of 72 pre-university centre students was carried out. The results are shown in Fig. 15. The question 'How important do you consider laboratory work for the training process as a future engineer?' was put to the students.

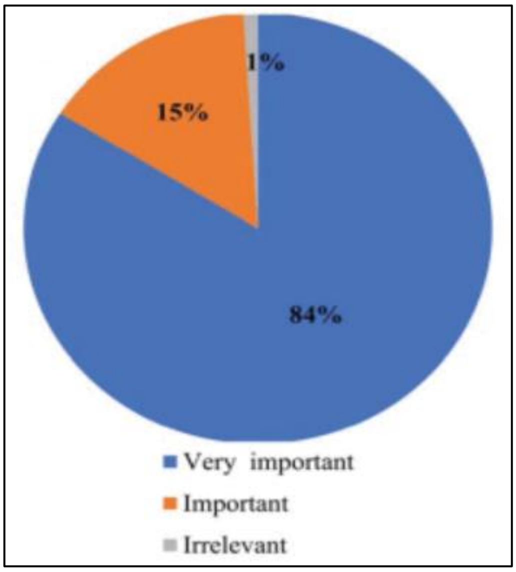

Figure 15 Survey Results (Tapia *et al*, 2020)

The results of the survey are clear, 84% considered that laboratory work was very important for the training of new engineers (Tapia *et al,* 2020). Lecturers will be familiar with marking a student's work who may state that the breaking strength of a piece of steel, by their calculations is several million tons per square inch (Easton, 1963), an obviously incorrect calculation given the design problem. This was written over 50 years ago but is as true today as it was then. Modern thinking still looks to laboratories to educate trainee engineers, but more and more are looking to E-Laboratories to fulfil this role.

To enhance engineering education and hence produce better qualified design engineers Morton & Uhomoibhi, (2011) and Ng, (2022) argue that E-Laboratories can be used to achieve this. E-Laboratories are not simulations but complete “hands on” experiments that can be remotely accessed off campus in a virtual learning environment. Is this possible? Or is this just simulation by another name. The degree of interaction varies considerably. Kirava *et al*, (2016) explored several E-laboratories from first programming principles requiring a high level of skill through to user-friendliness software requiring very little skill to use. Much of the software available is to simulate electronics which does tend to be easier to simulate than mechanical systems. The system proposed by Morton and Uhomoibhi, (2011) is a simulation where the learner interacts more fully with the materials and devices associated with the subject. More doing and less watching. Learners appeared to be more engaged with the laboratories and their level of enjoyment was increased, based on student surveys. This paper appears to be advocating E-Laboratories, but the papers own conclusion undermines this theory by showing the more ‘hands on’ the better for the student. Why not go fully ‘hands on’ and remove the computer simulation completely and go back to real, physical laboratories. Maybe the cost of resources is the limiting factor here? This argument is corroborated by Stefanovic, (2012) who concludes that remote laboratories provide a similar learning outcome to in-class learners but with important differences as to the perception of the experience including perceived difficulty and pace.

An opposite view of E-laboratories was suggested by Platts, (2004) who was involved in setting up a real laboratory where students worked in groups with an appointed manager and expert advice available. This is standard practice in industry. The interesting part was how the students were assessed. The team and individuals were assessed. The students must fully document the final system used and each student must write an individual essay reflecting on the learning acquired during the project. Observations are made by technical staff over the period of the project. The paper list in details the assessment criteria for the group and individuals. Taj *et al,* (2021) carried out an interesting survey of 150 students at the Polydisciplinary faculty of Beni Mellal in Morocco. The survey asked the students to compare their learning experience within a remote laboratory, a simulation, and hands-on (face-to-face). The survey questions are shown in Table 3.

Table 3 Questionnaire on the Interaction of Students to Practical Work (PW)

Interaction Students-PW environment	
Q1	The practical work environment is good for your learning?
Q2	Is this practical work environment collaborative?
Q3	Does the practical work environment save you time?
Q4	Does the practical work environment provide you with Good understanding?
Q5	Do you have more time flexibility in this practical work environment?
Interaction Teacher-PW environment	
Q6	Does the practical work environment improve teaching transmission?
Q7	Does the practical work environment ensure traceability?
Q8	The practical work environment facilities the framing of the students?
Q9	Is the practical work environment secure?
Q10	Effective time utilization in the practical work environment?
Interaction Teacher-Student	
Q11	Students more independent in this practical work environment?
Q12	Stronger group work in this practical work environment?
Q13	Do students make mistakes in this practical work environment?
Q14	Are Students motivated in this practical work environment?

The results are shown in Table 4. Hands-on (face-to-face) received a high score of 95% for Q1 - The practical work environment is good for your learning and Q4 – Does the practical work environment provide you with good understanding.

Table 4 Results of the Interaction of Students to Practical Work (PW)

Interaction	Question	Agree (Remote labs) %	Agree (Simulation)%	Agree (Hands-on)%
Students - Environment	1	80	75	95
	2	75	80	90
	3	95	80	75
	4	80	75	95
	5	90	70	60
Teacher - Environment	6	80	80	90
	7	85	80	90
	8	70	80	95
	9	100	100	75
	10	100	90	75
Teacher - Student	11	60	70	90
	12	50	60	80
	13	80	60	80
	14	80	60	80

Remote laboratories saved time (95%) better than simulations (80%) and hands-on (75%). The highest result was for Q9 – Is the practical work environment secure (100%) and Q10 – Effective time utilisation (100%). Table 4 highlights that there is little to choose between remote labs, simulations and hand-on (face-to-face).

2.2.4 Computer Software Summary

Summary

- Large range of specialist software available to produce single components through to complex assemblies.
- Virtual prototypes limited in usefulness. Physical prototypes still required.
- Software can be used to analyse the assembly and production process.
- AI used for designing the assembly process.
- 3D software combines with CAD/CAM systems.
- 3D software has difficulty simulating some complex parts.
- Complex companies can be organised by software to design and manufacture parts concurrently.
- E-books, Apps and social media can assist in the communication process.
- Virtual worlds and E-Laboratories can be limited in the experience they provide learners.
- Use virtual classroom but keep real teachers.

Signpost to Aims and Objectives

The use of computer specialist software is fundamental to the design process used by industry and so should be used to teach design in academia. Where possible, a physical prototype is better than a virtual prototype in teaching students and improving their experience. Virtual worlds and E-laboratories are acceptable to use, but students prefer face-to-face teaching. A full range of training aids are available to the teacher making it reasonably easy to differentiate between different student's abilities. Important not to rely on software more than industry does otherwise aim of this thesis may not be met.

Without computer software it would be near impossible for many of the complex designs to be achieved today. Two of the most important pieces of software are conferencing and modelling. It will be important to understand how industry uses these and apply that knowledge to academia.

2.3 Group Learning

It is very difficult to design anything without the assistance of others. This may be simply in the form of providing information/data such as materials, calculations, customer requirements, and dimensions to name just a few. The gathering of information is required in the early stages of design and continues throughout the design process at a lower rate. Often, a design engineer will work as part of a group, concentrating on just one part of a complex or large design project (De Hei *et al,* 2016). It is necessary for design students to learn how to work as part of a group.

Powers *et al,* (2009) describes using a graduate mechanical engineering student as a coach on a senior undergraduate design team. The role of the graduate was fourfold, design teacher, design reviewer, project manager, and customer. As a design teacher, the graduate introduced tools such as Critical Path Method and Program Evaluation and Review Technique. As a design reviewer, to ensure the design solution would be easily manufactured. As project manager, helping the team to create a schedule for the design project and making sure the team adhered to the schedule. The results of this study with design teams having a coach found that in all areas improvements were noted in the designs, but that the role of coach was a difficult and demanding one. A survey of 228 (Table 5) doctoral students in the American Psychological Society reporting receiving more socioemotional support from friends and family and student peers than from their faculty mentors (Tompkins *et al,* 2016).

Table 5 Social Support and Satisfaction Measures

	Life satisfaction	Program satisfaction	Faculty support	Student-peer support	Family/friend support
Mean	25.61	26.52	34.51	40.06	39.31
SD	5.81	4.55	8.51	8.52	8.15
Program satisfaction	.42**				
Faculty support	.45**	.50**			
Student-peer support	.40**	.38**	.44**		
Family/friend support	.39**	.21*	.31**	.37**	

As previously mentioned, Powers *et al,* (2009) describes a method to design as a team by using a coach. A major difficulty when trying to assess a team process is the need to measure collaborative design performance while at the same time maintaining or improving the final design output. This difficulty is addressed by Yin *et al,* (2011). Instead of looking at traditional methods to determine the success or not of a design, such as market share, investment return rate, and customer feedback, a matrix was developed of criteria to measure collaborative design across the lifecycle of the design. Such things as efficiency, effectiveness, collaboration, management skill, and innovation where measured (Table 6). The most important criteria were found to be decision-making efficiency. This provides a method to assess the effectiveness of a group but still leaves the problem of assessing the individuals when working in a group.

Table 6 Design Performance Measurement

Design Performance Measurement Matrix	
Efficiency	Problem solving skills, Work planning skills, Decision-making efficiency, Finishing work on time, Ability to work under pressure
Effectiveness	Delivering to the brief, Fast and detailed feedback, Personally responsible/work ownership, Managing conflict/mistakes, Separating work from social life
Collaboration	Information sharing, Cross-functional collaboration, Communication style, Clear team goal/objectives
Management Skill	Building team spirit, Creating an innovative working environment, Communicate effectively between individuals and the team (senior to junior), Define/fully understand role/s and responsibilities for yourself/ your team members, Personal motivation and passion
Innovation	Fully understand market potential & create a way to lead market, Enhance customer experience (creatively), Planning the innovation budget, Select the right creative concept to develop, Using the latest technology in the design

How does a design team decide on the direction the design is going to take? Toh & Miller, (2015) carried out quantitative and qualitative analysis in a controlled experiment. The conclusion was that design teams focus primarily on the technical feasibility of designs during the concept selection discussions as this is emphasised in engineering education. The teams neglect creativity during these discussions. The suggestion is to develop instructional strategies that encourage creativity. This is not a finished piece of research by Toh & Miller but does suggest one method to develop the design process.

Communication skills within groups is important. Millward, (2006) tries to improve how groups communication and what they communicate about. Two training devices are reviewed, STUFF (Table 7) architecture and SCRIP (Table 8) reports. Using common structures to communicate within groups found team performance increased. The improved communication also helped groups assess alternative designs.

Table 7 STUFF

Share information without being asked and do it often.
Try multiple communication strategies to ensure others understand you.
Use a common vocabulary.
Frequently confirm the group goal and your role in achieving it.
Forecast the needs and actions of other team members and adapt.

Table 8 SCRIP

State current group goal.
Clarify your role in achieving group goal.
Report your current role status.
Inform the team of your needs.
Predict needs of others and confirm them.

Choi *et al,* (2015) continues with the theme of group communication by suggesting the use of video clips on Smart phones. Experimental and control groups were used to determine the benefits of this form of group communication. The group size was small so would require further verification, but the initial finding appears positive.

2.3.1 Group Learning Summary

Summary

- Use of graduate students to act as a coach to undergraduate groups of students.
- Difficult to assess individual students while the students are working as part of a group.
- Design teams often focus on technical feasibility while ignoring the creative side of design.
- Various methods suggested to improve communication within groups.

Signpost to Aims and Objectives

The benefits of working within a group have long been known by industry. As the complexity of mechanical engineering design has increased, so has the need to design in a group. All members of a group would benefit if everyone collaborated fully on the design process. Aristotle said, ‘The sum of the parts is greater than the whole’ (Collins, 2023). With full collaboration from all individuals, the group would benefit. The challenge for academia is to develop a method where individual students can be assessed fairly while working as part of a group. Students are biased toward working as individuals and prefer not to be part of a team. The reality is that most teamwork is successful, and students find teamwork rewarding and problem free. If students are lacking in knowledge on a topic, then other team members with their knowledge will be able to help.

2.4 Educational

There is a vast quantity of knowledge based around educational theories. More recent theories have increased the focus on project-based learning, student centred learning, distance learning, flipped, blended, and hybrid or inverted classroom (Shuman, 2016). This thesis does not propose to review general theories of education. This literature review has researched education theories specifically directed for the teaching of design to mechanical engineers. Many graduate engineers report that their undergraduate degree covered very little in what they now do day to day in industry. Some found the analytical methods they were taught were useful, but they still found much required knowledge lacking (Sounding Board, 2015). Many engineering programs concentrate on teaching theory and methodology, often neglecting their application to real world problems. Can theory and practical be combined using web-based interactive software? This is partially looked at in the previous section on virtual world and E-laboratories. The need to combine theory and practical is not disputed (Nickchen & Mertsching, 2016).

2.4.1 Required Knowledge

Mechanical engineering design is a non-trivial and a largely knowledge-based and information-rich activity. To achieve qualitatively good and well-functioning designs, it is crucial to understand the details. Deep domain knowledge is required to come up with any reasonably realistic design in the end (Reimlinger *et al,* 2019). This can be judged by the range of different products designed by engineers: cars, computers, aeroplanes, telephones, machine tools, tape recorders, spin driers, lifts, light switches, sewing machines, excavators, digital voltmeter, the list goes on. Break these products into the individual parts required and the list of parts and the required knowledge becomes enormous.

Has teaching and learning in engineering education kept moving with the times? This was exactly the question asked by Kapranos, (2013). Innovative teaching and learning activities at the University of Sheffield were used as an example. What mindset do the lecturers at Sheffield adopt? It was not, 'if it ain 't broke don't fix it', instead it was 'yes this is great, but how can we do it better?'. The last quote sums up this thesis. There is a need for change, to move with the times. Industry has moved forward as has education but not at the same pace. In industry, things never stay still. Over the last few years, according to Toit-Brits, (2019) and James-Gordon, (2003) work-related training and formal instructor-led courses contribute to only part of the individuals learning. There is an increase in self-directed learning and self-development methods. The benefits of self-directed learning, according to James-Gordon, (2003) are listed in Table 9.

Table 9 Benefits of Self-Directed Learning

Self-development, self-awareness, and personal fulfilment.
Self-motivation due to being in control of the above learning variables.
Confident to work with others in the organisation and boosts morale.
Opportunity for pay-incentives, promotion, and reward for achievement.
Self-worth, self-esteem and feeling of belonging in an organisation.
Learner's ownership of the process ensures learning is personally relevant to the employee's role in the organisation.
Better equipped to contribute and better qualified to do the work.

Lewis *et al,* (2011) introduces an interesting pedagogic approach applied to international students. The issues that caused concern was a lack of preparation or engagement and plagiarism. Incremental changes were made to a postgraduate quality management module, the most interesting one being the mandatory requirement of students to complete a pre-lecture activity. The mandatory work was considered as a 'passport', if completed they were given access to the class, if not they were turned away until the 'passport' could be presented.

The learning methods of two companies was investigated. It was found that if the learning climate and learning methods were correct, the effects are beneficial to the organisation's learning and individual's self-development. Exactly what the correct learning climate and learning methods were not clear. After providing training, the engineer was encouraged to take the initiative straight away and use their newly acquired skills in a live design project. If they encountered difficulties, they were encouraged to turn to appropriate reference books and manuals and ask peers and experts. This sounds like it could be the equivalent of being thrown in at the deep end. Asking peers to gain required knowledge could be a two-edged sword, good and bad. The idea of learning by using appropriate reference books and manuals or by asking peers and experts is contradicted by Salandin, (2014) who's research, points to the need for active learning activities to foster better learning.

Design engineers require knowledge in many specific areas such as materials, engineering science, and manufacture. Designs must comply with safety legislation of the countries the design will be used in. Student design engineers must develop a way of thinking that includes designing safe artefacts. Behm *et al,* (2014) recognise that education is a primary source to infuse safe design knowledge. Table 10 lists the perceived design responsibilities of engineering students completing a four-year degree. They were asked to assign a value 'N' to each of the perceived responsibilities, one, strongly disagree, five, strongly agree.

Table 10 Perceived Design Responsibilities

Thinking generally, when designing an "item" (structure, machine, material, process, tool, work system, etc.), it is a designer's responsibility to design/allow for ...	Year	N	Mean	SD	*p*-Value
The item's purpose - e.g. capacity, power, size, output	1	70	4.37	.641	<0.01
	4	35	4.71	.519	
How safe the item will be to manufacture/build	1	69	4.29	.644	0.85
	4	35	4.31	.631	
Eventual users/workers who don't have their mind on the job	1	70	3.07	1.068	0.13
	4	35	3.40	.946	
How the item will be refurbished	1	70	3.66	.778	0.49
	4	35	3.77	.843	
Keeping the design to budget	1	70	4.14	.785	0.12
	4	35	4.40	.775	
Uses to which the item could be put other than the original purpose	1	70	3.34	.991	0.79
	4	35	3.29	1.152	
Access for workers who repair or maintain the item	1	70	4.10	.640	<0.01
	4	35	4.49	.612	
Workers/users who take short cuts when using the item	1	70	2.70	1.012	0.66
	4	35	2.80	1.232	
Information that will be needed to use the item safely	1	68	4.40	.650	0.29
	4	35	4.54	.657	
Making the item reliable – e.g. avoiding structural failure, overbalancing, breakdowns, overheating, etc.)	1	70	4.56	.673	0.21
	4	35	4.71	.458	
What will happen with the item is no longer needed	1	70	3.26	.988	0.07
	4	35	3.66	1.056	

To arrive at a good design, designers must get involved in a systematic inquiry beyond aesthetics and functions. Every student brings with them three elements to help in this inquiry, heart, hand, and mind. Heart implies a love and passion for participating in a process of making and creating. Hand is to do with aspects of making. A curious mind generates ideas and carefully inquires and reflects on the ongoing design. A working knowledge and practicality of engineering design prepares students for embracing the challenges of the future. The challenge for design education is to enable students to set up their own, independent inquiries into a situation that allows them to discover new insights and invent novel solutions (Junginger, 2007) (Brand, 2020). According to Newman *et al,* (2003) evidence suggests that modern undergraduates are not receiving the background understanding of how all the emerging technologies can be best used in the modern workplace. The design process is split into Primary Key Decisions which freezes the basic form of the design and on which all subsequent design considerations are based. After Primary Key Decisions comes Supporting Key Decisions which are based on the Primary Key Decisions and are a means of progressing the design (Fig. 16).

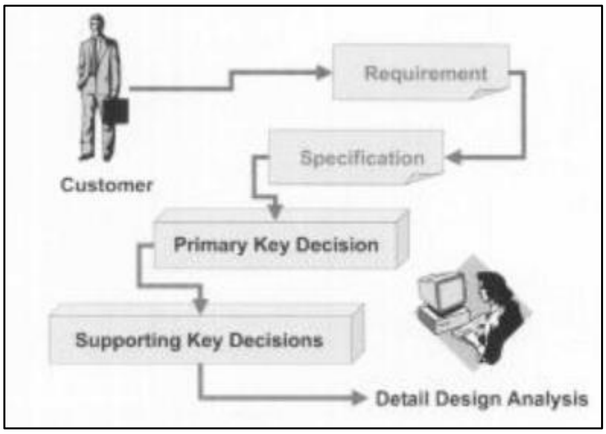

Figure 16 Engineering Design Process (Newman *et al*, 2003)

One way to deal with this is to develop library resources beyond what is normally accepted so that physical examples are also displayed. A library becomes a resource centre that can be accessed by students (Jha, 2016). Wicklein, (2006) puts as a primary need when teaching technology teachers of the future, elevated mathematics, and science. Most technology teachers are not prepared to tackle the mathematics associated with the analytical components of engineering. The paper suggests this issue must be addressed to produce design engineers of the future. As well as mathematics and science, Kadarova *et al,* (2014) adds the ability to diagnose problems, analyse them, suggest ways for improvements and decide which of the management tools should be used and which should not be used. But there are even larger areas of knowledge required that the mechanical engineering curriculum does not include. This lack of required knowledge is discussed by Cohen & Katz, (2015). They suggest a laboratory course that specifically shows students how to use manufacturers catalogues to select basic things such as fasteners, bearings, couplings, thermal treatment, measuring instruments. This list is produced to match the needs of the students depending on the design project being assessed. The author has found that when students are set a design problem it is the little things like fasteners that can cause the greatest difficulty. It is easy as lecturers, to assume, because our students are completing the degree and are studying at level 6 that they now have the required knowledge. The facts are, they do not have the required detailed knowledge.

Specifically, knowledge of mathematics, physics and technology is required for all mechanical engineers and especially mechanical design engineers. McDonnell & O'Neill, (2009) point to this lack of knowledge as stemming from secondary education and continuing into college (university) education. They suggest that these subject areas be encouraged in secondary schools and that college students should be mentored to ensure that students develop the required skills. They hope this will enable graduates to be used by industry in real live projects much quicker, rather than spending years in training them to improve their skill base. This paper reasons on the requirements that mechanical design engineers have and addresses part of the problem. They do not say how these subject areas can be encouraged in secondary schools. Additional to the knowledge that McDonnell & O'Neill refer to, Miller, (2017) looks at the knowledge engineers will require for the future (Table 11). All the things listed focus on the human dimension of engineering, working with others to create solutions.

Table 11 Future Design Knowledge

1	Teamwork and consensus building.
2	Entrepreneurial mindset.
3	Creative design.
4	Empathy and social responsibility.
5	Global awareness and perspective.
6	Ethical behaviour and trustworthiness.
7	Broad systems thinking.
8	Multidisciplinary thinking.

The knowledge listed above in Table 11 is very like those listed by Parsad & Athre, (2013) who provide a more detailed list of 15 key skills required in design (Table 12).

Table 12 Key Design Skills

1	Explore problem representation.
2	Explore graphical representation/visualisation.
3	Use functional decomposition.
4	Explore engineering facts.
5	Explore issues of measurement.
6	Build normative model.
7	Explore scope of constraints.
8	Refine constraints.
9	Conduct failure analysis.
10	Validate assumptions and constraints.
11	Search the space (evaluate design alternatives).
12	Examine existing design/artefacts.
13	Follow interactive/recursive/iterative design methodology.
14	Explore user perspective(s).
15	Encourage reflection on design process (self-reflect).

This list of key skills (Table 12) shows a process through which most designs would be submitted. It is very like constructivism which has been suggested as a good educational theory to teach design in the classroom. The above list could be written by an engineer or scientist. An important area of design not mentioned above but is critical to the design process is that of creativity. Charyton & Merrill, (2009) discuss the need for creativity after defining it as a preference for thinking in novel ways and the ability to produce work that is novel and appropriate. They introduce a method to assess a student's ability to be creative so that educators can enable students to develop their talents as future innovative engineers.

Mechanical engineering, by its very nature is hands on, and practical. Knowledge, as previously stated is critical in the design process. But knowledge needs to be applied so that it has a practical element. This has partially been accomplished by The Franklin W. Olin College of Engineering in the USA. They have produced an extensive library of material samples. These samples are available for students to use in their courses and enhance the mechanical engineering understanding of the students. This takes time to achieve, requires a lot of resources to maintain it, but does provide one aspect of practical knowledge essential for a successful mechanical design engineer (Magnoni, *et al*, 2012). In the UK, University College London has developed an Institute of Making which has its own materials library. This library is a collection of materials which students can pick up, feel, smell, shape, create into new materials (Institute of Making, 2020). Parallel to The Franklin W. Olin College of Engineering is the Rocky Mountain Institute, USA, who developed educational case studies to help engineers expand their whole system of thinking. At the time of writing the paper their ideas were still being developed but have shown potential to improve the way design engineers think on a project (Blizzard *et al,* 2012). Another proven method of bringing practical engineering into the classroom is to use lecturers with extensive industrial experience. A survey carried out by Johan, (2015) on student perception towards lecturers with industrial experience showed that students benefit from learning from experienced lecturers in the context of preparing them for employment as engineers.

With the vast amount of knowledge and in many different disciplines required by the design engineer the problem arises, how does the design engineer organise and retrieve this knowledge? Flores *et al,* (2015) suggests the use of Computer Aided Innovation. This computer tool is sub-divided into three sections (Table 13):

Table 13 Organisation of CAI

1	Strategy management such as arranging portfolios or scenario management.
2	Idea management which includes idea generation to idea evaluation.
3	Patent management used to protect inventions and search and analyse patents.

Many benefits are claimed; more efficient innovation process; dedicated tools to support innovation; collaborative work within the design process; simplified use of creativity techniques such as Theory of Inventive Problem Solving; and access to databases and to patent analysis. The suggestion is to move from Computer Aided Innovation to a more open Computer Aided Innovation which encourages collaboration not just between individuals but also companies. This may be a step too far as intellectual property rights of a company may be infringed as well as patent and copyright protection.

Capobianco & Joyal, (1996) make an important but not new point to do with required knowledge. Most research so far looked at, dealt with the required knowledge of the student, but this paper researches the required knowledge of the lecturer. To quote, 'To improve student learning, we must improve teaching. To improve teaching, teachers must engage in learning continuously as an integral part of their job'. This is an accepted fact. The article suggests that teacher knowledge can be improved by research. This would improve knowledge, but as has previously been stated, engineering is a practical skill that requires up to date practical knowledge, not just research. La Velle, (2022) suggests that teachers require knowledge of the subject content, knowledge of pedagogy, and knowledge of students. Most colleges and universities recommend Continuous Professional Development (CPD), sometimes stating a minimum number of hours per year to remain as a qualified teacher. This CPD could have a practical element, but usually does not. Academics like to stay as academics.

Lecturers, as previously stated can bring to the classroom real-world practical knowledge but must keep their knowledge up to date with CPD. This development does not always provide the required knowledge that a lecturer needs as it is often limited by time. Baroutian *et al,* (2016) carried out research into the benefits or not of co-teaching between academics and R&D professionals to integrate real world research into a Biotechnology course. The academics covered the theoretical parts, and the R&D engineers exposed the students to current R&D works. The academics have broad expertise in the discipline and teaching but often struggle with helping students understand that the principles of their discipline will be useful to them in their future employment. After quantitative and qualitative data was collected from students and R&D professional surveys it was found that co-teaching positively impacted on the students' learning. Fig. 17 lists statements made by the students highlighting the benefits they felt they received from working alongside R&D engineers.

Content removed due to copyright reasons.

Figure 17 Student Survey Statements (Baroutian *et al*, 2016)

MacLean & Scott, (2007) provides some very interesting research into how students view the training they receive and how it has benefited them as design engineers. Of 307 respondents from Canada and USA, just over 50% achieved a master's degree which compared with just over 30% in the UK. When asked if students agreed that they received sufficient training and development, Canada and USA led the field with around 30% while the UK was only at 13%. Membership of a professional body was around 80% for Canada, USA, and Australia, but for the UK it was at 50%. This data, though not conclusive indicates that in the UK, design engineers are not receiving enough appropriate education and development opportunities. Mertins *et al,* (2016) takes this a little further. Experience gained at university shows that training of a competent professional is impossible without an employer involved in this process. Table 14 list the abilities (skills) and competences required of a professional engineer.

Table 14 Required Skills and Competences for Engineers

Abilities (Skills)	Content of Competences
Planning and organisation.	Accuracy, punctuality, control, planning.
Leadership skills.	Activity, leadership, colleagues, respect.
The ability to analytical thinking.	Analysis, information search.
Cooperation.	Confidence, sociability.
Teamwork.	Ability to cooperate, emotional support.
Focus on success.	Perseverance, following the quality standards.
Perception of innovation.	Flexibility, initiative.
Professional skills.	Tutorship, professionalism, self-development.
Motivation.	Positive attitude toward work, energy.
Corporate spirit.	Loyalty, promotion of corporate values, following the corporate standards.
Stress resistance.	Attitude toward failures, work under pressure, emotional stability.
Independence.	Independent opinion, confidence.
Oral communication.	Oral literate speed, persuasion skills.
Writing skills.	Informative presentation, literate written speech.
Creativity.	Ideas generation.

2.4.2 Comparison of Industry and Educational Practice

The need and benefits of collaboration between engineering and science teaching is not new. Schneider & Picket, (2006) discussed the improvements in instruction when collaboration with industry is possible, but also that conflict and struggle is likely. Lilley, (1998) also discussed the importance of collaboration between industry and education. From pre-school through to university, continuous engineering education was suggested. It will take time to develop the necessary relationships. Comacho & Alexandre, (2019) provides a case study of a start-up company, AsPortuguesas and the University Lusiada Norte. After collaborating on a new design problem, the industry feedback was all positive (Table 15).

Table 15 Industry Feedback

They praised and appreciated the proactivity and audacity of the challenge and showed their complete openness for future proposals, even considering other methodologies.
The results presented as well as the human relationship generated made the experience fluid and stimulating, adding value for both parties.
The perspective of the students, of an age group identified with 'AsPortuguesas' products, allowed new reflections, until then not identified, on their brand image and products.

Their work is not complete and requires more research to determine how deep the collaboration is required and how to maintain it for the most benefit of students. Rentzos *et al,* (2014) carried out similar research. They point out the need for workers to adopt teaching curricula to cope with increasing industrial requirements. They suggest a very close relationship with industry allowing students to watch an industrial process such as welding live on video so that they can interact with the workers by asking questions and making suggestions. This is a good idea, but the practical application may be much more difficult. Brahimi *et al,* (2013) takes the collaboration suggested by Rentzos *et al,* (2014) to a higher level by developing cooperative training between students and industry. This is not a new idea, the first collaboration between industry and education was recorded as far back as 1906. Research found the attainment of students who collaborated with industry achieved higher grades than those students who selected not to carry out collaboration.

In several area's there are significant differences between design in the classroom and design in industry. Classroom settings normally set well defined problems for students to solve. Engineering students who only practice engineering problems often have a false sense of security that engineering problems are crisp and narrow analytical problems (Kelley, 2009). This is rarely the case in industry. Most design problems are open ended and are seldom well defined. Real world problems were found to improve the teaching, learning and assessment of mathematics in undergraduate engineering students (Nedaei *et al,* 2022). The Mechanical Engineering Department at the Rochester Institute of Technology appreciated the need to give their students a comprehensive design project, where their students get their first exposure to open-ended problems, teamwork issues, and communication skills needed to succeed after graduation (DeBartolo & Robinson, 2007). To try and create a more realistic design problem in the classroom the teacher must relinquish some control over the process by setting broad ideas and concepts and continues in the direction of ever-increasing detail, resulting in an acceptable solution. This open-ended process of teaching has a name, it is Constructivist teaching. Part of this method is for students to enhance their own knowledge and skill base by using interactive e-books with various multimedia components such as videos, animations, and case studies (Kelley, 2009) before attempting to suggest design solutions. Students' knowledge was enhanced more by creating a library of engineering case studies, often from everyday items that students would be familiar with (Fig. 18). This method reduces the need for trial-and-error design and contextualises the learning (Burghardt & Hacker, 2004) (Miller & Bures, 2015).

Figure 18 Library Case Studies (Burghardt & Hacker, 2004)

Do mechanical engineering design students have a preferred way of learning? According to James-Gordon & Bal, (2001) the preferred way of learning is by using visual means. Diagrams, sketches, photographs, schematics, flow charts, pictures, video, computer graphics and demonstrations in training programmes would all be excellent methods to use. To maximise their knowledge, student's need to design from broad ideas and concepts toward ever increasing detail. History confirms this. From early water pump design, airships, and aircraft, the use of visual means of paper drawings through to computer images has been an important, even crucial part of design (Sole *et al*, 2021). The material presented to them needs to be in a format that will maximise the preferred learning methods. Constructivism linked with formatted teaching material to match student needs. Walker & Prod, (1959), even though written some 63 years ago uses the teaching of Jig and Tool Design as an example of the need to follow constructivist teaching, (even though this term was not known then). Building from a broad knowledge base and constructing on this while narrowing the knowledge required to more detailed, specific knowledge. This is confirmed today by many experts in the field of engineering and pedagogy. The challenge is to overcome the passive instructional methods such as lectures and memorisation of facts. Constructivist teaching strategies, in contrast, increase students' engagement, link what student learn to meaningful contexts, and potentially help students to better organise and transfer knowledge (Reeves *et al,* 2020).

There are several paths that can be used to achieve detailed knowledge. Two automotive companies whose workers have increased demands for their work while at the same time have less time to learn have adopted a more self-directed learning approach. By having the right learning climate and methods available in the organisation, the individual can engage in self-directed learning. This method of learning involves individuals using their own initiative and taking responsibility for their own learning (Fig. 19).

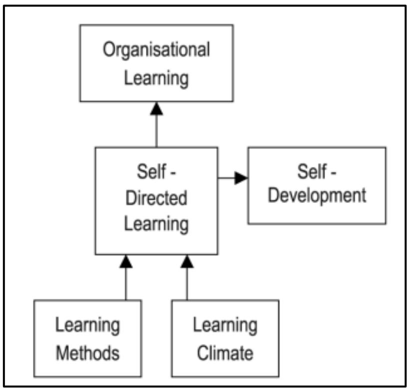

Figure 19 Self Directed Study
(James-Gordon et al, 2003)

The benefits are great for students as they have unlimited time and space when compared with attending university. Exactly what the correct learning climate is and methods available are not made clear (James-Gordon *et al*, 2003) (Lasfeto, 2020). Another automotive company carried out research into the preferred learning styles of their engineers. The evidence showed that the engineers investigated have a significant visual learning style preference. This means their learning was more effective by using diagrams, sketches, photographs, schematics, flow charts, pictures, videos, computer graphics and demonstrations (James-Gordon, 2001) (Sole *et al*, 2021). The above examples were taken from industry. How do these compare with education? The Dwight Look College of Engineering at Texas A & M University thinks the way to get students to communicate and learn is by remodelling their classroom and wiring them to accommodate laptop computers, printers, video, and audio. These may enhance the learning environment but will not replace teaching by the more traditional methods (Downey, 1998).

Most designs do not start with a clean sheet of paper. Constraints are normal and expected by industry. Most products are developed from an earlier version or to form part of a range of products which share some common characteristics (Newman *et al,* 2003). In education, constraints are also used but Starkey *et al,* (2016) warns that if the wrong ones are selected, or too many, this may make students discard their novel ideas during the concept selection process in favour of more conventional alternatives. This is important as creativity and innovation are both required for long term success of a company. Companies will not survive economically in the long term if their designers can only think of conventional ways of solving problems. How to set the correct number of constraints and the right type is an area that requires further research.

Companies need to keep certain information secret, especially from their competitors. Industrial espionage is not just something made up in films but exists and has been successful in many world-leading projects such as the design of Concorde, the first supersonic commercial airline. This secrecy is vital to maintain competitive advantage. If this is lost, then a company can sustain serious economic damage. In contrast, within a company knowledge transfer is a critical element that will enable a company to progress and grow. Peansupap & Walker, (2009), after detailing the importance of knowledge transfer within companies, continues their research by highlighting the importance of developing an open culture of questioning, re-framing assumptions, sharing perceptions insights and knowledge (Fig. 20). When methods to enhance knowledge transfer are found, these efforts should be rewarded. Ghobadian *et al,* (2021) highlights that knowledge transfer can also be successful between strategic partners. How does knowledge transfer work within the education sector? Within a classroom, knowledge is not imparted in a one-way direction. Most knowledge comes from the lecturer, especially in the early stages of a design process, but some knowledge will be shared by students to the class. This is a good process and benefits all present.

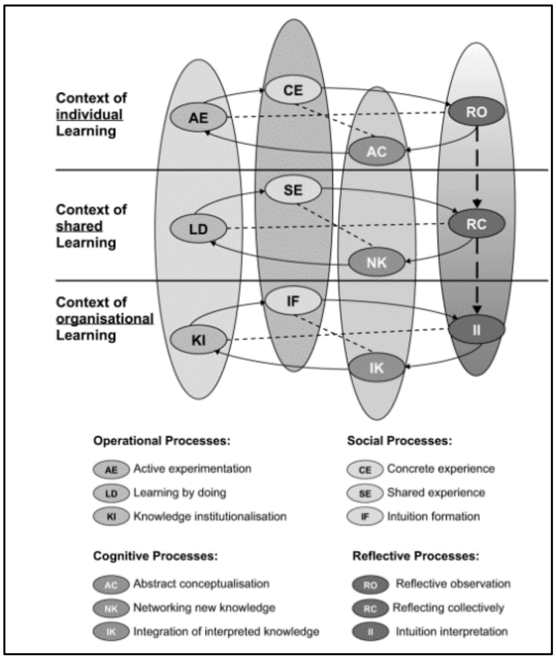

Figure 20 Group Model of Reflection and Knowledge Transfer (Peansupap & Walker, 2009)

But not all knowledge is shared openly within a class. Many students, after spending a considerable amount of time researching and calculating may not be willing to share that information, especially if others in the class put less effort into the task. Students are naturally competitive with each other, which is healthy, but would not be acceptable within a company. Competitiveness within a company's employees must be very carefully managed. In the early stages of the design process, it is necessary to produce a design specification. This requires benchmarking data so that the designer can set values on their own design. Because of the need for companies to maintain secrecy from their competitors, as mentioned previously, this information is not available. Often a company may resort to purchasing competitor's product so that it can be reverse engineered. This option is not open to education establishment due to funding, time, and expertise.

2.4.3 Industry Expectations

What are the requirements of modern industry when selecting mechanical engineers? The expectation was that industry requires technical skills. Research has shown that technical skills are important, but just as important were personal skills such as communication skills, interpersonal relationships skills, team skills, organisational skills, management skills; business skills; technical skills such as better knowledge of speciality trades, computer skills, staying current with industry, interaction with management skills, importance of codes and regulations; education versus training (Back & Sanders, 1998). Two very interesting points were made in the articles conclusion, (1) industry desired academia to cover more material than can adequately be covered in an undergraduate engineering programme and (2) one senior vice president of a top 10 engineering/construction company in USA said that in over 25 years of dealing with universities he had never been asked for his opinion about the engineering curriculum. This lack of a relationship between industry and academia has improved since the writing of this paper but more needs to be done (Islam, 2022).

2.4.4 Educational Summary

Summary

- Real world practical knowledge is often neglected by academia and replaced by theories.
- There has been an increase in self-directed learning and self-development especially in research.
- Libraries are more than just books they are a resource centre. Some centres now have a library of material samples for example.
- The need for future design engineers to have a very good understanding of maths and science.
- Students need to be shown some basics; how to use manufacturers catalogues and basic parts selection.
- Lecturers with up-to-date practical experience benefit their students greater than those without.
- Use of computers to organise knowledge database.
- Co-teaching between industry specialists and academia produces better academic results for students.
- Design engineers in the UK are not receiving enough appropriate education and development opportunities.
- More collaboration required between industry and education.
- Problems set by educators are usually crisp and analytical, industrial design problems are open ended and not well defined.
- Visual learning is preferred by most engineers.
- Knowledge is shared within a company, but not by students in education.

Signpost to Aims & Objectives

The mechanical engineering knowledge required by a design engineer is vast and continuously changing and growing. The aim of this thesis is to help HEI's develop this knowledge in their students. To achieve this, it is not expected to develop a whole new teaching theory, rather it is to apply existing theories in a new, innovative way.

Self-directed learning and self-development especially in research are increasing. Achieving the aim of this research will make students research more productive in understanding design problems and their solution.

Libraries have always been an importance source of information. Enhanced libraries become resource centres with, as an example, a library of materials that students can look at, feel, and interact with.

The more lecturers can show students practical engineering. The more lecturers will enhance the learning experience and prepare better design engineers ready for industry.

2.5 Books

Books have long been considered a reliable source of information if they have been Peer reviewed, or published by well-regarded academic presses, generally if it has been at least preliminarily vetted by one or more scholars (The Leaf Project, 2013). Some books claiming to be design books, are in fact reference books containing data to be used in the design process, these will be not included in this review. Once these books have been rejected, the difficulty faced by this review is the vast quantity of books available covering all aspects of design. As it is not possible to include all design books, it is suggested that a sample be reviewed. The sample will contain new and old books and will be as comprehensive as possible.

The book Mechanical Design Engineering Handbook by Childs, (2018) provides a reasonably detailed description of the mechanical engineering design process and includes some advanced design features such as six sigma, optimisation, risk assessment, and project management. Each chapter concludes with a detailed reference section, standards, websites, and further reading. The book continues with detailed descriptions of engineering components most likely required in a typical mechanical engineering design. Fig. 21 provides an example of the detail for bearing selection and is typical of most of the graphics in the book.

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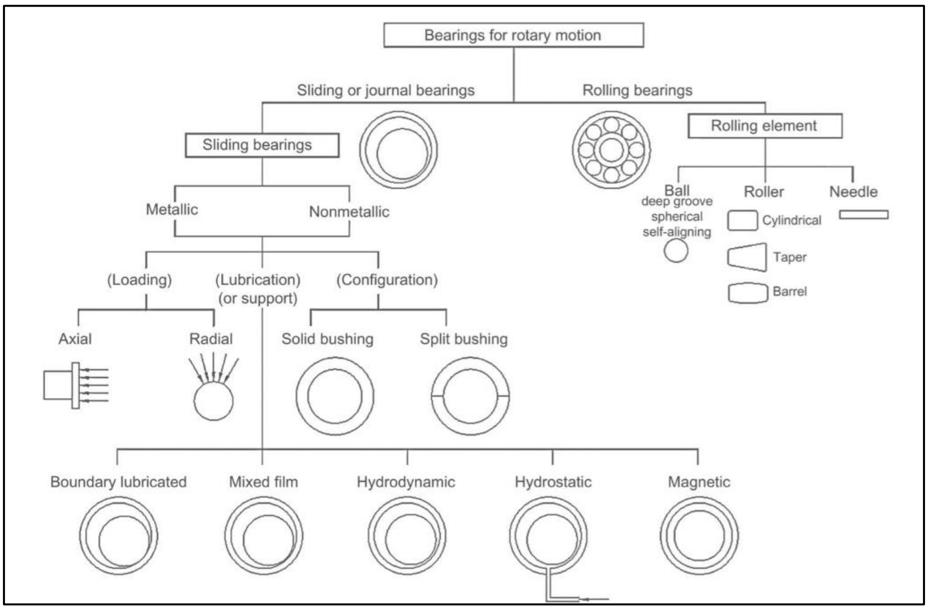

Figure 21 Bearing Classification (Childs, 2018)

The list of engineering components is wide and varied. Shafts, gears, belts and chains, clutches and brakes, seals, springs, fastenings, pneumatics, hydraulics, tolerancing and mechanisms. The detail provided for each engineering component is good. No help is provided in making a precise engineering component selection, this is left to the choice of the design engineer. Students with good engineering knowledge should find this book helpful. Ones with less engineering knowledge may find the book a little overwhelming in the quantity of information provided (Childs, 2018).

Many design books, such as Shigley *et al,* (2004) introduce design by taking the reader through the basic design process including codes and standards, stress and strength considerations, reliability, economics, safety and product reliability, and units. Most books look at specific areas required when designing a component or system. These include, stress, deflection and stiffness, materials, steady and variable loading, springs, lubrication, gearing, clutches, shafts, axles, and spindles. A large appendix section is included with useful tables such as conversion factors, properties of a range of materials, geometric properties, and fatigue life. The second part of the appendix provides answers to selected problems. This type of book provides a large amount of data and information useful to the design engineer but little in the way of the design process and how to teach a student to design. This type of book deals with design as if it is a problem-solving exercise in which creativity plays only a small part.

Dieter & Schmidt, (2020) approached design in a different way. Rather than a problem-solving exercise, they present design as a process or a journey. Within the front cover they provide a flow chart (Fig. 22) depicting the required steps in the design process; define a problem, gather information, concept generation, evaluate & select concept are part of conceptual design, product architecture, configuration design, parametric design, and detail design are part of embodiment design. Each step is then expanded upon in the following chapters. The book deals with legal and ethical issues which would apply in a work situation but not so much for students learning design.

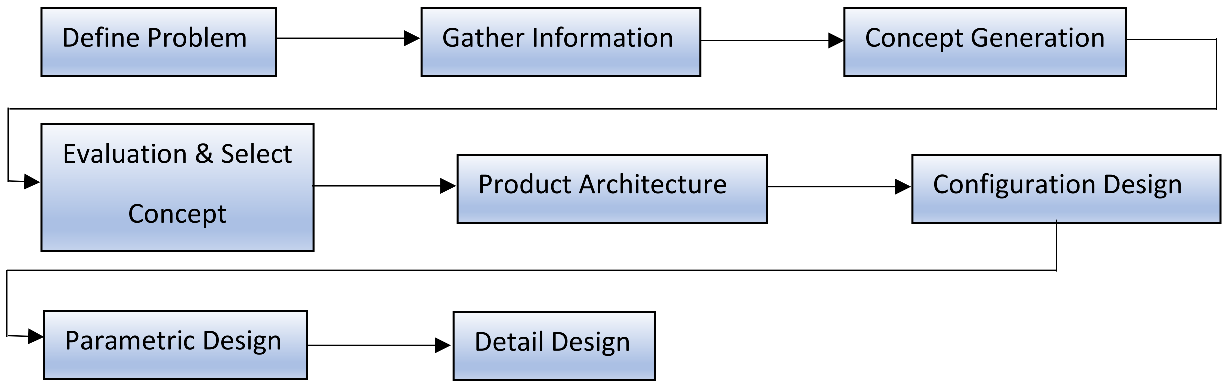

Figure 22 Roadmap to Engineering Design (Dieter & Schmidt, 2020)

Hurst, (1999) takes a different view from the two already mentioned. This book includes a significant history of design but also accepts Dieter & Schmidt approach by treating design as a process. Hurst does not reach the depth of detail that Dieter & Schmidt do as it was written by an academic from the University of Hull whose readers would be university students. Because of the intended audience, areas which cause students the most difficulties are dealt with such as writing a Product Design Specification and writing a formal report at the end of the design process.

Some books try to achieve a balance between fully explaining the design process and fully providing data for different applications that a design engineer can apply. This balance is achieved by Hawkes & Abinett, (1984) who look at the design process to achieve economic, anthropometric, and aesthetic design. Some analysis and calculations are provided as well as considering future development. The book is designed for first year rather than third year students.

Exploring Engineering – An introduction to Engineering and Design (Kosky *et al,* 2021) is an interesting book. It is written for young men and women considering engineering design as a profession and the challenges their futures could face.

Engineering can be mechanical, electrical, materials, nuclear, and computing. It highlights 14 Grand Challenges for Engineering in the 21st Century such as: provide energy from fusion, reverse-engineer the brain, enhanced virtual reality, and engineer better medicines. For each type of engineering, a chapter providing details is provided. The details do not give the reader a full insight into the breadth and depth of the subject area. As an example, the section on mechanical engineering introduces thermal properties, fluid mechanics, thermodynamics, and machine design. This type of design book would be very good for students thinking of becoming a design engineer in the field of engineering. It would not help students on their course at university who would require many more details and explanations of the subject areas.

An interesting book, written by Morris, (2021) gives many examples of good practice for a designer. An example is shown in Fig. 23.

If your welded assembly is made up of laser cut plates, put **Tabs on Plate Edges** and slots in the adjacent plate for the tabs to fit in to. This will self-position the plates for welding and simplify the welding fixture.

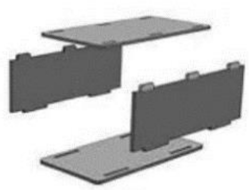

Figure 23 Example Advice (Morris, 2021)

A wealth of information is provided ranging from the setup of a design office, maintenance, health and safety, procurement, project planning, basic drafting, tips on Computer Aided Design models. This is a very good book for students as it explains clearly mechanical engineering generally, but also mechanical engineering design and how it operates with the many multifunctional areas. The knowledge it imparts would make a good beginning for students with limited engineering knowledge (Morris, 2021)

2.5.1 Books Summary

Summary

- Many books look at the design process as a problem-solving exercise or as a journey.
- Some books, written by academics are specifically written for students but do not go into detail on the industrial requirements for design.

Signpost to Aims & Objectives

Some books describe the mechanical engineering design process carried out by industry in detail. To keep up to date with industry methods for a book author is difficult due to the time required to research and write the book. Most authors prefer to either concentrate on general descriptions of the design process or provide a catalogue of design features that a design engineer may require. No comparison between industry design methods and those used in academia were found. Many design books try to provide knowledge of parts, materials, calculations etc. but the knowledge required of a design engineer cannot ever fit into a book. Students must be taught how to research this knowledge from primary sources.

2.6 Design Models

Early mechanical engineering design, when compared to the complexity of modern design was a simple process. Take an idea, develop it to the point that it can be manufactured, manufacture it, and then see if it functions correctly. If not, modify the design until the desired function was achieved (Sole *et al*, 2021). As complexity increased, systems or design models were developed to try and simplify the design process and organise it. These systems or design models have developed not only to cover the design phase of a product but also the products lifecycle.

Innovation and invention were considered for a long time as a mysterious phenomenon, until in the 1990's Armand Hatchuel & Benolt Weil and their research team discovered that these activities could be explained. The C-K theory is a logic framework that explains how, in a natural or planned way, new ideas are conceived and designed. Its name is an acronym for C = Concept and K = knowledge (Hatchuel *et al,* 2017).

Beginning Engineering Science and Technology were designed by NASA to teach engineering design students the Engineering Design Process as an iterative process that engineers use to guide them in problem solving. The steps are (Fig. 24); Ask questions to identify the problem, requirements that must be met, and constraints that must be considered: Imagine solutions and research ideas. Identify what others have done; Plan two or three best ideas, sketch the designs, ultimately choose a single design to prototype; Create a working model, or prototype, that aligns with desired requirements and that is within the design constraints; Test and evaluate the solution, collect and analyse data, summarise strengths and weaknesses of their design; Improve, based on the results of testing, make improvements, identify changes and justify the revisions (Nikulin *et al,* 2019).

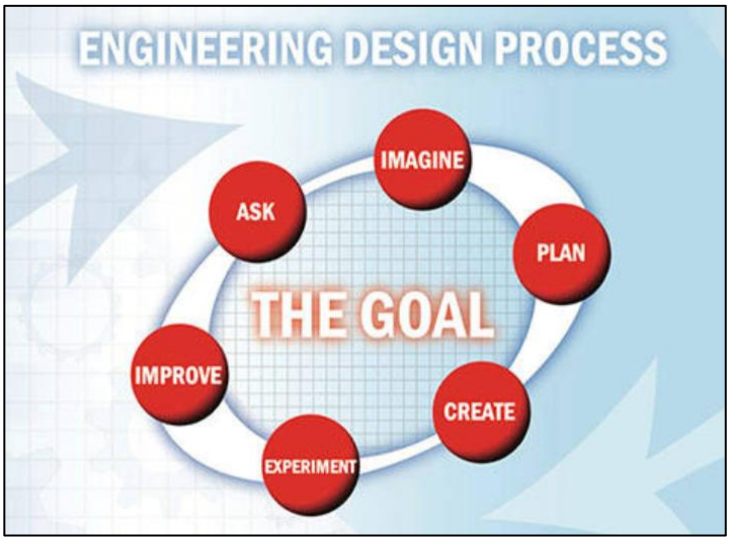

Figure 24 NASA's BEST (NASA, 2022)

NASA's BEST is one of many design models available for design engineers and educators to use. Ohers available are:

- Double Diamond and 4D – Defines the design stages as Discover, Define, Develop and Deliver (Caulliraux *et al*, 2020).
- Stage-Gate – Gates or checkpoints are positioned at strategic locations to evaluate the process from time to time so that growth and profit are not

hampered. These gates are manned by specific management authorities or 'gatekeepers' who decide if the project should continue (Conforto & Amaral, 2016).

Design Failure Mode and Effect Analysis determines what might go wrong, how bad the effect may be, and how to prevent or mitigate it. When applied at the design stage it can assist in developing more robust designs with longer service lives. The automotive sector is one of the main users of this system (Barsalou, 2020). Without the application Design Failure Mode and Effective Analysis or similar systems, the possible failure of a product may not become clear until further down a products life cycle making remedial action more expensive and reducing customer confidence (Fig. 25) (Hartwell, 2022).

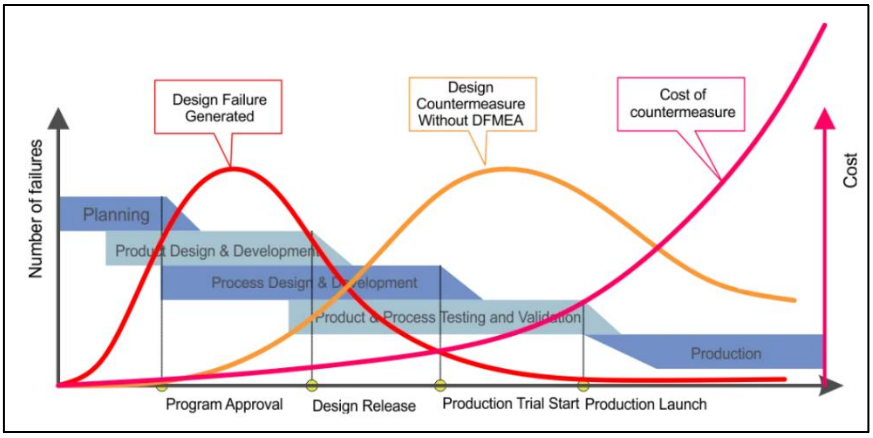

Figure 25 Design Failure and Countermeasure (Hartwell, 2022)

In the 1980's a Russian engineer Genrich Altshuller developed the TRIZ theory which is an acronym for Teorya Resheniya Izobreatatelskikh Zadatch. The literal translation is: 'theory of inventive problem solving'. The research carried out by Altshuller into the design process made clear that the evolution of technological progress follows several predictable patterns. It became an innovative way of looking at problems and solutions. His goal was to develop a standard process for successful innovations. This is how he discovered that 98% of patented innovations were based on an already known principle. Only 2% of all patents were new innovations (Sheu *et al,* 2020). The list of generic suggestion strategies that Altshuller developed are shown in Table 16.

Table 16 List of Generic Suggestions (Russo & Spreafico, 2020)

1. Switch to super system 2. Trimming 3. Dematerialization/ideality 4. Merging 5. Redesign the internal structure	6. Change the state of aggregation 7. Local quality 8. Substitute 9. Segmentation of the parts/components 10. Design for Assembly	11. Dynamics 12 The Other Way Around 13. Taking out 14. Increase control 15. Recycle/Reuse 16. Optimize

Quality Function Deployment (QFD) is a systematic analysis of customer requirements that is used to improve the quality of a product. As part of this method, customer requirements, product performance, and the products offered by the competition are all taken into consideration. All elements are brought together in a graphic and positioned in relation to one another (Fig. 26) forming what looks like a house which is known as a House of Quality. The House of Quality encompasses different QFD elements used for understanding customer requirements and aligning business processes to meet these customer requirements. The roof or correlation matrix provides a good example. This shows the degree of dependence among the engineering characteristics. It is best to recognise these correlated relationships early so that appropriate trade-offs can be made early in the design process.

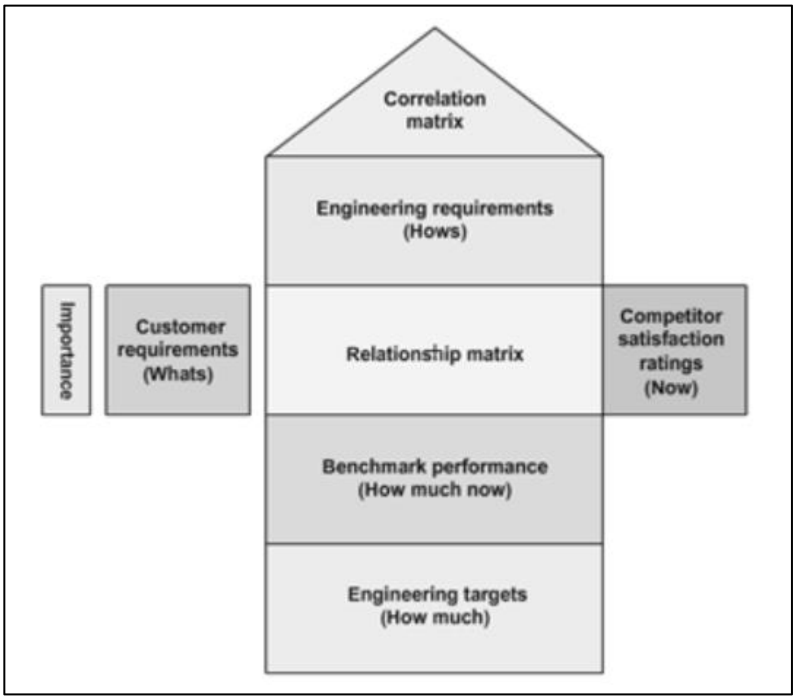

Figure 26 QFD Elements (Certification Course, 2023)

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Figure 27 Quality Function Deployment (Concept Draw, 2023)

At the end of the Quality Function Deployment process, a clear catalogue of measures will be produced (Fig. 27). The knowledge gained must now be communicated and implemented in product development, product management, production, sales, and marketing (ASQ, 2023). The final step is the setting of target values. By knowing the most important engineering requirements, understanding the customer requirements, and having a feel for the technical performance, the design team is in a good position to set targets for each engineering characteristic. The benefits of such a system are many; Improves a company's efficiency, superior product design; shorter design cycles, fewer engineering changes, lower project and production costs, satisfied customers, reduction in implementation time, promotion of teamwork, and systematic documentation (Chan & Wu, 2003).

The V-Model can be used to assist in tackling complex system development, lifecycle models and project management. A key feature of the V-Model is definition of who must do what and when in a project, and the use of decision gates to indicate milestones in the progress of the project. In the V-Model, emphasis is placed on verification on the left-hand side of the V (Fig. 28) and validation on the right-hand side with the use of test cases to ensure adherence between equivalent activities on either side of the V (Whyte & Bytheway, 2016).

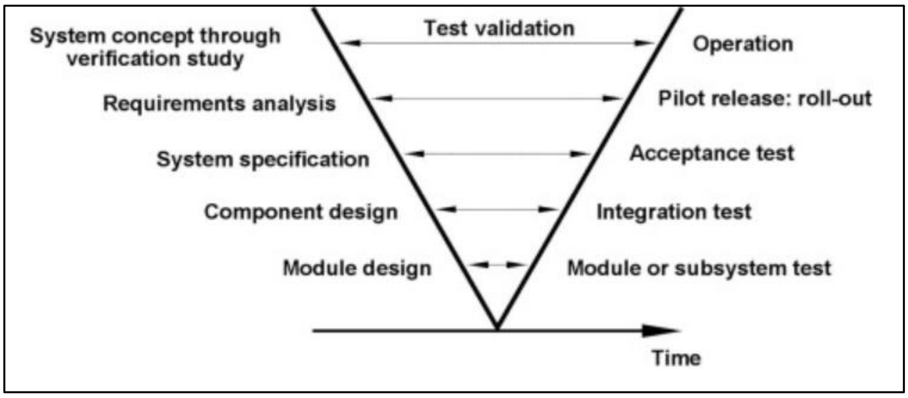

Figure 28 V-Model (Science Direct, 2022)

2.6.1 Design Models Summary

Summary

- There are many variations on the process of mechanical engineering design, each following a similar pattern of Discover, Define, Develop and Deliver.
- Logic frameworks have been suggested to try and control the innovation and invention process of mechanical engineering design. Most achieve limited success.
- Some logic frameworks are focused on reducing possible future failings of a design, thus producing a more robust design.
- Design models make it easier to control the design process, especially for large, multiple or complex designs.

Signpost to Aim and Objectives

Many companies in the engineering industry use design models to organise their mechanical engineering design process. These models, over time, become adapted to the specific requirements of the company. It is important for students to learn mechanical engineering design using a generic design model to prepare them for industry. Using a structured approach will make assessment easier to arrange and control but must not be too structured otherwise creativity could be reduced.

2.7 Pedagogy for Teaching Design

Pedagogy, according to Collins Concise Dictionary (1999) is the principles, practice, or profession of teaching. The subject of pedagogy is very large with several proponents presenting various theories and approaches and can be traced back over many centuries and can include such important thinkers as Socrates and Confucius.

This section of the literature review, to keep it a reasonable size and relevant to this thesis will focus on pedagogy appropriate to teaching mechanical engineering design.

Looking at past examples in mechanical engineering design highlights that mechanical engineers learn best by doing (Sole *et al*, 2021). This is most evident when teaching engineering design. Technical drawings or 3D models can be detailed, precise, accurate, checked and double checked, but it's not until manufacture that the mechanical design engineer students learns if their design is a success by functioning correctly and meeting the required design specification criteria.

Teacher's asking a class a question and then waiting for an answer, followed by subsidiary questions, and again waiting for an answer, has been used for many years as one method to determine the level of understanding a student may have of a topic (Petty, 2004). Maitra, (2013) suggests a slightly different approach. When carrying out a question-and-answer sessions student's normally put more emphasis on the answer rather than the question. Maitra thinks the quest to answer the question is where learning takes place, not the answer itself. Rather than pose a question to a student, ask the student to come up with their own questions and answers. This requires research where the teaching and learning takes place. An example of this approach is where students are asked to provide two questions which they can think of when looking at Fig. 29.

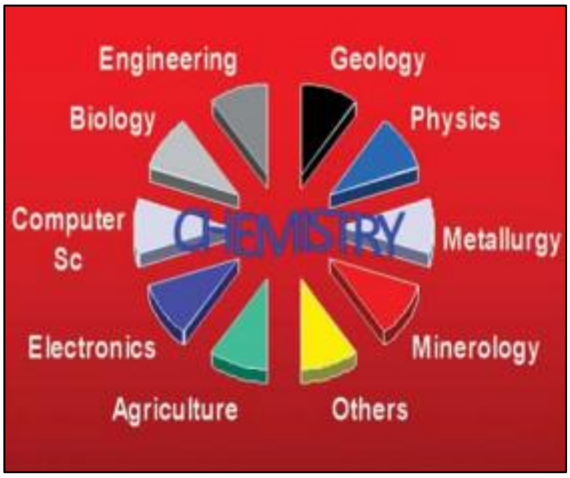

Figure 29 Think of Two Questions (Maitra, 2013)

The traditional approach to teaching design used to be based around a behaviourist approach, sometimes called Stimulus-Response because the behaviourist would only consider observable stimuli and responses and ignore everything else. Emami *et al,* (2019) argues that a behaviourist approach doesn't adequately prepare students to deal with real-world engineering problems. A constructivist approach was found better when teaching design engineers. Hands-on, project-based courses have proven useful in addressing the requirements of industry who want engineers with practical ability to solve real-world engineering problems and not just a theory-based knowledge.

The traditional approach to teaching design is given another dimension by Blum, (2019) who suggest user experience and user-centred design which focus on the relationship and interactivity between a product and the user's experience of the product. The goal is to stimulate a positive emotional response in the user. This involves looking for design opportunities that may affect people's emotions in a positive way and requires the design engineer to have empathy.

New learning approaches are suggested by Wrigley & Straker, (2017) to prepare student to work nationally and internationally. After investigation of the current curriculum content of 28 international institutions that currently teach design thinking, five different thematic levels were identified. These levels form the basis for The Educational Design Ladder (Fig.30).

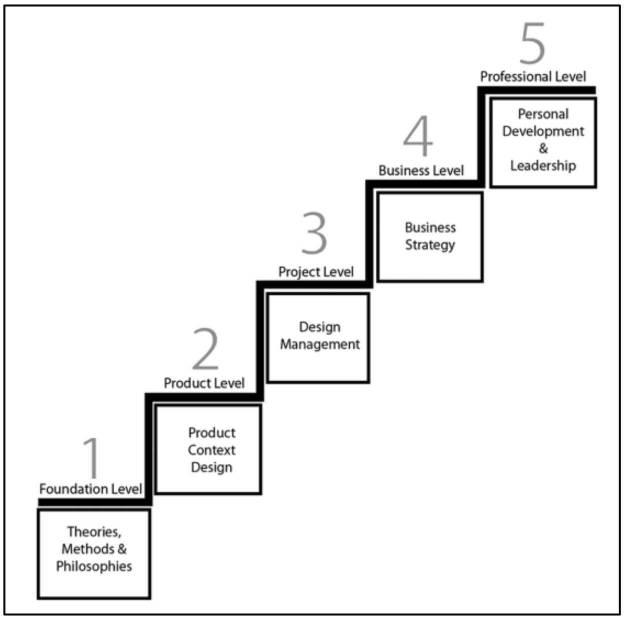

Figure 30 Educational Design Ladder (Wrigley & Straker, 2017)

The pedagogy theory for teaching mechanical engineering design reviewed in this section are not stand-alone theories but can be combined as teachers see the need. Aziz & Islam, (2022) researched established pedagogical theories and developed their research by combining the theories to explore their effect upon a student's engagement and motivation. The theories look at were:

- **Kinesthetics' Learning** – Allows students to learn from hands-on experience by applying real-life problem-solving activities where students applied their knowledge of energy-efficient design practices.

- **Flipped Classroom** – Teachers prepare pre-recorded lectures and then facilitate interactive discussions or activities during the lecture time. In this approach, students get the opportunity to learn at their own pace and the face-to-face sessions can be utilised more effectively.

- **Inquiry-Based, Mastery-Based Learning** - This approach fosters critical thinking practices and sequential skill-building among students through reflections on how they address a research question and improves their ability to correlate information from different topics.

- **Project-Based Learning** - Students get the opportunity to explore real-world problems in this expeditionary learning and engage more deeply with theoretical concepts. In problem-based Teaching and Learning students are usually presented with a situation, a case, or problem and they need to design, create, build, or improve the project and finally, produce a report under the guidance of the facilitators.

2.7.1 Pedagogy for Teaching Design Summary

Summary

- Mechanical engineering design is best learnt by doing.
- Normal process is question and answer, one theory is the important part is the question which requires research.
- Constructivism can replace behaviourist approach.
- User-experience and user-centred design is used to produce a positive emotional response.
- Educational Design Ladder is a five-step approach to design.
- Combining of pedagogical theories works best.

Signpost to Aim and Objectives

When teaching design, different pedagogical theories have been devised. Many of these were developed for the convenience of teaching and are not used by industry. This thesis will try to develop a compromise between required pedagogical theories used to teach and assess students and the methods used by industry to produce functional, safe designs.

2.8 Industry Standards

A new design requires a design specification. To be a successful design, the design must comply with constraints in the design specification. Constraints can come from many different areas, the customer, research into the product, manufacturers, R&D are some examples. This section will look at the constraints applied from industrial standards. These standards can be across different industrial sectors or can apply to a specific sector only. A good knowledge and understanding of industry, company in-house standards, national and international standards is critical for the design engineer. Use of standards and the ability to apply the appropriate standards during the design process is an important skill future engineering design students must develop.

2.8.1 ISO 9001:2015

ISO 9001:2015 is a Quality Management System which does not guarantee product quality but is required when an organisation must be able to demonstrate the following (Table 17) (Tricker, 2015).

Table 17 ISO 9001 Aims

Enables organisations to manage their processes and systems in order that customer and other stakeholder requirements can be achieved.
Continuous improvement.
Aims to ensure that products and services are safe, reliable and of good quality.
Ensure that the processes that surround the product are controlled and performed in a consistent manner.
Viewed as strategic tools used to reduce costs by minimising waste and errors and increasing productivity.

2.8.2 IATF 16949:2016

The International Automotive Task Force (IATF) developed **IATF 16949:2016** which is an internationally recognised Quality Management System for the automotive industry and is an update from TS 16949:2009 and is based on ISO 9001:2015. IATF 16949:2016 emphasises the development of a process-oriented quality management system that provides for continual improvement, defect prevention and reduction of variation and waste in the supply chain. The goal is to meet customer requirements efficiently and effectively. This industrial standard will help to reduce operating costs, deliver components that are consistently to customer standards, and provide global recognition as a reputable supplier (Foley, 2018).

2.8.3 British Standards

British Standards is an agreed way of doing something. It's a statement of good practice, designed to make things better, safer, and more efficient. The range of standards can be from making a product to delivering a service or creating a process. A standard is a collective work. It represents the consensus of a group of experts and other people with an interest in the subject matter. Standards are a tried and tested way for organisations to follow good practice and work more effectively. The general benefits of using a British Standard are (Table 18).

Table 18 British Standard General Benefits

Improve performance.
Cut costs.
Manage and reduce risk.
Increase international trade.
Speed up innovation.
Increase sustainability.
Demonstrate quality.
Build customer trust.
Improve performance.

Several British Standards are available to the design engineer. The general benefits of using British Standards were shown in Table 18. A more detailed look at a sample of British Standards reveals the scope and detail that can be covered by them. It's important that students be taught how to use these standards and the benefits that they give.

BS7373-1:2001 – Product Specifications. Guide to Preparation. Provides guidance on layout, and preparation management.

BS7373-2:2001 – Product Specifications. Guide to identifying criteria for a product specification and to declaring product conformity.

BS7373-3:2005 – Product Specifications. Guide to identifying criteria for specifying a service offering.

BS8888:2017 – Technical product documentation, geometric product specification, geometric tolerance specification and engineering drawings.

BS8887:2010 – This series of standards help designers make informed choices about a product's function and use, the materials from which it is made, manufacturing processes and ability to recycle or reuse the product at the end of its life.

BS3737 guides a design engineer in preparing a design specification. In the early stages of the design process, sustainability is incorporated. BS8887 provides the guidance required to plan for sustainable design (circular economy). BS8888 provides the guidance to produce the documentation to manufacture the design using technical drawings. Many British Standards are available, other international standards and company standards can also be used.

2.8.4 Kitemark

Following a standard doesn't guarantee that you are within the relevant laws governing a country. Governments often use standards when putting together legislation. They are often used to establish technical detail. In these cases, complying with the standard will often mean complying with the legislation at the same time (BSI, 2022). When making a product, delivering a service, or creating a process, if it meets the appropriate British Standard then it can receive the Kitemark (Fig. 31) symbol. Consumers who identify the kitemark can have confidence that the standards have been met.

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Figure 31 BSI Kitemark (BSI, 2022)

2.8.5 CE Mark

A similar system is used for many products that are traded in the single market of the European Community. A **CE Mark** (Fig. 32) is used to show that the manufacturer has checked that these products meet the EU safety, health, or environment requirements. It indicates a products compliance with EU legislation, allows the free movement of products within the European market (Gov.UK, 2022).

Figure 32 CE Mark (Gov.UK, 2022)

2.8.6 VDA 6.4

VDA 6.4 is part of the VDA 6.x family of standards and is aimed explicitly at manufacturers of automotive production equipment. The German set of standards was created in 1999 based on VDA 6.1 and was republished in 2017 after being revised and adapted to ISO 9001:2015. VDA 6.4 covers an area of the industry that is not covered by the new International Automotive Standard IATF 16949:2016 - which is also particularly important for internationally active manufacturers (Surinova, 2014).

2.8.7 Toyota Production System

The **Toyota Production System** is a strategy that helps organise the manufacturing and logistical aspects of a business. Developed by the Japanese auto manufacturing company Toyota, this Lean method has a special focus on automobile manufacturing. However, it has been modified to work with other manufacturing outlets and businesses as well. The system helps bring improved organisation efforts to a facility, reduces waste, and can improve the bottom line of companies that choose to adopt it.

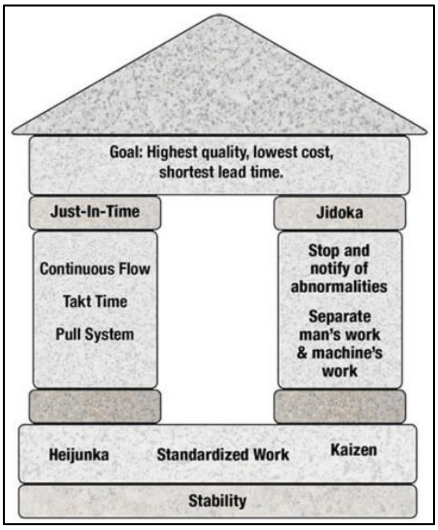

Figure 33 The Toyota Production System (Chiarini *et al*, 2018)

Toyota Production System is commonly depicted by visually imagining the system as a house (Fig. 33). A well-made home must undergo renovations as time passes whether that's because of outdated materials or broken appliances. Toyota Production System is made to achieve the same goals regarding updating old and worn-out systems for ones that are new and improved. Applying the Toyota Production System into any business model makes for 'living' in that metaphorical house better for those within the organisation (Chiarini, *et al,* 2018) (Creative Industry Supply, 2022).

2.8.8 IMechE

The **IMechE** is licensed by the Engineering Council to accredit academic programmes from universities and colleges that drive engineers toward professional registration as a Chartered or Incorporated engineer. Accreditation is a mark of assurance that the programme meets the standards set by the relevant profession. It is, in essence a peer review process. The accreditation is conducted under the fourth edition of the Accreditation of Higher Education Programmes (AHEP4) which was first published in August 2020 (Engineering Council, 2021) (IMechE, 2023). The benefits of accreditation of a degree programme are listed in Table 19.

Table 19 Benefits of Accreditation

Ensure that UK engineering education provides those industry relevant skills.
Draw students towards a career in the engineering profession.
Demonstrate, both nationally and internationally, the high standard of UK engineering education.
Provides a basis for HEIs to review their programmes and develop excellence in delivery and content.

To achieve accreditation a programme must deliver the learning outcomes stated in AHEP4. These cover five engineering-specific areas of learning (Table 20). Each specific area of learning has their own learning outcomes. An example of the learning outcomes for Design and Innovation are shown in Table 21. These are quite broad-based as their application will also be broad-based throughout the engineering sector.

Table 20 Areas of Learning

1	Science and mathematics.
2	Engineering analysis.
3	Design and innovation.
4	The Engineer and society.
5	Engineering practice.

Table 21 Design and Innovation Learning Outcomes

Area of learning	Chartered Engineer (continued) Bachelors (Honours) degrees and equivalents (continued)	Masters degrees other than the Integrated Masters and Doctoral programmes and equivalents (continued)	Integrated Masters degrees and equivalents (continued)
On successful completion of an approved or accredited programme, an individual will be able to:			
Design and innovation Design is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges commensurate with the level of study.			
Design	**C5.** Design solutions for complex problems that meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.	**M5.** Design solutions for complex problems that evidence some originality and meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.	**M5.** Design solutions for complex problems that evidence some originality and meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.
Integrated/systems approach	**C6.** Apply an integrated or systems approach to the solution of complex problems.	Learning outcome achieved at previous level of study.	**M6.** Apply an integrated or systems approach to the solution of complex problems.

AHEP4 standards are internationally recognised with several accords with Europe, USA, Australia, and Ireland. This recognition is important as it makes possible the degrees offered in the UK to be internationally recognised if they are accredited.

2.8.9 UK-SPEC

The **UK Standard for Professional Engineering (UK SPEC)** outlines the competence and commitment requirements that people must meet and demonstrate to be professionally registered in each of these registration categories:

- Engineering Technician (EngTech)
- Incorporated Engineer (IEng)
- Chartered Engineer (CEng)

Professional registration verifies that an individual can meet the engineering and technological needs of today, while anticipating the needs of, and impact on, future generations. Registration also demonstrates that an engineer or technician has reached a set standard of knowledge, understanding and occupational competence.

An applicant applies for professional registration through a Licensee relevant to their discipline. For Mechanical Engineers, the Institute of Mechanical Engineers (IMechE) is the appropriate licensee (Engineering Council, 2023).

The standards an individual must achieve to receive professional registration are detailed in the UK-SPEC. The design requirements are listed in Table 22.

Table 22 UK-SPEC Design Requirements

Registration Categories	Design Requirements
Engineering Technician (EngTech)	Contribute to design
Incorporated Engineer (IEng)	Apply appropriate theoretical and practical method to design
Chartered Engineer (CEng)	Apply appropriate theoretical and practical methods to the analysis and solution of engineering problems.

Students achieving a BEng will be eligible to apply for Incorporated Engineer (IEng). The UK-SPEC requires theoretical and practical design requirements to be covered. The difficult area will be the practical element. Part-time students can achieve this through their work, full-time students will find this more challenging. Academia tries to address this issue by introducing as many practical elements as possible into the syllabus and running competitions with practical challenges.

2.8.10 QAA

The Quality Assurance Agency (QAA) for Higher Education provide impartial regulatory and collaborative quality assurance and enhancement. They work in the UK and internationally to ensure that students and learners experience the highest possible quality of education.

Subject benchmark statements describe the nature of study and the academic standards expected of graduates in specific subject areas. They show what graduates might reasonably be expected to know, do and understand at the end of their studies.

The threshold level for a BEng (Hons) degree (3rd class degree), graduates will have demonstrated the following (Table 23):

Table 23 QAA Subject Benchmarks

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A student can expect, once they have completed their degree, to have the required knowledge and understanding of engineering, and the ability to apply that practical knowledge and understanding to a problem. This would include the ability to design. Design is primarily a problem-solving skill which requires the ability to identify complex engineering problems (QAA, 2023).

2.8.11 Engineers Europe (FEANI)

The Federation Europeenne d'Associations Nationales d'Ingenieurs (FEANI) was renamed Engineers Europe. Its aim is to unite the national associations from 33 European Higher Education Area (EHEA) countries. Its aim is a single voice for the engineering profession in Europe and wants to affirm and develop the professional identity of engineers. It aims for a mutual recognition of engineering qualifications within Europe and to strengthen the position, role and responsibility of engineers in society. The mutual recognition of engineering qualifications is achieved through the gaining a EUR ING certificate. This certificate requires meeting certain requirements in education and experience. The education criteria are shown in Table 24 (Engineers Europe 2023).

Table 24 Engineers Europe Competence

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This standard is set very generally as it is trying to recognise several different qualifications through Europe. For design, a knowledge of existing and emerging technologies and of relevant knowledge of the standards and regulations is required. The analysis requires theoretical and practical methods to the analysis and solution of engineering problems.

2.8.12 Industrial Standards Summary

Summary

- ISO 9001:2015 is a very important standard that is often used as a benchmark for other standards. Many other standards have been developed to compliment it.
- IATF 16949:2016 is a quality management automotive standard to primarily reduce waste and costs and deliver consistent customer standards.
- British Standards delivers good practice, designed to make things better, safer, and more efficient.
- CE Mark on a product shows it meets the EU safety, health, or environment requirements.
- VDA 6.4 is an add-in for the automotive sector and was developed to cover things that IATF 16949:2016 missed.
- Toyota Production System is a strategy that helps organise the manufacturing and logistical aspects of a business.
- IMechE Accreditation of degrees provides a standard that is internationally recognised.
- UK-SPEC sets the standards required to achieve professional accreditation.
- QAA set the standards students can expect once achieving a degree.
- Engineers Europe (FEANI) provides a standard for recognition of qualifications for engineers through Europe.

Signpost to Aim and Objectives

Most quality managerial systems are developed to produce more efficient organisations by looking at waste and costs. These are aspects of a mechanical engineering design but generally are not dealt with at this level when teaching design to students. The British Standards and CE Mark are both critical to teaching mechanical engineering design as a knowledge and understanding of applied standards when designing will be expected by industry. Many companies have developed their own in-house standards that will be specific to a company's requirements. AHEP4 is an internationally recognised standard that the IMechE uses when validating university and colleges programmes. The programmes are mapped to the AHEP4 outcomes and used to determine if the if the validation will be successful or not.

2.9 Assessment

Assessment will be divided into two distinct areas, assessment carried out in academia and assessment carried out in industry.

2.9.1 Assessment in Academia

Assessment is a core aspect of all that is done in education: assessing others, assessing ourselves, assessing the impact of our work. Assessment is a broad term that includes processes, purposes, and pedagogies. According to Hollis & Finch, (2019) the world of assessment can seem complex at best and impossibly confusing at worst. The book divides assessment into three broad areas, 1) Assessment for Learning, 2) Assessment of Learning, and 3) Assessment for Planning. This book provides a basic outline of assessment, starting with the fundamentals (Table 25).

Table 25 Assessment Fundamentals

Assessment for Learning	Activities/strategies/approaches/interventions used to support, challenge, and extend learning.
Formative Assessment	Assessment which takes place during learning; is an integral part of the learning process; highlights learners' area for development; provides opportunities for learners to improve.
Summative Assessment	Assessment which captures the learners' attainment for a given outcome, often linked to descriptors of gradations of attainment pertinent to the skills, knowledge and/or attributes which have been the focus of the assessment task. These assessments can be used to generate outcomes data such as GCSE examination and internal end-of-unit tasks.

Brown, (2019) links together assessment and evaluation. Evaluation, a much older term than assessment has embedded in it the word 'value'. This indicates a process for determining the merit, value or worth of some product, process, program, personnel etc. Assessment sat under evaluation when most assessment was either a test or examination. Assessment for Learning seem to be focussed on classroom strategies and techniques that are associated with classroom learning.

For formative assessment to be truly formative, the information must be used by the learner to improve. A lecturer can provide the formative assessment, but a learner can also formatively assess themselves and each other. Feedback while you learn has more effect on student achievement that any other factor (Petty, 2014). Three important pieces of information are required if students are to learn to maximum effect (Table 26).

Table 26 Learner Information

1. Clear Goals If learners don't know what they are trying to do, they are most unlikely to do it. Students must understand their tasks, for example the difference between 'evaluate', 'analyse', and 'describe'. They must also understand the criteria for a good piece of work which includes the assessment criteria.
2. A Medal Information about what they have done well, and what is good about it. You cannot learn if you never discover when you have succeeded. Medals can refer to the student's work, product, or how they approached the work, the process.
3. A Mission Information about what needs improving, and how to improve it. This needs to be constructive, which means forward looking and positive, showing how to improve, not just what is wrong. Missions can be targets for the next piece of work, or improvements for the existing piece of work. Simple grades or marks are not missions.

An area of formative assessment which has been written about extensively is formative assessment when applied to group work. Thistlethwaite *et al,* (2016) is a good example. A tool was developed to allow a means of observing and giving feedback to individual learners undertaking a professional teamwork task. The tool was called The Individual Teamwork Observation and Feedback Tool (iTOFT). This was developed by researching existing teamwork assessment tools and discussions of accreditation standards for healthcare professionals. These tools have been developed by many different academics and HEI's to try and apply a system to assess an individual when working as part of a team.

A popular method to guide students in formative and summative assessment is the application of rubrics. Ackermans *et al,* (2019) discusses the most effective method of using a rubric as either text or video based. Text based rubrics lack three main things. (1) Contextual information needed to convey real-world attributes (2) sensor-motoric information (such as gesturing in the complex skill of presenting) (3) Procedural information needed to support the automation of subskills. These deficiencies can be remedied by the addition of text or video-based rubrics.

The aim of summative assessment may be to sum up what a candidate can do (criterion referencing). This could be done with the aid of a checklist of skills or competences, and/or by reports or profiles. Another aim may be to grade candidates or place them in rank order (norm referencing). This is usually done be means of an examination, designed to differentiate between candidates based on the breadth and depth of their learning (Petty, 2014).

Paola, (2017) carried out surveys of mathematic and education students on their perceptions of summative assessment. It was found the perception varied depending on who was surveyed, a mathematics or education student. This may indicate that the context that summative assessment is carried out in may directly affect the perception of students as to the appropriateness of that form of assessment.

Formative and summative assessments were summarised by Dixson, (2016) in Table 27. The distinction between formative and summative assessment is primarily related to the ways in which assessment results are used. Many assessments developed for formative purposes can also be used for summative purposes and vice versa. Formative assessment encompasses a whole host of tools that provide feedback to teachers or students to help students learn more effectively.

Table 27 Characteristics of Formative and Summative Assessment

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2.9.2 Assessment in Industry

Assessment, as the last section highlighted, is something normally reserved by academia. In certain areas, Industry also uses assessment. Concern over Green issues has grown in importance for many years. Companies are required to carry out an assessment of their green credentials. Cherrafi *et al,* (2021) proposes a self-assessment model to evaluate the readiness of organisations to implement Green Lean Initiatives. The proposed self-assessment model was able to display the potential challenges a company will face if it aims to implement Green and Lean policies.

A similar area of assessment was suggested by Takhar *et al,* (2020) where companies assessed the requirements to change their design and manufacture to one that encompasses the circular economy by the adoption of open loop manufacturing systems where products are designed using resources which enable products to be repaired, reused, repurposed, and recycled. To accurately assess a company's needs, real time data is needed. Industry 4.0 promotes interconnectivity, enabling real time data collection, communication, and data analytics.

The areas of assessment mentioned above are mainly to do with assessing a company's way of doing business. Gerdsri & Manotungvorapun, (2022) highlight an area of assessment which applies equally to academia and industry, this is the area of collaboration. Collaboration aims to create innovation through the commercialisation of scientific knowledge. Sometimes, due to a mismatch between a company's interests and the value delivered by academia (common knowledge base, strategic goals, agreement on intellectual property management) can create a challenging relationship. This paper builds on previous work to develop an analytical model to help industry and academia to build a strong collaborative partnership.

A product, once designed, requires assessing to determine if the design specification has been met. The products life cycle, reliability, production, costs, and manufacture methods also require assessment. Westerweel *et al,* (2018) looks at traditional machining methods and compares them to Additive Manufacturing assessing them using a lifecycle cost analysis. This introduces one method of assessing a component.

Summary

- Assessment of learners can be categorised into three areas: Assessment for Learning; Formative assessment; Summative assessment.
- Formative assessment requires clear goals, information on things done well, information on things to improve.
- Tools are available to assist assessing a student's ability when working as part of a group.
- Rubrics are a popular and tested method to help assess individuals.
- Summative assessment sums up the abilities of a learner.
- It is important for companies to be continually assessed so they can improve their ways of working. Green issues are top of the assessment agenda (2023).
- Assessment on collaboration between industry and academia is critical.

Signpost to Aims and Objectives

Assessment is critical in both academia and industry. To improve, it is important to assess where an individual or a company has reached in a particular journey. This thesis does not plan to make large changes to the assessment methods used in academia but to use them as a benchmark to provide confidence that any changes made to the teaching of design will not impact detrimentally on the assessment process. If necessary, the assessment process in academia could be revised to assist is assessing any new teaching methods, but these changes would be incremental and would be kept to a minimum.

2.10 General

A large amount of research has been carried out on the design process and teaching design that does not come under any of the categories above. This section will analyse this research as it will make a significant contribution to the understanding of industrial design process and teaching design.

Mention has been made in the previous sections on the need for future design engineers to have a very good subject knowledge. Design, according to McAlpine *et al,* (2017) may be viewed as an information transformation process with information from multiple sources gathered, integrated, transformed, and used to create an artefact. The management of this information is crucial if important information is not to be lost. Computer systems are ideal for this. The information stored by these computer systems is viewed as formal information. Other information not stored by computers is informal. The paper researches the use of logbooks to record and save this information. It was found that logbooks provided an almost unique source of insight into the interaction between the engineer and the information involved in engineering design work, with logbooks linking to over 130 other information sources. An interesting comparison was made between logbooks and reports. Logbooks contain many more sketches than reports, and reports contain many more formal representations in the form of Computer Aided Design drawings (Table 28).

Table 28 Characteristic of Dataset

Characteristic	Logbooks	Reports
Number of logbooks and reports	6	11
Total page volume	540	375
Total entries	372	405
Average length of entries (pages)	1.45	0.93
% of entries with 2+ info types	33	18%
Average info types per entry	1.45	1.21
Number of sketches	124	34
Number of calculations	52	21
Number of CAD drawings	0	20

A design study serves three purposes: effective design process, better products, and laws to govern the formation of artefacts or systems. Much has been written on the design process including this literature review. A better, improved product is often the aim of a designer and is achieved most of the time. To determine if a product is better or improved can often be subjective and difficult to judge. The laws to govern the formation of artefacts or systems, known as frameworks (Gbededo *et al,* 2016), can be put into several categories: Pahl & Beitz's, (1986) divides the design process into nine processes; Gero & Kannengiesser, (2004) represents the design process by eight processes (formulation, synthesis, analysis, evaluation, documentation, and three reformation types); Fig. 34 highlights a difficulty when creating a framework for design. It can very quickly become so complicated that the framework itself becomes the centre of attention rather than the design.

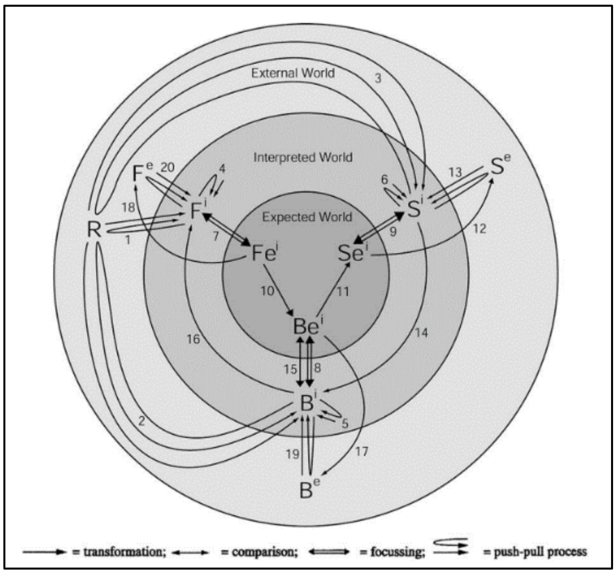

Figure 34 Gero & Kannengiesser (2004) Framework

The theory of inventive problem solving (Orloff, 2003) focuses on mapping between the question space and the solution space by using a contradiction matrix, which relates engineering parameters and inventive principles. The paper by Hou & Ji, (2008) investigates the generic principle governing the formation of systems or artefacts with analogy and embryogenesis, the formation of an embryo, the embryo being the design system. The paper uses mathematical matrix calculations (Hall & Lingefjard, 2017) to find a conclusion. There appears to be a contradiction in this method. Design, by its very nature is a creative process, mathematics by its very nature is surrounded by rules which strictly govern how things are done. Can the two be reconciled?

Witney's, (2006) paper describes a technique looking at how to design assemblies of products which are complex and comprised of many parts, designed at different times, by different people and companies. As an example, the body of an automobile or fuselage of an aircraft must meet certain dimensions and specifications. If these specifications are not met, how can it be determined what has caused the problem? What information will be needed? Is one, or more than one part out of specification? Is the problem with as assembly fixture? The number of areas required looking at can be many. Where do you start to solve the problem? The method this paper research is to identify and use key characteristics, each one is a possible cause of the design problem. The Key Characteristics are then put into a diagram (Fig. 35) to illustrate the design intent of the object. It is hoped that by applying these strategies it will be possible to help design engineers identify the part, dimension or tool that is causing the problem.

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Figure 35 Design Intent (Witney, 2006)

A similar approach was researched by Hosseinpour & Peng, (2014) when looking how to incorporate sustainable solutions in product development. They appreciated that product performance is evaluated not only in durability, reliability, affordability, and aesthetics but also by being environmentally friendly considering global warming, reducing energy consumption, and conducting the end-of-product life cycle management such as reusing, recycling, and remanufacturing. A tool known as Quality Function Deployment was used. This can translate product design requirements into engineering parameters which provide a useful tool to understand the design requirements. This research is very limited in its scope, only looking at the design and material processing. Further work is required to look at the whole life cycle of a product to achieve complete product sustainability in its design.

Boothroyd & Dewhurst, (1984), after emphasising the importance of designing for assembly i.e., to identify, in the early stages of design how a product will be assembled, manually or automatically, describes a methodical method to make this decision between manual or automatic assembly. To make this decision, detailed knowledge of product design is not required. What is essential is projected market life, number of parts, projected production volume and company investment policy. This contradicts other papers which were reviewed earlier and which emphasis the need for good engineering knowledge.

Once a component has been designed and put into production, the role of the design engineer is not finished. New products, if they are good will hopefully capture a good percentage of the market share. This is not a time for the design engineer to sit back as it will not be long before the market share will begin to drop off, especially if a competitor produces a rival product. To continue to capture the maximum market share, manufacturers must effectively and efficiently manage engineering changes throughout the entire product life. Ullah *et al,* (2016) carried out a literature review on engineering change management. The aim of all the methods covered by the latest literature was to produce components with the ideal aim of 'do it right the first time'. The literature review revealed that to effectively manage engineering product/process design change, it is paramount to comprehend the impact, likelihood, and propagation paths of engineering design changes. Insight from earlier design change problems is a significant resource for companies. The change process is shown graphically in Fig. 36.

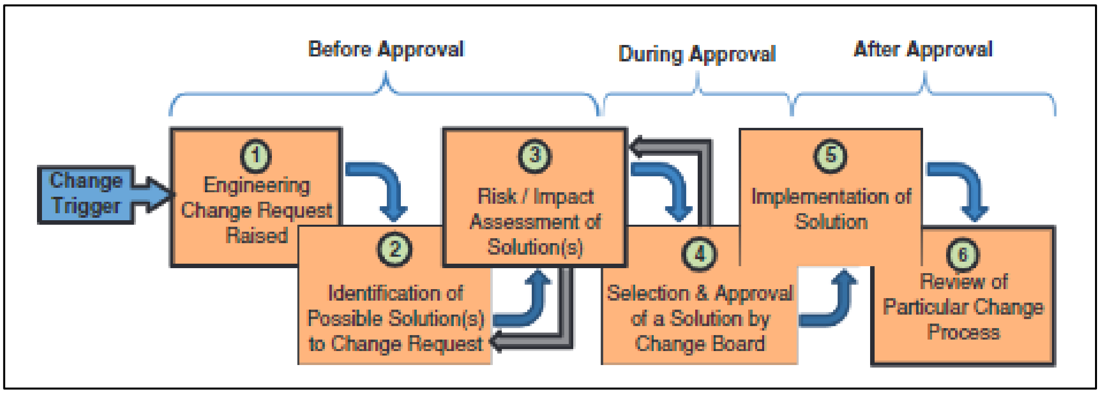

Figure 36 Generic Change Process (Ullah *et al*, 2016)

The design process, according to Kelley, (2010) has two main processes; the first and most widely used is the analysis stage when mathematical models and scientific principles are employed to help the designer predict design results; the second is optimisation stage which is a systematic process using design constraints and criteria to allow the designer to locate the optimal solution. Modern software allows the designer to carry out most of these two processes. Hand calculations based on sound scientific principles are used to verify the modelling software used to create the component or system. The same software can then be used to set constraints and criteria to optimise the components to give the best possible results. But how do you decide on the constraints? Kelly provides many answers including using an engineer's design notebook to record design thinking and decision making, leading class discussion, and allowing students to optimise the best solution, using a decision matrix that allows students to assign weights to constraints and criteria in a way to systematically locate the optimum design solution. It is suggested that it is critical to employ these optimisation techniques as they are recognised authentic engineering design strategies.

Every manufacturer employs designers who take an idea and develop it into a product which can be made at economical cost on special jigs and tools integrated into cost effective production and assembly lines. This process requires many engineering disciplines and requires coordination. A well-designed product will be easy to assemble and maintain, will have aesthetic appeal which will attract potential customers. The Design Council, on average, award around 20 products annually from British manufacturing industry. This paper (Armstrong, 1981) looks at some of the designs which received a reward from the design council. **Presco and SGB Presslock** scaffold fittings; very little material waste, captive lids, bolts are riveted into the fitting, nuts and washers are retained by turning over the last bolt thread, all fittings are zinc plated and passivated to ensure maximum resistance to corrosion. **Motor Panels (Coventry) Ltd**; developed the MP standard panel concept for press tools, parts comprising 705 of a cab shell can be produced from a common set of press tools. **David Brown**: developed a range of trucks with payloads of up to 50 tonnes, set new international standards of performance and reliability, includes a self-levelling feature that maintains a constant load height. The above examples show imagination and innovation by developing novel designs to solve existing problems. The latest awards (Fig. 37) from the Design Awards for 2022 are interesting to compare with those back in 1981. Design is much more technology based with the use of Computer Aided Design/CAM systems (Design Awards, 2022).

Tensegrity Sensor | Fluid Transporter | 3D Printer

Content Removed due to copyright reasons.

Figure 37 Design Council Awards (Design Awards, 2022)

Eastman Kodak Company's disk camera was marketed as being a usable camera with nearly 50 usable features. The camera failed in its most basic function; it did not take good photographs. Another example provided by Chiang *et al,* (2001) was of manual tin-can openers. To cut the lid, the cutting edge in the can opener must progress around the lid and sever it completely and cleanly without leaving slivers of metal behind. In both the above examples, the designers failed to ensure that their designs achieved their main function. An understanding of the key elements in the design and manufacturing of consumer products and the tools used to model their functionality should help to explain why designers often fail in designing functionality. Modern simulation software allows function to be modelled but this can only be within the limits of the software writer. Simulation only successfully simulates the known, it cannot do the unknown. In modern design it is common to combine functionality but at a cost in increased complexity (Modler *et al,* 2020).

The early part of the design process consists of research to write a design specification based on similar existing products. A difficulty arrives when the research highlights that only a small quantity of information is available to the design engineer. To fill the gaps in the design engineer's knowledge, experimentation is often used. Useful data is made available by this experimentation, but it can be costly and time consuming to produce as many variables may need to be assessed. Antony, (1998) suggests using matrices to determine experimental data. Use experiments to find the extremes of data and then use matrices to fill in the gaps in between. Antony is producing a computer-based system which will speed the calculations up and make them easier to produce. Today (2023), experimentation is cheaper and quicker as much can accomplished with computer simulations. Matrices may still be used as part of the simulation calculations, but the computer makes the whole process easy to use (Xie *et al,* 2018).

2.11 Chapter Summary

Summary

- Benefits of storing information on computers and logbooks.
- Frameworks developed to define the design process.
- Use of contradiction matrices to enable problem solving.
- Use of key characteristics to determine the ideal method to solve a problem.
- Assembly and production methods must be considered early in the design process.

Signpost to Aim and Objectives

Many systems have been developed to try and formulise the design process. Most can only partially work because a major input into the design process is creativity, which is very hard to formulise. AI may be able to move this area forward. Assembly must be considered in the design process and is a difficult area as student's often research a completed design solution (already assembled) and so have difficulty understanding this design area.

2.12 Thematic Analysis

The literature review will be analysed using a Thematic process (see section 7.1) to identify specific themes and gaps in knowledge.

2.12.1 Step 1 Familiarisation

Each topic area in the literature review was reviewed and a summary made as well as a signpost to the aims and objectives of this research. From these summaries certain themes began to appear.

2.12.2 Step 2 Themes

- Organisation of design engineers to maximise individual strengths and minimise potential weaknesses.
- Use of design teams and methods to maintain communication.
- Knowledge is a key property of a design engineer.
- Industry methods of design are constantly being updated to allow for changes in technology and commercial pressures.
- Various models have been developed to try and simplify the design process by creating various logic frameworks.
- Engineering design is best learnt by doing. A hands-on approach.
- Use of company in-house, national, and international standards are important for any design engineer to know about and use.
- Assessment of students and companies is important to maintain or improve standards.

2.12.3 Step 3 Theme Refining

The themes in step 2 were refined by further research to identify final themes and gaps in knowledge.

- Use of the internet and specialist software to organise teams and the simplify the design process.
- A design engineers' knowledge is vast often leading to design engineers specialising in certain areas and the development of a team approach.
- Complex design can often be simplified by adopting a standard approach developed in-house or commercially.

- Industry methods of design is constantly changing and so must be reviewed regularly.

2.12.4 Step 4 Gaps in Knowledge

Two main gaps in knowledge have been identified:

1. The detailed methods to design a complex component in industry are constantly changes and so require to be updated by institutions that train future design engineers.
2. The knowledge of design engineers in industry is vast. The required knowledge of mechanical engineering students should be researched to determine if upon graduation they have the required knowledge.

CHAPTER 3

RESEARCH METHODOLOGY

(Objectives 2 & 3 Section 1.2.2)

3.0 Introduction

The aim of this research (Section 1.2) is to narrow the difference between the requirements of mechanical engineering designers leaving colleges and universities and the requirements of modern industry, while at the same time making an accurate assessment of a student’s abilities based on the criteria set out in programme and module documents.

The literature review in chapter 2 identified two gaps in knowledge. These are:

3.01 Research the methods used by industry to design complex mechanical engineering components making full use of the latest tools, many of which are a part of the internet (see introduction for definition of internet in the context of this thesis) such as 3D modelling, virtual simulation, conferencing software etc.

3.02 Research the specific knowledge students require when learning to design complex mechanical engineering components and research the effect any changes made to teaching mechanical engineering design have on the students experience and achievement.

To meet the aim of this research it is necessary to make changes to the methods used in academia. These changes will be applied to students studying a BEng (Hons) Mechanical Engineering degree at the University of Derby (UK). This University was formed with the passing of the Further and Higher Education Act in 1992 which made it possible for colleges, polytechnics, and other HEI’s to receive university awarding powers It is critical that the same changes can also be applied in other HEI’s. Research will be carried out to determine if the changes made at The University of Derby (UK) can successfully be made in other HEI’s.

3.03 Research methods used in other HEI’s to teach mechanical engineering design and compare the methods to those used in The University of Derby (UK).

The research methodology to be used in the three areas listed above will be detailed in the rest of this chapter.

3.1 Research Methodology

The methodology of this thesis is based on the model commonly referred to as the Saunders Research Onion (Saunders *et al,* 2019). This model was chosen as it is widely accepted by academia and provides a framework for research methods that are appropriate for the aims of this thesis. The different layers of the model represent the various stages through which a researcher must pass when preparing an effective research methodology. The research methodology will detail the five different layers of the onion (Fig. 38), explaining the reasoning behind the choices and applying those choices to three different research streams highlighted in sections 3.01, 3.02 and 3.03. Borrego *et al,* (2009) will be used to assist in defining the terminology used in these methodologies. The research onion encompasses all the commonly used research methods. Other lesser-known methods are available such as Participatory action,

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Figure 38 Saunders research Onion (Dissertation Writers, 2019)

Photo ethnography, and Autoethnography (Donley & Grauerholz, 2012) but these tend to be used for specialist research and so will not be used in this section.

3.2 Philosophy Stances (First Layer)

In the first layer of the onion are found six beliefs which are often framed in the context of ontology and epistemology (Table 29).

Epistemology, which is a primary branch of philosophy is concerned with what is (or should be) acceptable knowledge. Most modern philosophers have narrowed down acceptable knowledge to three major criteria, belief, truth, and justification. To illustrate, John knows there are tools in a toolbox because he believes this to be true (belief), there are tools in the toolbox (truth), and John saw the tools in the toolbox as he walked past (justification). This example uses a combination of empirical and rational knowledge to come to a justified and true belief (Blakeley, 2022).

Ontology is part of the school of thought of philosophy and more closely a branch of metaphysics, which investigates the nature of things including their cause and identity (Keefe, 2022). Ontology is concerned with the study of knowledge (O'Gorman & MacIntosh, 2015). Another definition of ontology is the nature of the world and what is known about it (Snape & Spenser, 2003). An example could be a person who claims to be in pain. Someone looking at the person may not see any physical signs of pain (injury or bleeding). Is the pain real or imagined? The pain would be real to the person feeling it but possibly considered imagined by the person looking on. Whose viewpoint is real, and which imagined?

Table 29 Saunders Philosophy Stances (First Layer)

Epistemology	Positivism	Understanding can only come from knowledge that can be scientifically verified.
	Realism	Questions the reliability of scientific knowledge and maintains that all theories can be revised.
	Interpretivism	An approach that asserts that understanding the beliefs, motivations, and reasoning of individuals in a social situation is essential to understanding the world.
Ontology	Objectivism	Human knowledge and values are objective and are determined by the nature of reality.
	Constructivism	Focuses on how bodies of knowledge come to be and how ideas are constructed.
	Pragmatism	Centres on linking theory and practice. Uses the most appropriate tools and approaches to do so.

The gaps in knowledge (section 3.01, 3.02, and 3.03) will each require a different approach.

- Research question 3.01 and 3.03 has an interpretivist epistemology, objectivist ontology. The methods used by industry to design a complex component, and then the application of those methods to teaching design engineering students, will require qualitative judgements to be made as to the best way to apply those methods. Or even raise a question if those methods should be applied at all. The methods may require varying, recognising the difference between individual students. The methods are from an acceptable source (industry) making the knowledge also acceptable. The methods will be researched objectively, removing any personal viewpoints. The researcher will observe the methods used by industry without attempting to interpret them.

- Research question 3.02 has an interpretivist epistemology, pragmatist ontology. Research into students' knowledge will require identifying the areas of knowledge a design engineer would have. Understanding how knowledge come to be and how ideas are constructed will be required, so that methods can be developed to teach the appropriate knowledge. A pragmatist ontology will be required using a constructivist approach linking theory and practice. This will require a survey of students to determine their depth of knowledge.

The two research methodologies shown above to research the gaps in knowledge recorded in sections 3.01, 3.03 and 3.03 based on Saunders Research Onion, leads to a very large number of possibilities when developing a research methodology. There are similar research methodologies that can be referred to to support the two selected above (Grote & Hefasi, 2021) (Rogalewicz & Sika, 2016).

3.3 Approaches (Second Layer)

A research approach could be either deductive or inductive (Table 30).

Table 30 Saunders Approaches (Second Layer)

Deductive	This approach tends to flow from generic to specific. A researcher using deductive reasoning would start with a theory and move on to research question or hypotheses which is tested through data collection afterwards. Findings derived from the collected data would either confirm or reject the research question or hypothesis.
Inductive	This approach is often used or helpful when there is little research available on a topic. A researcher would move from research question to observation and description to analysis before finally getting on to a theory.

Looking at the gaps in knowledge (section 3.01, 3.02 and 3.03) all require a deductive approach. The methods used by industry to design complex components change as new technologies develop, it is a continuous process. This research will look at an overview of industry methods, and then narrowing the research to specific areas and how these can be applied to teaching in colleges and universities. Students' knowledge will be researched by narrowing the research down to determine in detail what knowledge students require and the best methods to impart the knowledge. Any identified gaps in knowledge would be tested through data collection.

To assist the deductive approach for research question 3.03, Thematic Analysis will be applied, which uses six steps to analyse the data from interviews of academics in HEI's (Braun & Victoria, 2022).

3.4 Methodological Choice (Third Layer)

This research will require data collection so that any determined gaps in knowledge can be filled. More than one method can be used to collect the data. Table 31 lists options that are available:

Table 31 Saunders Methodological Choice

Data Collection Method	Description and Example
Experiment	Designed to test causal effects of phenomena on group. Data collected using this method could be statistically analysed. Example: Big data collection of automobile driver reaction to car-following and car-approaching to be used in autonomous cars (Wang *et al*, 2014).
Survey	This often results from a deductive approach and can collect large volumes of data that is apt for statistical analysis. Can produce highly reliable data that is difficult to observe or record (Meyerhoff *et al,* 2015). Example: Automatic survey of engine data to determine acceptable operating parameters/possible failure.
Case Study	Provides unique examples of real people or cases in real situations. The number of such case studies is often restricted for drawing clear conclusions from the data. Example: Monitoring of input/output to a steam turbine to ascertain why degradation occurs (Wiley, 2016).
Action Research	Designed to deal with a specific problem in a specific situation. Begins with setting up a clear objective. The problem is then fully diagnosed, and a list of solutions is prepared and presented as

	recommendations to solve the issue. Can also be a critical self-reflection of ones practice (McNiff, 2013). Example: Data collected from aircraft pilots on communication issues in multi-crew flight decks to determine adequate Cockpit Resource Management.
Grounded Theory	This approach of collecting data to build theory rather than to test or refine one. After data collection through observation, the research question is then applied to the data, creating a basis for a new theory. Grounded theory was designed to create theories that were empirically derived from real-world situations (Oktay, 2012). Example: Computer Big Data collected over years and used to identify a new, previously unidentified failure mode in automobile operation.
Ethnography	Studies people in natural surroundings to develop theory around behaviour and culture. It can be an in-depth study of a group or setting over an extended period (Curtis *et al,* 2013). Example: Use of emergency oxygen by airline passengers travelling with dependents.
Archival Research	Derives information from existing data and archive documents. Accuracy and amount of available information could present issues. Example: Predicting crashes using traffic offences (Barraclough *et al*, 2016).

Looking at the gaps in knowledge (section 3.0):

- Research question 3.01 will investigate the methods used to design complex components, by looking at different companies ranging from small to large world leading. These companies will be from a range of different industries. Data collection will suit a case study approach (see chapter 6).

- Research question 3.02 the depth of student's knowledge and 3.03 methods used by HEI's to teach mechanical engineering design will be ascertained by data collection. The method of data collection will be action research. This will allow targeted, specific research to be carried out. If an issue is found in the student's knowledge, this will require addressing and will be dealt later in this thesis.

3.5 Qualitative & Quantitative (Fourth Layer)

Quantitative research relates to numbers, measurements, and quantity whereas qualitative research is concerned with rich data including opinions, description, and personal accounts. Saunders, (2019) gives three methods of using quantitative and quantitative research (Table 32):

Table 32 Saunders Qualitative & Quantitative (Fourth Level)

Mono-method	Researcher collects either qualitative data or quantitative data based on the decisions made earlier in the research onion.
Mixed-method	Researcher collects both quantitative and qualitative data with the intention to use these equally in the research study.
Multi-method	Both qualitative and quantitative data collection techniques are used. Analysis of the data is done using one perspective only.

Looking at the gaps in knowledge, a mono-method will be used (section 3.0):

- Early research will require identifying design methods used in industry and comparing them with design methods used to teach design in colleges and universities (section 3.01 and 3.03). This will consist of descriptions and will be qualitative in nature. Later, a survey to determine the basic engineering knowledge of full-time and part-time students will be completed (section 3.02). This data will be quantitative in nature. The qualitative area of research will help identify methods that colleges and universities can adopt to align closer with industry. The quantitative area of research will develop a method to assist students an applying industry method to their design.

3.6 Timeframe (Fifth Layer)

The timeframe for research can have two options available to the researcher:

Table 33 Saunders Timeframe (Fifth Level)

Cross-sectional	Presents a snapshot view of a particular situation at a single point in time and confines the duration of data collection and research to a short period of time.
Longitudinal	Studies events and behaviours using concentrated samples over a long period of time.

The timeframe for researching the gaps in knowledge will use both timeframes found in Table 33:

- Research question 3.01 on the design methods used by industry and 3.03 methods used by HEI's to teach mechanical engineering design will use a cross-sectional timeframe. This timeframe is appropriate as design methods continuously change as technology changes so any research of the methods can only be a snapshot at that moment in time.

- Research question 3.02 into required knowledge of design students will be carried out over several years. This will use a cross-sectional survey, a snapshot, at the beginning of an academic year. These snapshots, over several years will develop into a longitudinal timeframe which will provide quantitative data and highlight improvements in the knowledge over time.

3.7 Techniques & Procedures (Sixth Level)

Table 34 is a summary of the methodologies for the three research areas:

Table 34 Summary of Methodologies

	Research Industry Methods (3.01)	Research Student's Knowledge (3.02)	Research HEI's Methods (3.03)
Philosophy Stance	Interpretivism epistemology Objectivist ontology	Interpretivist epistemology Pragmatist ontology	Interpretivism epistemology Objectivist ontology
Approaches	Deductive	Deductive	Deductive
Methodological Choice	Case Study	Action Research	Action Research
Qualitative & Quantitative	Qualitative	Quantitative	Qualitative
Timeframe	Cross-sectional	Cross Sectional & Longitudinal	Cross-sectional

3.7.1 Research Industry Methods

Research question 3.01 will begin with an interpretivist epistemology, objectivist ontology with a general literature review of design and design methods in industry and academia. The qualitative process will continue by researching deductively in greater detail case studies of engineering industry design methods used in small to large companies. The emphasis will be on qualitative methods that can be applied in a college or university environment. It is expected that most design methods used by industry will work in academia with little or no changes. As design methods are continuously changing, driven by changes in technology, so this research will be a snapshot using a cross-sectional timeframe.

Identified changes to the methods of teaching design will be applied to classes of students in their final year of a BEng (Hons) Mechanical Engineering degree. These changes will be applied incrementally so that an accurate assessment and validation can be made of their effect on the students learning and achieving the module outcomes.

Once a change has been successfully applied to a class the changes will be validated using the conference and journal papers peer review process. This process uses academic and engineering design specialists to critically review the papers, applying appropriate academic rigour. This will provide a high degree of confidence and validation.

Once all changes have been applied to classes and validated by conference and journal papers, industry specialist will be asked to validate the changes by providing comments on the methods and applications used, and how closely they replicate industry methods. The main question to be answered at this stage is: Will these changes to the design methods used in academia bring academia closer in-line with the methods used by industry and so produce better qualified, industry ready, design engineers?

3.7.2 Research Student's Knowledge

Research question 3.02, a determination of student's basic engineering knowledge was identified as an area for research. This will be an interpretivist epistemology, pragmatist ontology based on qualitative analysis of a survey of basic engineering knowledge of students studying the final year of a BEng (Hons) Mechanical Engineering degree. Deductive research was carried out to determine what, if any, knowledge was lacking, followed by active research in the form of a specific survey of the students to narrow the area of knowledge required. The survey (Appendix 1) used specific quantitative methods and was completed initially at the beginning of the academic year over a cross-sectional timeframe. This will be repeated for 5 years. The results forming a longitudinal timeframe.

The results of the survey were published in conference and journal papers which have been peer reviewed by industry and academic specialist. This provides a degree of confidence and validation.

All research of the student's knowledge will be subject to ethical approval by the University of Derby's (UK) Research Ethical Committee. This deals with issues such as informed consent, confidentiality, anonymity, voluntary participation, disclosure of information, and potential for harm.

3.7.3 Research HEI's Methods

Research question 3.03 will begin with an interpretivist epistemology, objectivist ontology with several interviews on teaching design and design methods in HEI's. The qualitative process will continue by researching deductively in greater detail the action research of HEI's. The emphasis will be on qualitative methods that are applied in a college or university environment. It is expected that most design methods used by HEI's will be similar or the same as those methods used in The University of Derby (UK). As design methods are continuously changing, driven by changes in technology, so this research will be a snapshot using a cross-sectional timeframe.

The main question to be answered at this stage is: Will the methods used by other HEI's to teach mechanical engineering design be similar or the same as the methods used by The University of Derby (UK)? If this is found to be the case, then this will provide the confidence required to recommend that other HEI's adopt the methods created in the thesis.

3.8 Chapter Summary

Three research questions (section 3.01, 3.02, and 3.03) were identified, the first, looking at industry methods to design a complex component, the second, looking at the knowledge design engineering students require to design a complex component, and the third, researching the methods used by other HEI's to teach mechanical engineering design. A research methodology based on Saunders Research Onion was used for all research questions that will allow methodical and logical research to be completed to answer the research questions. The results of all research questions will be validated by peer review of conference and journal papers followed by specialist designers from industry.

CHAPTER 4

THE DESIGN PROCESS

(Objective 2 Section 1.2.2)

4.0 Introduction

This chapter describes the important steps in a systematic approach to mechanical engineering design and helps to define common terminology. It will look first at Systematic Design Technique with an example, followed by an Iterative Design Procedure. There is no single universally acclaimed sequence of steps that lead to a workable design solution. Different writers and designers have outlined the design process in as little as five steps, or as many as 25 (Dieter & Schmidt, 2020).

The designer's initial task is to identify the primary needs of a product. This is really the design problem expressed in clear terms. Once the primary needs are identified, secondary needs may be established (Seibel & Schiller, 2018).

The primary needs for a new design or redesign can be for various reasons:

- A machine requires to update the process and so requires the mechanism to be modified.
- Use of new technology.
- Product requires improving compared with a competitor's product.
- Legislation changes.
- Redesign to meet the needs of the circular economy.

Secondary needs are ancillary to the primary needs and may consist of the following (Fermentini *et al,* 2022).

- Reliability.
- Ergonomics and Anthropometrics.
- Aesthetics.
- Safety.
- Economics.
- Quantity.
- Quality.
- Cost.

Methods are available to the design engineer to help in gathering the necessary information so that the primary and secondary needs can be determined. One popular method used by industry is Functional Analysis System Technique (Bartolomei & Miller, 2001) (Value Analysis, 2023). This method develops a graphical representation showing the relationship between the functions of a project, process or service (Fig 39). This method addresses three key questions:

1. How do you achieve this function?
2. Why do you do this function?
3. When you do this function, what other functions must you do?

The following diagram illustrates how a function is expanded into 'How' and 'Why' directions in a FAST diagram.

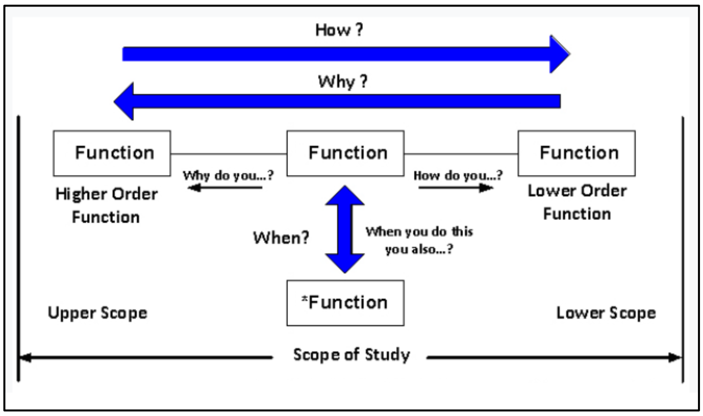


Figure 39 FAST Diagram (Value Analysis, 2023)

A mechanical engineering design problem can be solved in many ways, but by applying certain rules, the effort required can be reduced. By a systematic process of elimination, workable design solutions may evolve. This method is called, Systematic Design Technique and is shown in Fig 40. By identifying the best aspects of each design solution based on the primary and secondary needs, and then rating them, an assessment can be made as to the best solution (see section 4.1 for an example). This process, which can have many variations will eventually achieve a design solution (Eder & Hosnedl, 2010).

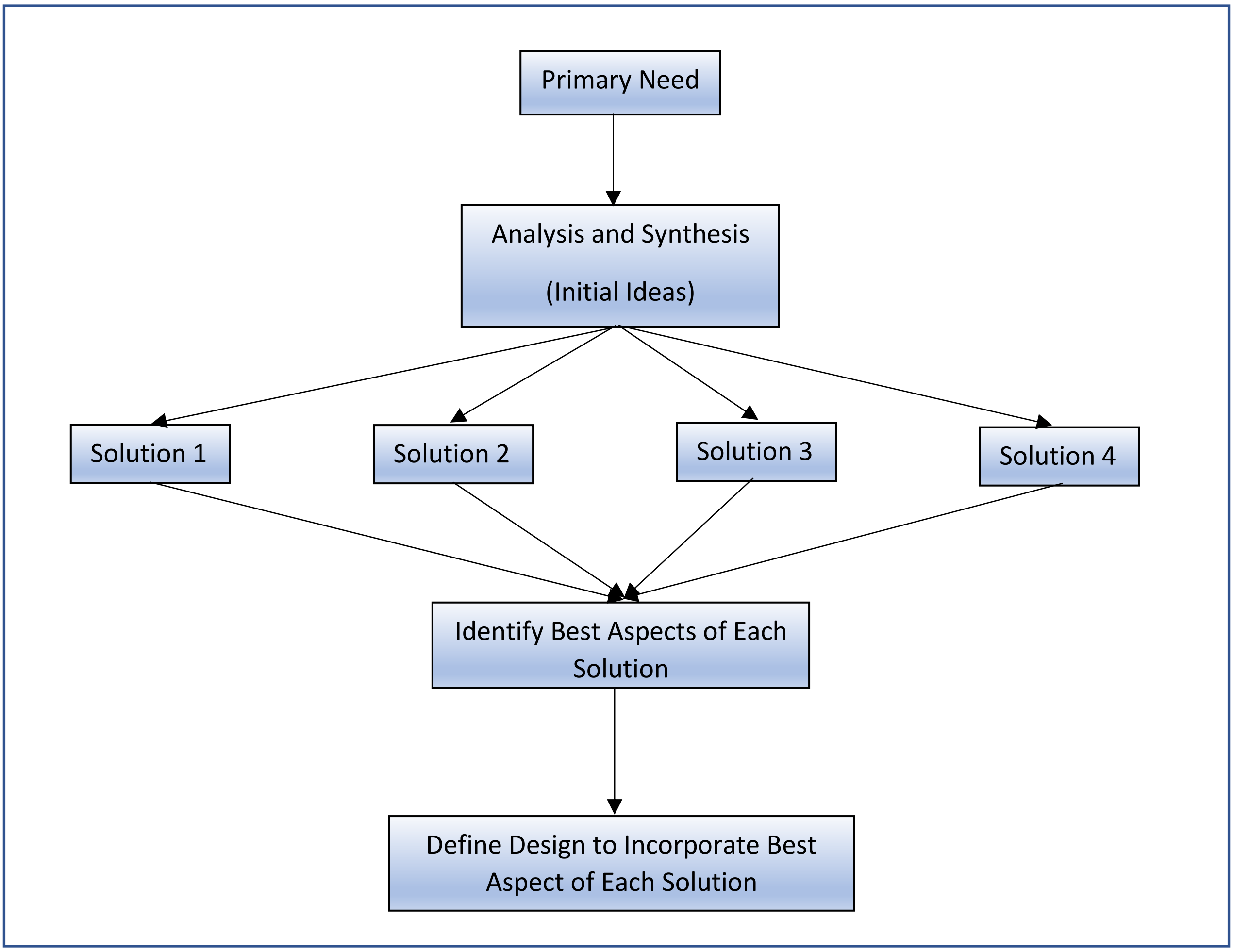


Figure 40 The Systematic Design Technique Process (Eder & Hosnedl, 2010)

A designer requires a clear train of thought which is developed through analysis of the problem. This will provide the answer to:

- Method of operation.
- Production procedures.
- Method of power flow.
- Method of control.

Both practical and theoretical knowledge will be required during the analysis (Kraslawski *et al,* 2015). The practical knowledge could be from experience, physical prototypes, previous designs, and competitor designs. The theoretical knowledge could be from research or experimentation. The required practical and theoretical knowledge can come from both scholars and practitioners (Fernando, 2018). This may include:

- Manufacturing Tolerances.
- Design form.
- Maintenance.
- Ergonomics.
- Strength.
- Size.

Synthesis involves collecting design information and ideas. This results in a number of possible solutions being sketched and analysed. The sketches are carefully annotated to provide details of important features. A systematic process of comparison and evaluation is carried out often using a points system or ranking technique (Kraslawski *et al,* 2015).

4.1 Example (Dieter & Schmidt, 2020)

A machine operates a mechanism to move a table a certain distance and return it in one revolution of the driver motor. The purpose is to reject bottles from a conveyor. Fig. 41 shows a diagrammatic representation of the problem. It is required to design a simple mechanism to achieve the desired motion.

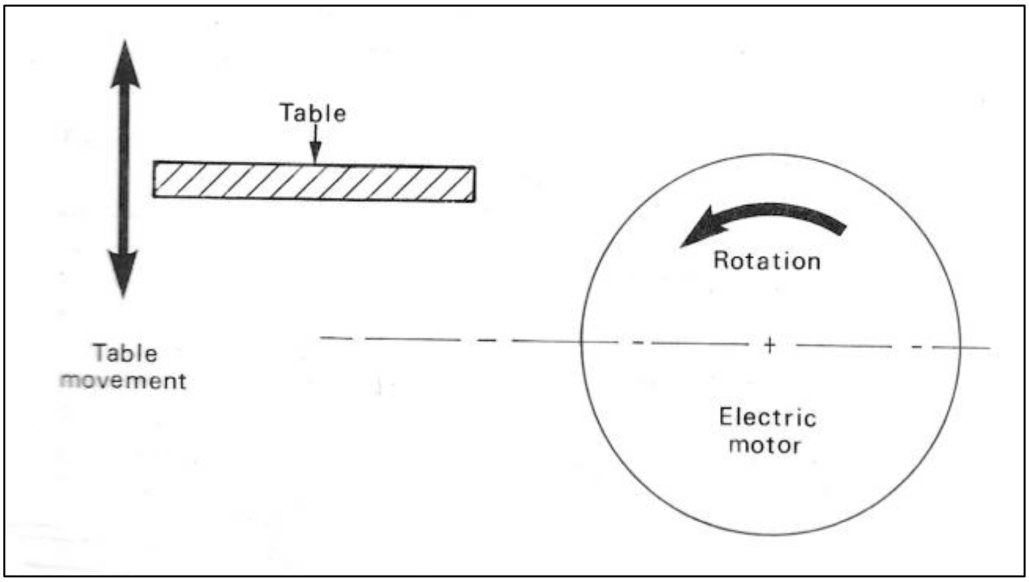


Figure 41 Diagrammatic Representation (Dieter & Schmidt, 2020)

Design sketches of possible solutions are made, suitably annotated to show the important features. Fig 42.

Content removed due to copyright reasons.

Figure 42 Design Sketches (Dieter & Schmidt, 2020)

A systematic process to identify the best aspects of each solution would now be made (Table 35).

Table 35 Design Feature Rating

Feature	Design A	Design B	Design C	Design E
Fulfilment of Function.	H	H	H	H
Reliability.	M	H	L	L
Serviceability.	M	M	M	L
Life.	L	M	L	L
Ease of Maintenance.	M	M	M	L
Ease of Manufacture.	M	H	L	L
Efficiency of Operation.	L	M	L	L
Simplicity of Layout.	M	H	L	L
Cost.	Moderate	Cheap	Moderate	Expensive

H = High indicates a most satisfactory solution

M = medium indicates a nearly satisfactory solution

L = Low indicates the unsatisfactory solution

The rating scores are now added up and an assessment made as to the best solution (Table 36).

Table 36 Rating Scores for Each design

	Design A	Design B	Design C	Design D
High	1	4	1	1
Medium	5	4	2	0
Low	2	0	5	7
Cost	Moderate	Cheap	Moderate	Expensive

This method depends upon the designers understanding of the terms High, Medium and Low and should be used objectively.

Design B has more ratings in the High and Medium category than the other designs. Cost is favourable due to the simple design of the components used.

Design D has the lowest number of High/Medium ratings and high cost. This design is considered to give most problems in manufacture, operation, and cost.

Larger and more complex designs may require more detail analysis. A large complex design such as an aircraft would be broken down into individual assemblies, or even single components. The analyse of these may highlight multiple positive aspects across several designs. Further analysis will then be required to determine the preferred design. These individual components and assemblies will then require combining, which would require even further analysis to determine the effect the two assemblies have on each other (Battaia *et al,* 2018).

4.2 Iterative Design Procedure

An iterative mathematical procedure is one in which an approximate solution to a problem is initially guessed and then fed into an iterative formula which reveals a more accurate solution. The process is repeated, each time a more accurate solution is determined. Once a solution with the required accuracy is achieved, the process stops (Zhitnikov *et al,* 2021).

The process in the above mathematical model also works well in mechanical engineering design. The iterative mechanical engineering design process makes a realistic assumption, or a realistic guess at a design solution. The design solution is then tested by comparing it to the design specification. The comparison will highlight areas that the design solution might be improved. The original design solution is redesigned to include the required improvements and then compared again to the design specification. The process of redesign continues until the design solution meets all the requirements in the design specification. Complex components may require more iterations than non-complex components and in the latter stages of design may require making a virtual or physical prototype with possibly testing to prove functionality.

The example iterative (Bertoni, 2019) (Feng *et al,* 2022) process in Fig.43 starts with cost. If the cost is found to be too high, the design process loops back. A redesigned is carried out to reduce the costs and repeated until the cost is reduced to an acceptable level. Once the cost is acceptable, the design moves onto the next stage, designing for function. If the function is not acceptable, then the design process loops back to the costing stage and the process begins over. Once the cost and functions meet the customer requirements the next stage in the example is to design for batch manufacture. Once the trial batch reaches an acceptable level the design can be sent for production. Each loop will improve the design incrementally until, finally, an acceptable design, meeting all the design requirements set by the customer are met (Muller *et al*, 2016).

In practice, the number of iterations for each loop could be many, and the number of loops, large. The acceptable values that allow the design process to break out of a loop are critical to the design being a success. These are determined in the design specification (Feng *et al,* 2022).

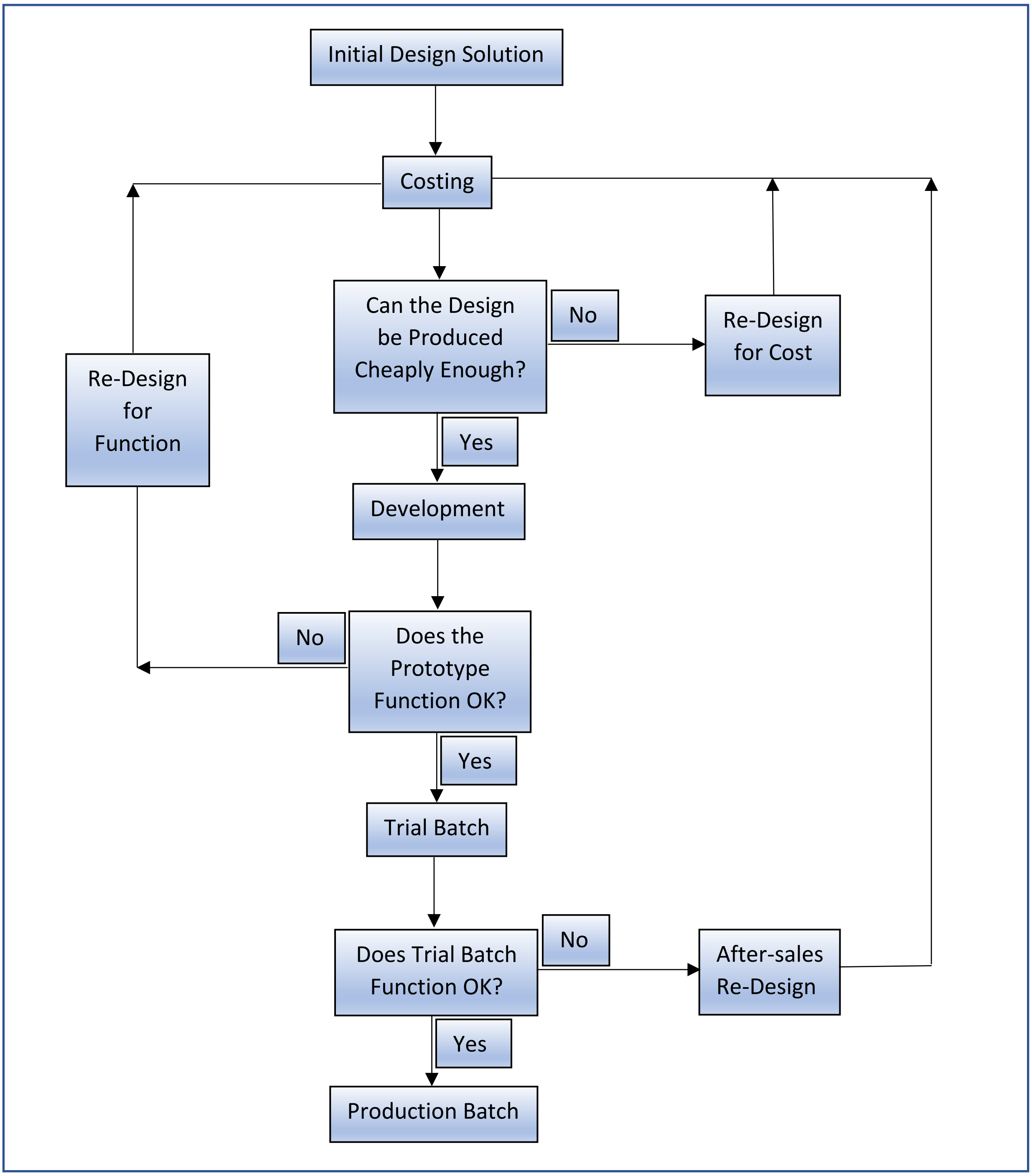


Figure 43 iterative Design Procedure (Bertoni, 2029)

An example of the Iterative design progress of a concept sports car was provided by Dickison *et al,* (2020). Using a combination of CFD software, StarCCM+, and a $1/4^{th}$ full-scale fibreglass model for validation using a wind tunnel. The design was gradually improved until a final design solution was achieved (Fig. 44).

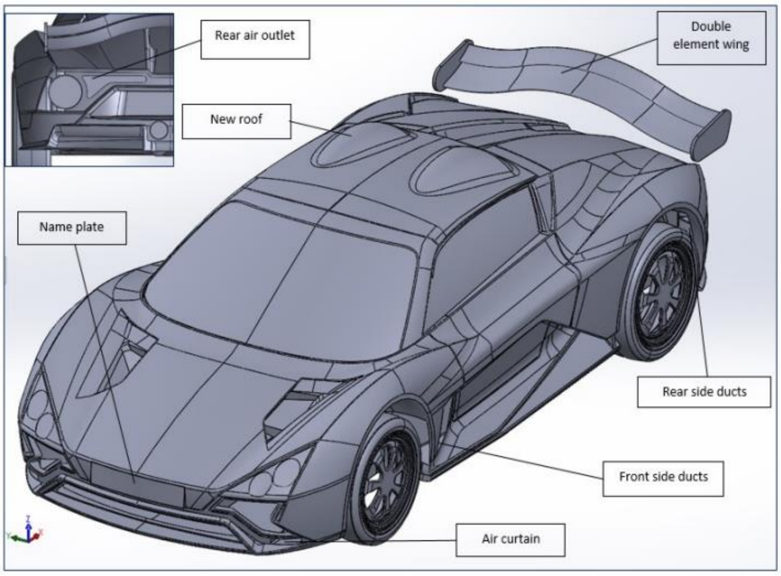


Figure 44 Integrated Design Modifications (Dickison *et al*, 2020)

4.3 Specification (Jiang *et al, 2015)*

The primary need (section 4.0) is the trigger which starts a new design or redesign. Secondary needs are ancillary to the primary needs and are a list of the areas the designer will be required to consider completing the design. Research of these areas will provide specific details and values that the design must meet or surpass to provide the confidence to the designer that their design will be successful. This detailed list of requirements is known as the design specification. The primary and secondary needs may be supplied by either the customer or from a marketing request. The detailed design specification comes from the designer. The content of the specification can be varied and detailed. Generally, it would include at least:

- Title
- History and background
- Scope
- Definitions
- Conditions of use
- Characteristics
- Reliability
- Servicing Features

4.4 Modern Technology

The basic design stages have changed very little from that recorded above. The methods used to complete each design stage have changed, mainly due to new technology. The largest, and possibly the most important change was when mankind entered the age of the computer, also known as the fourth revolution or Industry 4.0. This has reduced the design office in size, increased the speed to produce a design, and has made possible the design of very complex components and assemblies of components (Kenett *et al*, 2020). Due to the speed of change computers have made possible, there is now a constant need to update the methods used during each stage of design.

The drawing board has been replaced with Computer Aided Design (CAD) where 2D technical drawings can be produced quickly, cheaply, and accurately. The drawings can be stored in computer memory, printed when required, edited, and sent anywhere in the world electronically (Sabin *et al*, 2021).

2D drawings have led the way to 3D modelling where complex components and assemblies can be modelled using software. These models can be used to produce virtual prototypes that can be used to check the function, fitting, and strength of the components and assemblies. The models can be used to produce machine code to manufacture the components known as Computer Aided Manufacture (CAM).

3D modelling has made possible many powerful features such as parametric models where the geometry of a design can be controlled by mathematical equations. By entering one variable, the whole geometry of a component can be changed. Designs can then be optimised using a computer iterative process. Fixing some design parameters, the designer can use the computer to vary other parameters to try and find an improved design. The improvement could be to reduce a components mass while maintaining its required strength. Finite Element Analysis (FEA) can be used to put a component under a load and then calculate the stress, strain, factor of safety and many other features (Sanchez *et al,* 2021) (Michalak & Przybysc, 2021).

3D modelling has led the way to a virtual world where complex components and assemblies can be viewed as if a physical prototype had been manufactured. Sound, smell, and touch can be provided to enhance the experience. The two design processes previously given (Systematic and Iterative), have both been improved by 3D modelling. The Systematic Design Technique (section 4.0), by applying parametric design, makes the development of solutions quicker and easier. The Iterative Design Procedure (section 4.2) is improved by using Parametric Design, and can be further improved with the Optimisation of the final Parametric Design. Both processes can use FEA to confirm the design functionality and loading (Michalak & Przybysc, 2021).

Design, especially of complex components and assemblies has always been a group activity. Modern technology with its conferencing tools and 3D modelling has expanded group work so that individuals making up a group can be based anywhere in the world (Kyratsis *et al,* 2020).

4.5 Efficient Design

An essential element in the design process is assessing a designs efficiency. This can be applied to many different areas that are usually quantifiable such as cost and energy which can then be broken down into smaller efficiencies such as cost of labour, cost of materials, energy to operate, energy to assemble, energy to manufacture. The importance of this area has increased over the last few years due to concerns over sustainability and the need to operate more efficiently, producing less waste (Ehrlenspiel *et al,* 2007). A major tool assisting design engineers to achieve efficient design is the use of 3D modelling. In 1994, the Boeing 777 commercial jet first flew. This was one of the first complex design to be completed using 3D modelling. At the time, 3D modelling was an extremely expensive method, requiring some of the most powerful computers in the world. To justify the cost, Boeing looked at an earlier commercial jet, the Boeing 767. This aircraft had two different types of doors, passenger and cargo. When these were designed using physical prototypes 1,300 modifications were required at a monetary cost of $64 million. After the Boeing 777 was completed using the new 3D modelling, research showed that modifications were reduced by 98%. A huge saving in money, time and materials and a huge increase in efficiency (Sabbagh, 1995).

4.6 Shape Complexity

A complex design was defined in section 1.0 Introduction. With the increased power of computers and the ability of a software engineer to write software which can complete calculations which could only be dreamed of a few years ago, another area of complexity has developed, shape complexity. This can broadly be defined as the number of 'simple shapes' required to create a more complex shape, and the self-similarity of those composite parts. Research is focussed on coping with or on reducing shape complexity. Shape complexity can be measure in many ways (Table 37) (Rossignac, 2005) (Boothroyd *et al*. 2011).

Table 37 Shape Complexity Measurement

Complexity Method	Definition
Algebraic	Measures the degree of polynomials needed to represent the shape exactly in its implicit or parametric form.
Topological	Measures the number of handles and components or the existence of non-manifold singularities, non-regularised components, holes or self-intersections.
Morphological	Complexity measures smoothness and feature size.
Combinatorial	Complexity measures the vertex count in polygonal meshes.
Representational	Complexity measures the footprint and ease-of-use of a data structure, or the storage size of a compressed model.

Shape complexity is important in the manufacture of a component. In metal extrusion, it provides an estimate of how complex the die cavity will be. In metal casting it provides an estimate of the complexity of the moulds. It is also important in the development of 2D and 3D modelling used in CAD/CAM systems.

4.7 Design Process Transferability

This thesis primarily researched the design process used by mechanical engineers. Could the changes recorded in this thesis be used in other industries that also require design? Table 38 looks to answer this question by comparing the design process in mechanical, electrical, motorsport, and civil engineering.

Table 38 Design Transferability

Mechanical Engineering Systematic Design Technique	Mechanical Engineering Iterative Design Procedure	Electrical Engineering Design Process	Civil Engineering Design Process
	Make a realistic guess at a design solution.		Understand the problem.
Identify the primary and secondary needs (design specification).	Test the design solutions against the design specification.	Design Specification which incorporates a design proposal.	Conceptual design with specification.
Analysis and synthesis.	Identify areas for improvements.		Embodiment design which could include models.
Design solutions.		Schematics and layout with design review.	Detail design with elevations and detailed plans.
Identify best aspect of each design solution.	Update the design solution.	Prototype and simulation.	Prototype and testing.
Define design to incorporate best aspect of each solution.	Refine design solution until it meets the design specification.	Printed circuit board design.	Completion of detailed designs utilising best aspects.

Table 39 clearly shows the design process is similar between other disciplines such as electronics engineering and civil engineering. This provides confidence that the suggested changes in this thesis do not just apply to mechanical engineering design but with very little modification will also apply to electronics engineering and civil engineering.

4.8 Chapter Summary

The systematic approach to mechanical engineering design detailed above have as many variations as the components and assemblies they produce. The creative requirements of mechanical engineering design preclude the systematic approach being more regulated. With little modification the same design process can be used in electronic engineering and civil engineering.

Technology has made mechanical engineering design of complex components possible, with minimum effort. Designing in teams, which is not new, has been enhanced by expanding the size of the teams by making their physical location unimportant. Computers provide tools to the designer that enhance the whole design process, making it quicker and easier to design while at the same time increasing design complexity manyfold.

As shown by the research into the mechanical engineering design process used in other HEI's (chapter 7), the teaching of mechanical engineering design is an accepted standard. The way that modern technology is used and its effect on our way of teaching is an area that this research will be looking at.

CHAPTER 5

THE UNIVERSITY OF DERBY (UK) DESIGN ORGANISATION

(Objective 3 Section 1.2.2)

5.0 Introduction

Design is a multi-disciplined area requiring many skills. This thesis will be focusing on the final year module 6ME500 Advanced Engineering Design Modelling as this module is the pinnacle design module of the BEng (Hons) Mechanical Engineering degree programme at The University of Derby (UK).

This thesis will not be looking at the programme in detail but only where it affects the 6ME500 module. To aid the reader, the programme is explained in this chapter.

5.1 BEng (Hons) Mechanical Engineering Degree

As of 2016, the University of Derby (UK), has two main routes to achieving a BEng (Hons) in Mechanical Engineering degree. These routes are divided into part-time and full-time.

5.1.1 Part Time Entry Requirements

Direct entry to the BEng (Hons) Mechanical Engineering as a part time student is not possible. The part time route requires that a student complete a Foundation Degree (Science) in Mechanical and Manufacturing Engineering. As of September 2014, this takes two years. If the student achieves 70% or greater in their Foundation degree classification, they can transfer onto the final year of the BEng (Hons) Mechanical Engineering program. As a part-time student, the final year or top-up year will take two academic years to complete.

The entry requirements to start a Foundation Degree (Science) in Mechanical and Manufacturing Engineering are listed in Table 39:

Table 39 FdSc (Science) in Mechanical and Manufacturing Engineering (Part Time) - Entry Requirements

Full time or part time appropriate engineering-based employment that will allow a student to undertake their studies on a day release basis.
BTEC National Diploma.
‘A’ levels or equivalent qualification.
Scottish Highers.
Access/Foundation course.

5.1.2 Module Content

The part time Foundation Degree is in the form of a ‘Work-based Enhanced Part Time’ route, which allows a student (in appropriate engineering-based employment) to complete 120 credits each academic year, on a normal day release basis from their employer. Work-based Enhanced Part Time students can, and normally do, complete this programme over two academic tears.

The modules studied over this two-year period from September 2014 are listed in Table 40.

Table 40 FdSc (Science) in Mechanical and Manufacturing Engineering (Part Time – Modules)

Module Code	Module Name	Credits
4ME501	Computer Aided Design.	20
4ME503	Materials and Manufacturing Processes.	20
4ME504	Quality, Reliability and Work Environment (WBL).	20
4ME502	Management of the Business Environment (WBL).	20
4ME505	Regulatory Systems (WBL).	20
4ME500	Applied Scientific Methods.	20
5ME500	Advanced Applied Analytical Methods.	20
5ME503	Corporate Responsibility and Professional Development (WBL).	20
5ME505	Engineering Design Modelling.	20
5ME510	Industrial Control Systems.	20
5ME513	Project Foundation Degree – Mechanical and Manufacturing (WBL).	20
5ME500	Advanced Applied Analytical Methods	20

Note: WBL = Work Based Learning.

5.2 Full Time Entry Requirements

Full time students can enrol directly onto the BEng (Hons) Mechanical Engineering degree, stage 1, 2 or 3 depending on their grades from school or college. At present (September 2014) they will need to achieve 112 points from the Universities and Colleges Admissions Service (UCAS) to enter at stage 1. The other entry requirements are shown in Tables 41 – 43.

Table 41 BEng (Hons) Mechanical Engineering - Entry Requirements Stage 1

Scottish Highers.
BTEC National Diploma.
Mathematics and at least one other A level in either Physics or Design Technology.
NVQ3 or Btech equivalent at Distinction level.
5 GCSEs or equivalent at grade C or above, including Maths and English.
Appropriate industrial or managerial experience.
Suitable work/life experience but do not satisfy the standard entry requirements will be considered on their individual merits, based on an interview and completed application.
Accreditation of Prior Learning (APEL) or Accreditation of Prior Certified Learning (APCL) may be possible.

Table 42 BEng (Hons) Mechanical Engineering - Entry Requirements Stage 2

A HNC or equivalent in a relevant subject area.
Successful completion of one year of a relevant degree programme and appropriate work-based experience.
Higher National Diploma in relevant subject area showing levels 4 and appropriate work-based experience.
International students with equivalent international qualifications to the above and with appropriate level in English Language for entry at level 5.

Table 43 BEng (Hons) Mechanical Engineering - Entry Requirements Stage 3

A Foundation degree in a relevant subject area with a minimum overall Distinction.
Successful completion of two years of a relevant degree programme and appropriate work-based experience.
Higher National Diploma in relevant subject area showing levels 4 and 5 and appropriate work-based experience.
International students with equivalent international qualifications to the above and with appropriate level in English Language for entry at level 6.

Additional non-standard entry to the programme may be considered. See Table 44.

Table 44 BEng (Hons) Mechanical Engineering - Non-Standard Entry

Accreditation of Prior Learning (APEL) or Accreditation of Prior Certified Learning (APCL) may be possible for stage 2 and 3.
Successful completion of the Technology Foundation Programme (TFP) may be able to progress onto the BEng (Hons) Mechanical Engineering provided that: • All registered modules within the TFP are passed. • The appropriate optional module for this programme has been chosen as recommended within the TFP handbook.

International student's will also be accepted on the course if they meet the required qualifications listed in Tables 41 – 43 and attain a minimum of one of the following listed in Table 45.

Table 45 BEng (Hons) Mechanical Engineering - International Entry Requirements

The International English Language Testing System (IELTS) 6.0.
Test of English as a Foreign Language (TOEFL) 550 (213 Online).
Cambridge Advanced Certificate pass.
London test of English: Level 4 for undergraduates, level 5 for postgraduates.
International GCE O-Level English language grade C.
International GCSE English/English as a second Language grade C.
Academic English Studies (AES) pass.

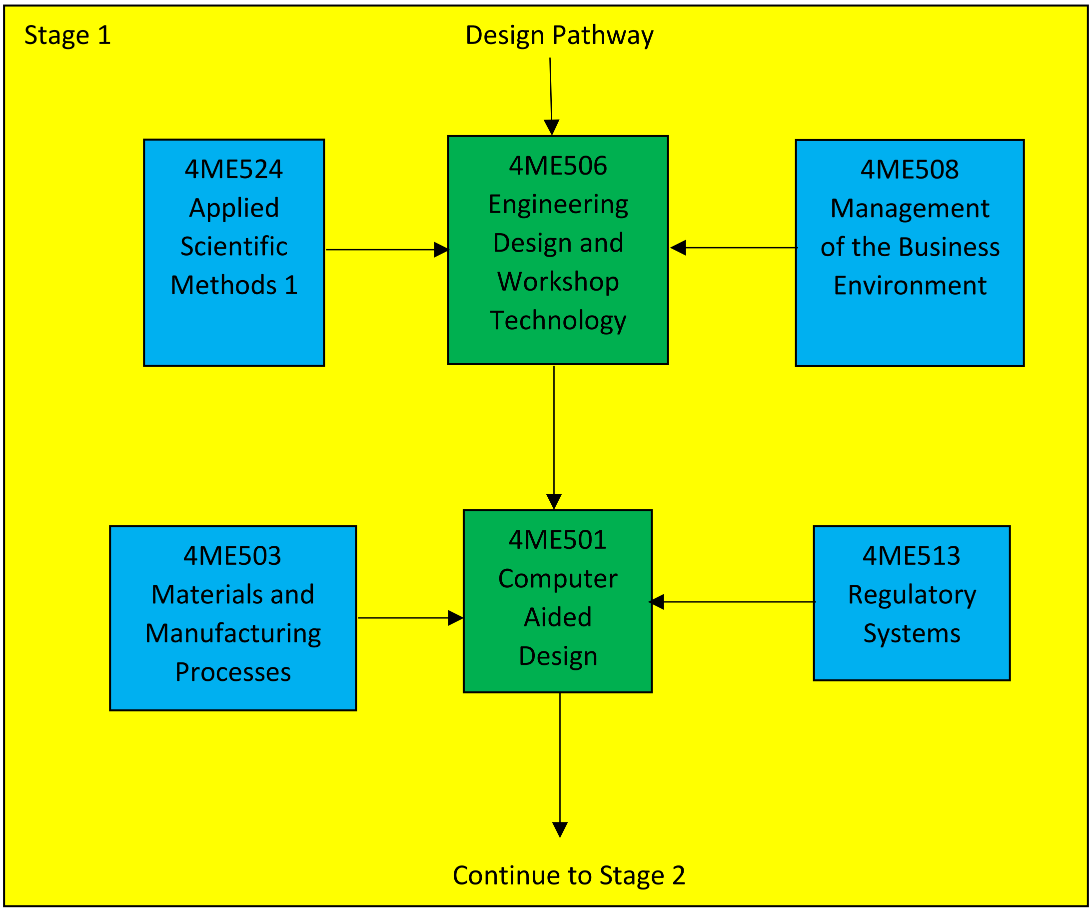
5.2.1 Module Content

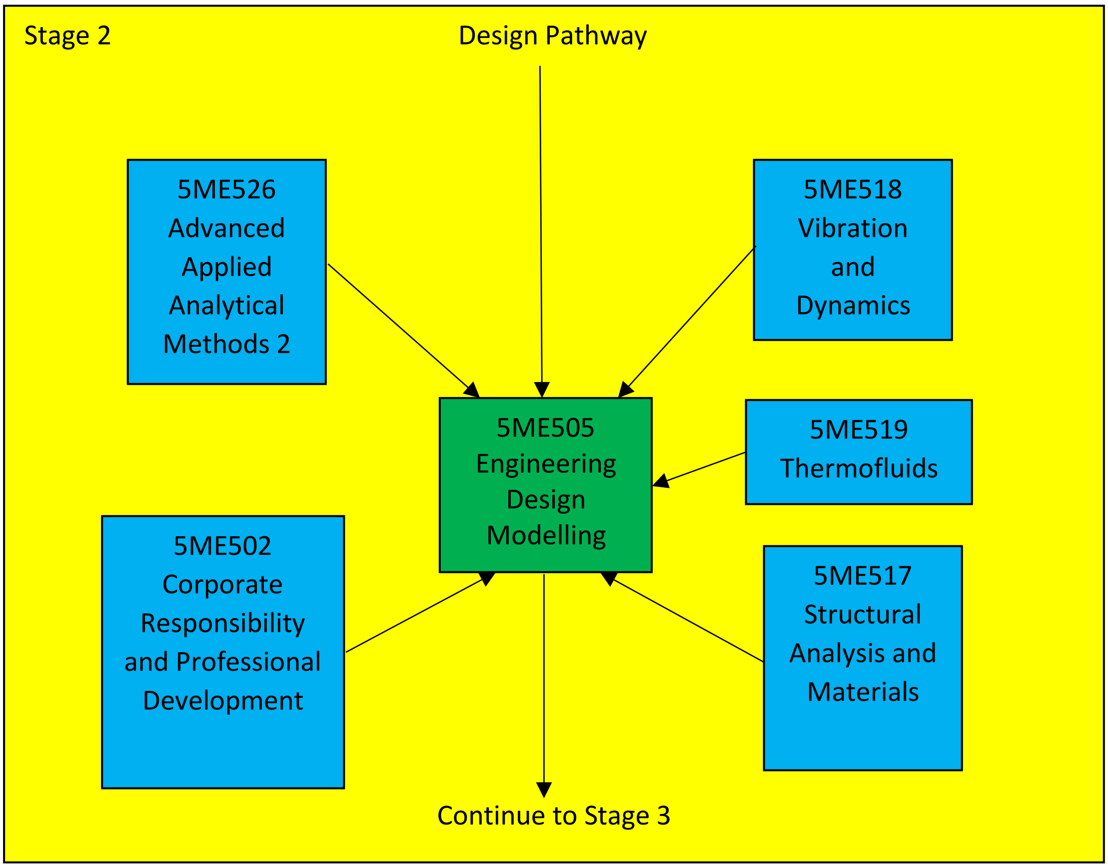
The full-time degree will take three years when starting at stage 1 and will require the student to complete 17 modules, each equal to 20 credits and 1 module equal to 40 credits. This will give a total credit value of 360 at the end of the third year and will make the student eligible for an Honours degree. The complete list of modules as of September 2014 are shown in Table 46.

Table 46 BEng (Hons) Mechanical Engineering - Modules

Module Code	Module Name	Credits
4ME501	Computer Aided Design.	20
4ME503	Materials and Manufacturing Processes.	20
4ME506	Engineering Design and Workshop Technology.	20
4ME508	Management of the Business Environment.	20
4ME513	Regulatory Systems.	20
4ME524	Applied Scientific Methods 1.	20
5ME502	Corporate Responsibility and Professional Development.	20
5ME505	Engineering Design Modelling.	20
5ME517	Structural Analysis and Materials.	20
5ME518	Vibration and Dynamics.	20
5ME519	Thermofluids.	20
5ME526	Advanced Applied Analytical Methods 2.	20
6ME500	Advanced Engineering Design Modelling.	20
6ME503	Advanced Mechanical Design and Materials.	20
6ME505	Computational Fluid Dynamics.	20
6ME511	Applied Thermodynamics.	20
6ME993	Independent Study and Professional Development (Mechanical).	40

The above programme is designed to build a student's knowledge progressively from level 4 through to level 6. Fig. 45 shows the path, starting at stage 1 a typical student may take toward becoming a graduate engineer. This thesis will concentrate on the green path which is made up of specific design modules. These modules form a path to prepare students for the final year design module at level 6. Other modules on the programme provide knowledge and understanding which feed into and support the green path.


Stage 1
Design Pathway
4ME524 Applied Scientific Methods 1
4ME506 Engineering Design and Workshop Technology
4ME508 Management of the Business Environment
4ME503 Materials and Manufacturing Processes
4ME501 Computer Aided Design
4ME513 Regulatory Systems
Continue to Stage 2


Stage 2
Design Pathway
5ME526 Advanced Applied Analytical Methods 2
5ME518 Vibration and Dynamics
5ME505 Engineering Design Modelling
5ME519 Thermofluids
5ME502 Corporate Responsibility and Professional Development
5ME517 Structural Analysis and Materials
Continue to Stage 3

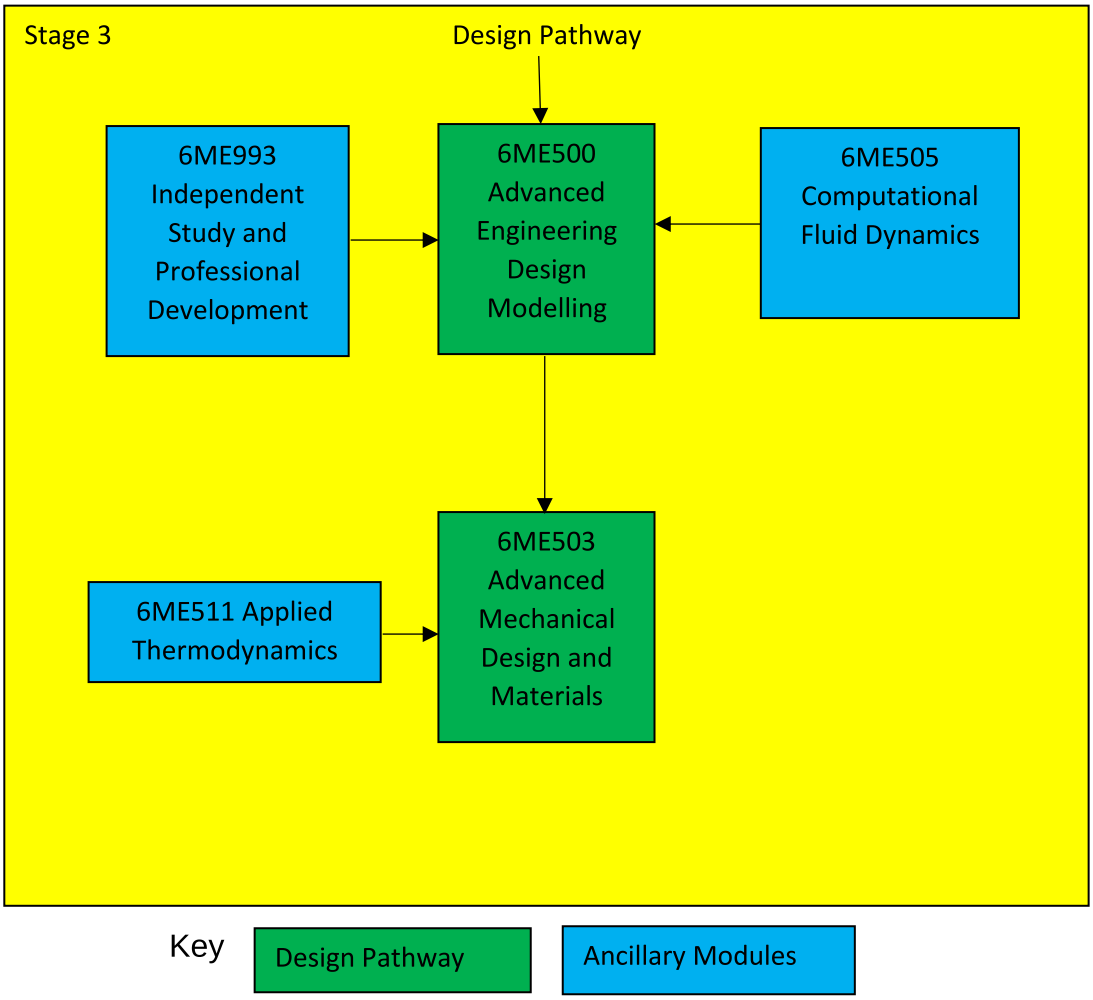


Figure 45 Design Pathway (Sole, 2023)

The above modules are in order of the stage they are taught on.

5.3 Module Application to Design

Stage 1

4ME501 Computer Aided Design. Introduction and use of industry standard CAD software. Students are taught the various tools available to produce 2D drawings using the latest version of Autocad. Tasks are increasingly more complex in the use of geometry to produce the required standard drawings. Layout, line types, views, sections, use of standard symbols, dimensioning, tolerancing, geometric tolerancing, text, scale, and layers. The design part of this module is more to do with the use of software rather than designing a component or system. An introduction of 3D Computer Aided Design is provided but the module is dominated by the 2D aspect.

4ME503 Materials and Manufacturing Processes. To design something that can be economically manufactured is part of the aim of this module. It is important that design engineers understand the machines and equipment in the workshop, their capabilities and limitations and then design components and systems within that understanding.

All components are made from materials. Materials are constantly being developed. This module introduces students to material specifications and selection. The materials descriptions in the module criteria are non-specific, dealing more in material families so that the specific materials can be updated regularly to incorporate new and emerging materials.

4ME506 Engineering Design and Workshop Technology. To introduce and teach students the equipment in a typical engineering workshop, the basic design of a simple component is produced, and after approval of the lecturer is then manufactured. The design and manufacture are carried out by the students. The design content of this unit is there to provide a component that will be used throughout the rest of the semester in teaching students the correct and safe use of the workshop equipment. The workshop is the dominant part of this module, the design element is a means to an end.

The design element that is carried out introduces students to a systematic method of design. Customer requirements are provided and researched, a design specification is produced, relevant design information is sourced, such as legislation, and new technologies that may be used, similar products or processes are identified. Design solutions are encouraged and then evaluated to select the most appropriate and best one to meet the specification. A compliance check that the specification has been met and finally a written report on all the above.

4ME508 Management of the Business Environment. This module helps students when they leave university to begin their career in industry. It provides understanding of the business world, financial planning and control, project planning, research, technical report writing, professional presentation and personal development. Some of the above will have an indirect effect on the design engineer. Once a design has been produced, the design engineer will often have to justify decisions they made in a report or presentation, they may need to contribute toward producing a schedule or calculating the costs.

4ME513 Regulatory Systems. This module makes students aware of the principle regulatory systems in the UK and EU. It covers safe working procedures, current health and safety legislation, risk assessment and its application and risk management guidelines and procedures. It is important for design engineers to appreciate legislation and how it can affect manufacturing and sales as well as importance of CPD and the role and use of professional bodies.

4ME524 Applied Scientific Methods 1. This module provides a student with the building blocks needed to analyse mechanical engineering problems and determine the effectiveness of their design solutions. It is a maths orientated module introducing students to trigonometric methods, vectors, and calculus, when applied to mechanical engineering problems. A certain amount of engineering science is considered; stress analysis; dynamics; fluids such as flow in pipes and Bernoulli's' equation; and electronic circuit theorems.

This module is designed to provide a basic knowledge of the above topics and should make possible further in-depth study for the future.

Stage 2

5ME502 Corporate Responsibility and Professional Development.

Environmental issues should be of concern to all. This module provides awareness for students of their corporate responsibilities and environmental issues. It helps them consider their role in the engineering sector and how this will develop over time. Design engineers must consider the environmental impact their design may have and the necessity to work within appropriate legislation. The whole life cycle of their design is to be considered.

5ME505 Engineering Design Modelling.

This builds on the introduction to 3D modelling in module 4ME501 Computer Aided Design. After students become familiar with the software interface, command interface, 3 button mouse, toolbars, graphic area, they are taught how to design components in 3D with parametric, design tables, fully defined sketches, dimensioning and editing of parts. Assembly of components exploded assemblies, movie motion, producing 2D drawings from 3D models to comply with existing standards are covered, finishing off with introduction to Finite Element Analysis (FEA).

This module provides all the building blocks required to produce 3D models using industry standard software, SolidWorks. It does not build on module 4ME524 Applied Scientific Methods 1 or how to apply those methods.

5ME517 Structural Analysis and Materials.

This module builds on module 4ME524 Applied Scientific Methods 1 by developing more complex real-life stress loading situations. Engineers need an understanding of the effects of different loading types. Beam bending, complex stresses, and thin vessels are developed.

After understanding the possible stress loading situations an engineer needs to be able to optimise the materials selection using Performance Materials Design Indices. Use of computer-based software such as Cambridge Engineering Selector to apply the material indices and other selection criteria.

The module is vital in building the knowledge required for a design engineer to produce designs that will be fit for purpose and safe.

5ME518 Vibration and Dynamics. Designs usually begin life as static models. Hand calculations, simulations, and prototypes are used to verify they meet the design specification. Many designs are not static but are dynamic, with movement. Kinematics of rigid bodies and vibration of machines including undamped and damped are considered. The use of industry standard software is used to simulate these properties.

Structures and components will fail when subjected to vibration and out of balance forces. A design engineer must understand these underlying principles so that they can design systems and components which will be robust enough to minimise their effect.

5ME519 Thermofluids.

Module 4ME524 Applied Scientific Methods 1 introduced the student to basic terms such as pressure, manometers, bourdon gauge, flow of fluid in pipes and

Bernoulli's' equation. The aim of this module is to extend the student knowledge of the principles of fluid mechanics. Static fluid systems: viscosity, flow of real fluids, hydraulic machines are considered and use of software to model their behaviour. An introduction to Thermodynamics is also considered.

Thermofluids, covers a vast area of mechanical engineering and is important for a design engineer to have a good understanding of the topic area as a component or system working within the laws of thermofluids could suffer a catastrophic failure if these laws are not applied correctly by the design engineer.

5ME526 Advanced Applied Analytical Methods 2.

This module builds on the previous module 4ME524 Applied Scientific Methods 1. Expressing engineering data as equations so that future predictions can be made; rates of change problems using differential calculus; derivation of equations related to fluid and structural mechanics; use and application of matrices; cartesian and polar co-ordinates; statistics and probability.

This module should allow a student to assess the suitability of a design using mathematical modelling techniques which will be applied later when using 3D modelling software.

Stage 3

6ME500 Advanced Engineering Design Modelling.

Nearly all design carried out in industry uses 3D parametric solid modelling. This module builds on module 5ME505 Engineering Design Modelling. Students are taught to use advanced modelling techniques to produce parametric parts and complete assemblies. Drawings to existing engineering standards are produced which a component could be manufactured to.

As a stage 3 module the student is expected to bring together the skills they have developed over the past two years. Hand calculations based on appropriate engineering science; 3D design modelling, 2D technical drawings, material selection; advanced use of software features.

This module is critical to the development of a design engineer as a student's design must show that they can design a component or assembly of components that fully meet the design specification from a customer (the university). It allows the student to demonstrate the knowledge and understanding they have acquired. See the module specification in Appendix 4.

6ME503 Advanced Mechanical Design and Materials.

This module builds on module 5ME517 Structural Analysis and Materials. Advanced material properties such as creep and fatigue; strengthening mechanisms in materials and advanced materials such as composites and ceramics; advanced material selection especially based around fracture resistance; FEA on pressure vessels, gear analysis, unsymmetrical bending of beams.

This module is another important stepping-stone that a future design engineer must become familiar with as it deals with concepts and principles that are likely to occur in their design career.

6ME505 Computational Fluid Dynamics.

This module builds on module 4ME524 Applied Scientific Methods 1 and 5ME519 Thermofluids. Introduction to CFD, fluid-flow equations and approximations and simplified equations; review of Euler's and Bernoulli's equations; Scalar-transport equation, momentum equation, time-dependent methods; Eddy viscosity, turbulent wall flows, modelling turbulence and introduction to advanced turbulence modelling.

This is a specialist module that design engineers will require. When used, the results can be critical to the success of a design.

6ME511 Applied Thermodynamics.

This module builds on module 5ME519 Thermofluids. An understanding of thermodynamics cycles is a pre-requisite to designing a thermodynamic system. This module covers thermal power plants, refrigeration cycles, reciprocating air compressors, gas turbines, and internal combustion engines.

To be able to design one of these systems, specialised knowledge is required. This module provides a basic knowledge for design engineers and will introduce them to this field.

6ME993 Independent Study and Professional Development.

This challenges students to identify and undertake an original and detailed study and present a major piece of relevant work. A student will be required to build on all the modules previously studied as well as work-based experience to complete this module.

Often the subject agreed with between a student and their supervisor will be a design-based subject; either producing a new design or re-designing an existing one.

5.4 Assessment

The modules are assessed using a combination of assignments and examinations. Table 47 details each module assessment as of September 2014.

Table 47 BEng (Hons) Mechanical Engineering - Assessment

Module	Coursework 1	Coursework 2	Examination
4ME501	100%	N/A	N/A
4ME503	60%	40%	N/A
4ME506	40%	60%	N/A
4ME508	100%	N/A	N/A
4ME513	50%	50%	N/A
4ME524	50%	50%	N/A
5ME502	50%	50%	N/A
5ME505	100%	N/A	N/A
5ME517	60%	N/A	40%
5ME518	60%	N/A	40%
5ME519	60%	N/A	40%
5ME526	60%	N/A	40%
6ME500	100%	N/A	N/A
6ME503	60%	N/A	40%
6ME505	60%	40%	N/A
6ME511	60%	N/A	40%
6ME993	30%	70%	N/A
Totals	**17**	**7**	**6**

5.5 Design Pathway

The module content is designed to build a student's knowledge and understanding. Year 1 builds on their general education from school or college, year 2 builds on year 1, year 3 builds on year 2.

This thesis does not have the scope in terms of time and resources to review the content of each module. In terms of design, the stage 3 module 6ME500 Advanced Engineering Design is the culmination of the student's study. This thesis will concentrate on the methods used to teach this module to align it more closely with design methods used in industry.

5.6 6ME500 Advanced Engineering Design Module – Teaching and Assessment

The assignment which has 100% summative assessment is given to the students in week 1 of the 12 weeks semester.

The assignment consists of multiple parts. As an example, students could be tasked with designing an Off-Road Buggy. The main parts of the assignment being, research on design of Off-Road Buggies; hand calculations to determine dimensions and materials of components; create an assembly of the buggy consisting of chassis, engine, suspension, shock absorber, tyres, seat, and roll bar as examples; write a formal report detailing the design methodology, hand calculations.

Each week the students are taken through sample calculations, solid modelling techniques, and explanations and examples of different aspects of the assignment.

A lesson will run once a week for four hours. The first hour is used for teaching as mentioned above, the rest is for students to carry out individual work.

Formative assessment is carried out on set tasks which are marked, and feedback provided. The set task may be part of the assignment task.

The student hand in their models and assignment on or before the hand-in date and are marked within three weeks of hand-in. Their marks and feedback are released. Any failures are allowed one resit of a new assignment which, if passed will be capped at 40%. The full module specification is in Appendix 4.

5.7 Chapter Summary

The chapter provides an overview of the structure for a BEng (Hons) Mechanical Engineering degree as taught at the University of Derby (UK). Within this structure, mechanical design is an important element and is the area that this thesis will concentrate on. The structure undergoes constant updating and changes to keep it relevant with industry needs. This thesis will be part of this process.

CHAPTER 6

INDUSTRY DESIGN PROCESS

(Objective 2 section 1.2.2)

6.0 Introduction

Having looked in chapter 5 at the process of design as taught at the University of Derby (UK), this chapter will look at the design process in industry. Design offices and design methods will be different depending on the size of a company. After defining a company size based on the number of its employees, a typical design office will be described. A review will be carried out of world leading companies to determine the design methods they use. These methods from industry will be the basis of redesigning the methods teaching design at university will be taught.

6.1 Design Office Structure

The design office layout depends upon the size of the company. A large company which produces many different products will require a well-organised structure employing engineers, draughtsmen and draughtswomen, technical clerks etc. In contrast, a small company that manufactures only a few products would require a small design office. A designer may be responsible for the design detailing, specification, feasibility studies, costing, organising the purchase of finished items, clerical work, and customer liaison.

The work of a designer in a small company requires a wide range of knowledge such as materials, processes, and organisation than a designer in a large company, where more designers may be available, thus spreading the required range of knowledge wider. As the destination of future mechanical design engineering students is not known it will be necessary to provide training that will provide the widest range of knowledge. The definition used for the size of a company (Table 48) is based on the model from Aggarwal *et al,* (2010).

Table 48 Company Size

Company Size	Number of Employees
Small	≤ 100
Small – Medium	100 – 999
Medium	1000 – 9,999
Large	≥ 10,000

Typical products for a small and large company are shown in Table 49.

Table 49 Types of Products - Small/Large Companies (Hawkes & Abinett, 1984)

Large Company	**Small Company**
Tractors.	Circlips.
Fuel Pumps (car / truck).	Hose Clips.
Aircraft.	Door Locks.
Computers.	Electric Kettles.
Engines.	Small Domestic Products.
Bearings.	Curtain Rails.

A typical organisation chart for the design office of a large company is shown in Fig. 46. A drawing may take a draughtsperson many weeks to produce, which makes the drawings an expensive item. The preservation of the drawings is of paramount importance. The originals do not leave the design office, only copies are released. If physical copies, they are released by the reprographic section, if electronic they are released by the chief draughtsperson (Engineering Drawing, 2018).

Content removed due to copyright reasons.

Figure 46 Design Office Organisation for a Large Company (Engineering Drawing, 2023)

In many large companies the roll of designer and draughtsperson has merged. Many designers prefer to produce their own drawings, especially since they can be produced using modern Computer Aided Systems.

Whether drawings are physical or electronic, their control is extremely important. Imagine the cost in labour, materials, and company reputation if the wrong issued drawings are released to the workshop. Imagine how helpful, financially, and timewise to a company’s competitor if they could acquire a set of drawings and begin manufacturing a component after another company has completed all the hard work of design.

Technical clerks provide designers with information they have researched on such things as material data, existing products, standards, bought in parts, and latest technologies.

With the growth in electronic Computer Aided Drawing, drawings can be produced and updated much quicker and more accurately than a designer using a draughtboard. They can be stored, retrieved, sent to other designers in any country that has access to the internet or to a workshop for manufacture. The speed and ease of producing drawings has increased, but at the same time the need to control them has also increased.

6.2 Design Methods Used by Industry

The following section will look at real life design problems and the methods industry use to solve them. An analysis of methods and the reasons why they were used will be conducted at the end of the section.

6.2.1 Whiteboard Cleaner (Sinichko, 2015)

Company Name	**Viget**
Number of Designers	**19**
Company Size	**Small**

Design problem: To design a robot that will clean off the lines made by drywipe marker pens on a whiteboard. The process will be automatic once the robot has been mounted onto the whiteboard.

The design process is broken down into five steps, (1) identify the problem, (2) research the problem, (3) brainstorm and choose a promising solution, (4) prototype the solution, and (5) evaluate and improve the prototype.

(1) Identify the problem. The problem needs to be clearly defined and understood. Where will it operate? Who is it for? What is the budget? What timeline is there? This stage was not specific but provided an overview of the problem; an automatic system, simple operation, minimum cost, and the result was something that would resemble a clean whiteboard.

(2) Research the problem. This is relevant self-education. Has this already been done? Can some aspects of existing designs be used? Are there similar technologies in other markets that may be used? There was found many autonomous cleaning systems such as robots that clean solar arrays and others that climb buildings to clean them. There are a few autonomous whiteboard cleaners, maybe the cost is prohibitive.

(3) Brainstorm and choose a promising solution. Use a team to gather as many ideas as possible. Throw caution to the wind. Temper the ideas put forward with the design constraints. Compare the solutions that are left and decide which one will be used to produce a prototype. The idea selected was to use fishing line to suspend the robot and use stepper motors to move the robot around (Fig. 47)

Content removed due to copyright reasons.

Figure 47 Early Sketch (Sinichko, 2015)

(4) Prototype the solution. A prototype is used to quickly verify a design and identify its strengths and weaknesses. Not everything needs to be tested at first. The design can be incremental, gradual, small changes so that it evolves into a final design. The first prototype (Fig. 48) was made from off the shelf parts and cardboard. The next prototype (Fig. 49) was made from off the shelf parts and 3D printed parts.

Content removed due to copyright reasons.

Figure 48 First Prototype (Sinichko, 2015)

Content removed due to copyright reasons.

Figure 49 Second Protype (Sinichko, 2015)

(5) Evaluate and improve the prototype. Once the prototype is tested get the team together to think critically. What works well, what didn't work so well? Did the design solve the original problem? Additional points of contact were required to stop the robot wobbling. In one test the robot dropped and broke. This identified that strengthening was required (Fig. 50).

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Figure 50 Strengthening (Sinichki, 2015)

Summary

- Start with an overview of the problem.
- Research detailed solutions.
- Group activity to temper the designs to meet the constraints.
- Determine or modify constraints.
- Make basic prototype.
- Improve the prototype

6.2.2 Lego (Design Council, 2018)

Company Name	**Lego**
Number of Designers	**135**
Company Size	**Medium**

120 designers at Lego have 15 different nationalities based in Billund, Denmark. Another 15 are based in Slough, UK, and other satellite offices in several key regions.

For individual design projects, Lego operated core teams containing a marketer, project leader, and a design manager.

Designers must be creative leading to the recruitment of staff from a tremendously wide range of educational and career backgrounds. Recently there has been an uptake of 'professional' designers, those who have received more conventional academic training in design disciplines.

The company was founded on a system of 'eight stud' bricks (Fig. 51) which can be combined in more than 900 million different ways (Fraser *et al*, 2014). Now, there are thousands of different brick designs leading to an infinite range of creative play possibilities. Some of the new bricks, still based around the original 'eight stud' system are people characters and special parts to allow construction of moving vehicles and working train sets.

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Figure 51 Lego Bricks (Design Council, 2018)

Due to the creative freedom given to the design teams over 14,000 different components have been designed, many of them unsuccessful. To address this problem Lego have started an initiative called Design for Business which aims to make sure all design activities are supported with a real business case and the proposed solutions can be tested against financial requirements. At the same time Lego wants to reduce the length of the design cycle down from an average of two years to less than twelve months.

Throughout the design process several prototypes (P Phase) and manufacturing (M Phase) phases are used. At each phase the business and marketing case must be proved sound before allowing the design to proceed. All the phases are controlled using standardised documentation.

The P phase has three stages:

1. Exploring the problem. This is a research phase where the background to the problem is examined. Field studies and interviews with consumers and expert knowledge holders are carried out.

2. Development stage. Basic ideas are sketched out. Mood and colour guidelines to visual or solid mock-ups of proposed designs, packaging or themes are explored. Critical evaluation of all aspects of the design.

3. Formal presentation. The designs are presented formally to the entire project team and then undergo a rigorous process of validation during which they are shown to potential users, their parents, retailers, and sector experts and assessed against the objectives set. Feedback from the validation process may be used to refine the design.

After successful completion of the P phase, the M phase begins which has five stages:

1. The product definition and business plan used to bring the product to market are refined, ensuring that the business brief is fulfilled.

2. The business case and product design are finalised.

3. After the product design is finalised attention turns to the packaging, marketing, and communication aspects of the project.

4. After all physical aspects of the product, packaging and communication materials are finalised the manufacturing specialists can begin the process of building the supply chain necessary to deliver the product to market.

5. The supply chain is completed, manufacturing is started, and the product is launched.

Lego has developed its own, bespoke 3D CAD tool that, combined with the physical modelling, helps designers build virtual concepts and final models of new designs.

Summary

- Core teamwork.
- Uptake of designers trained through traditional academic training.
- Designs must meet business and financial requirements.
- Formalised design process.
- Design time reduced from two to one year.
- Designs go through prototype and manufacturing.

6.2.3 British Telecom

Company Name	British Telecom (BT)
Number of Designers	Varies
Company Size	Large

British Telecom (BT) uses an extensive roster of outside design agencies. They complete an estimated 99% of the total design carried out by the company. High importance is given to the brand. Anyone coming to British Telecom for the first time takes part in a half day brand workshop. In addition, there is an online resource, the BT Brand Site. All external design agencies are brought together on a quarterly basis to bring them up to date with brand developments.

British Telecom is returning to the development of its own products as they feel they can differentiate its brand and services better than outside design agencies.

British Telecom has no formalised design process. The process is two-way between British Telecom and the outside agencies. Sometimes a designer can take the business in a direction it did not expect. Sometimes an outside agency may go in the wrong direction and must be brought back into British Telecom’s way of thinking.

An example of design from British Telecom is the Home Hub (Fig. 52). Rather than hide this away as most broadband connections, this design was to be displayed on the shelf, becoming a part of the home as the domestic telephone handset was in times past. The brand was to be displayed for all to see.

Content removed due to copyright reasons.

Figure 52 Home Hub (Design Council, 2018)

Due to dramatic change in the broadband market, the British Telecom Hub had only a very short lead time.

A competitor was offering a free-of-charge broadband line which threatened the British Telecom model which was to charge subscribers a monthly fee for their lines. An agency was engaged to make the router offered by British Telecom more appealing and useful than the ‘piece of grey plastic’ that British Telecom usually used for the router.

The electrical side of the design was already finalised, and British Telecom was already in discussion with manufacturers, so the design had to be completed within three weeks.

The designers turned the device on its side and built a cradle for a telephone handset. By including clever cable management functionality, they delivered a product that was appealing and easy to use. The packaging was redesigned ensuring that it was elegantly presented and logical to set up (Design Council, 2018).

Summary

- Outsource designs to design agencies.
- All designs must fit the brand.
- No formalised design processes.
- Designs must meet existing constraints.
- Innovation of existing designs to meet market need.

6.2.4 Virgin Atlantic Airways

Company Name	**Virgin Atlantic Airways**
Number of Designers	**15**
Company Size	**Medium**

Use a mix of in-house designers and agencies to deliver design projects. Each design project must have a business case to back it up. Physical mock-ups are used to help external stakeholders understand the design concept. Before manufacture begins, a design freeze is put on any external design input.

Virgin Atlantic is proud in having a low staff turnover within its design department. This is achieved despite the department's small size and flat management structure limiting opportunities for staff progression. Designers are expected to have a broad range of specialisms.

Sharing of ideas is encouraged with co-location of designers. Formal meetings every six weeks allow all designers to share their current work. This provides inspirational cross over and stimulation.

Individual designers are developed using a formalised system. Designers agree annual objectives with their managers and a link between pay and achievement of those objectives.

The design process has no formal structure but does regularly follow three consecutive stages, R&D, Design Development, and Implementation.

Research and Development (R&D)

The R&D phase starts with a product Challenge. This could be recognition of a need to carry out a particular activity, either to boost or prevent decline in performance or results of brainstorming.

The Opportunity Identifier stage allows the Product and Service senior directors group to review the design and release funds to conduct scoping work. Budgets and timelines begin to be set and risks assessed.

The product brief build on the Opportunity Identifier concept, incorporating commercial awareness and formulating Key Performance Indicators (KPIs).

A business case for the new design is produced by collaboration between the design team and the business unit. The business case will often include the presentation of fully developed mock-up designs and Detailed Design Specification.

Design Development

During the design development phase, there are a series of checks in place to ensure the final product is as close as physically possible to the Detailed Design Stage. This involves the close working of designers, engineers, and manufacturers. To achieve the close working required, several key meetings or milestones are used:

Initial Technical Coordination Meeting. The Detailed Design Stage is presented to manufacturers to make sure the design is possible to manufacture.

Preliminary Design Review. The manufacturers present their understanding and interpretation of the design.

Critical Design Review. Designers and manufacturers agree on a common interpretation of the design. It is considered a “cardinal sin” to make changes to the design after this point.

First Article Inspection. The first item is taken off the production line to ensure it is fully functional.

Implementation

In this phase, production, which can run in parallel with the First Article Inspection is followed by implementation, snagging in the aircraft environment and then finally evaluation of the KPIs. To prevent aircraft downtime, products are usually ready and in storage up to six months before the scheduled roll-out begins.

The following is a case study for the Upper-Class Suite as shown in Fig. 53. A need arose due to a competitor (British Airways) introducing the first fully flat aircraft seat-bed.

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Figure 53 Upper Class Suite Design Concept (Design Council, 2018)

The original requirement was to produce a flatbed into its upper-class cabins. The design team began exploring a wide range of different configurations. They settled on the concept of a seat and a bed that were in the same space but separate entities.

As the concept developed, an engineering team began to look at their function, safety, and airworthiness regulations. An external design consultancy was used to produce 3D models to assist in the evaluation. The design was presented to the board who gave the project the green light to move forward into the Design Development Stage.

Virgin Atlantic now use more specialist outside design support, including structural engineers to assist with the mechanical design and ensure compliance with aircraft safety specifications. Associated service elements were included in the design looking at the whole interior and lighting. Within 12 months a full-scale dynamic prototype was produced for evaluation purposes.

After the seat was approved by Virgin Atlantic’s executive board it underwent extensive testing and evaluation. This testing and evaluation continued through the manufacturing stages until a finished product was produced (Design Council, 2018)

Summary

- External design consultants used.
- Sharing of ideas is encouraged.
- 3D Prototypes.
- Design concept first followed by manufacturing details.
- Extensive testing and evaluation.

6.2.5 Whirlpool

Company Name	**Whirlpool**
Number of Designers	**150+**
Company Size	**92,000**

Design function is represented in the US, Mexico, Europe, India, and China. Most designers operate in brand studios, with 14 major brands and 30 sub-brands supported in this way.

The design team at Whirlpool has expanded in recent years. It now includes interaction design and enhanced usability function that includes staff with expertise in ethnography (the scientific description of peoples and cultures with their customs, habits, and mutual differences) and anthropology (the study of human biological and physiological characteristics and their evolution). These additions to the team were to make the company core products suit the widest possible range of brands and market. Whirlpool has a drive to standardise the capabilities available in different design offices. In all its major design facilities, industrial designers, usability specialists, human factors engineer's and interaction designers can be found.

Where appropriate, external design consultants are used. Five external agencies are used around the world choosing them when Whirlpool identifies a requirement to bring in 'fresh approaches in terms of process and methodology'.

The design teams can take a totally new product line from early concept to launch in only 12 months.

Whirlpool operates a phase gate process to ensure that each stage of the design is signed off by all the relevant stakeholders.

A thorough evaluation process once a design has entered production is carried out. The evaluation starts at the factory floor with end-of-the-line craftsmanship audits. These are used to ensure that production quality is running at the appropriate level and to feedback manufacturability insights to the design teams.

After products have been with users for six to eight months, the design group conducts a post-launch usability audit with selected customers. Data such as the number of service calls is fed to the design team to prove its cost effectiveness in future product launches (Design Council, 2018).

Summary

- Design teams in many countries.
- Drive to standardise the capabilities available in different design offices.
- Use of external design consultants.
- First concept to final design – 12 months.
- Product evaluation at end of production line.
- Audit carried out after 6-8 months, results fed back to design team.

6.3 Common Industry Design Practice

The above industries are diverse in the products they produce, from small bricks for children to internet home hubs and luxury seats in aircraft. The companies range in size from small, medium, and large. Based on research (Design Council, 2018), common practices can be identified (Table 50). Other practices are probably included in the design process but only those specifically mentioned in the research are included here.

Table 50 Common Design Processes

	Viget	Lego	BT	Virgin Atlantic	Whirlpool
Systemic approach	x	x		x	x
Time limited	x	x		x	x
Group activity	x	x		x	x
Use of specialists		x	x	x	x
Determine constraints	x		x		
Prototype (literal or virtual)	x	x	x	x	
Testing and evaluation	x	x	x	x	x
Consideration to manufacture		x		x	

6.4 Chapter Summary

The common industry design practices highlighted above (Table 50), combined with the findings of the literature review (chapter 2) will be used to begin redesigning the practical aspects of teaching design to final year students studying for a BEng (Hons) Mechanical Engineering at the University of Derby (UK).

These changes will be applied to real classes. To minimise any disruption to the classes and to assist in analysing the results, the changes will be made incrementally and be kept to a minimum. chapters 10 - 13 will introduce the incremental changes along with an analysis of the changes based on the module results, student surveys and lecturer observation.

CHAPTER 7

TEACHING DESIGN IN HEI’S

(Objective 7 section 1.2.2)

7.0 Introduction

The aim of this thesis was to align the mechanical engineering design process used in academia as close as possible to that used by industry. The changes would be applied to students studying on their final year of a BEng (Hons) Mechanical Engineering degree at the University of Derby (UK).

This chapter covers research carried out in HEI's into the methods and logistics of teaching mechanical engineering design to students on Higher Education Programme. The reasons for this research are:

1. Determine if there are any major differences in the methods and logistics of teaching mechanical engineering design between HEI's and the University of Derby (UK). It is important that any recommendations are applicable to other institutions.

2. Are the issues identified in teaching mechanical engineering design evident in other HEI's? How have these issues been dealt with?

3. To investigate the pedagogic approaches in delivering mechanical engineering design to a diverse student body. This will provide assurance that the research outcomes are not specific to a single HEI.

4. Review methods used to teach mechanical engineering design and apply the most frequent methods that match or are most like industry methods.

5. Receive critical commentary from HEI's on the proposed changes to teaching design developed in this thesis.

7.1 Research Procedure

A full research methodology based on Saunders Research Onion (Saunders *et al,* 2019) can be found in chapter 3. This section will explain the procedure used to carry out the interviews with HEI's academics, how the interviewees approve their answers by requesting their consent, how any follow up information was attained post interview, and the method used to analysis the interviews.

1. Research ethical approval (ETH2223-0194) was requested and granted on 11th October 2022.

2. Invitation to Participate (Appendix 2) were sent out to HEI academics teaching mechanical engineering design via the authors professional networks.

3. HEI Academics who agreed to participate were sent a Participant Information Form and Sample Interview Questions and Consent Form (Appendix 2).

4. The interviews were conducted either face-to-face or via Teams. All interviews were recorded, and a transcript produced.

5. After each interview, the HEI academics comments were added to the Interview and Consent Form and sent to the HEI academic for their approval and consent.

6. A debriefing Form (Appendix 2) was sent to each HEI academic.

7. Any subsequent information required from the HEI academic was gathered via email.

8. Analysis of the interviews of HEI specialist who teach mechanical engineering design. A Thematic analysis of the qualitative data collected by interviews or transcripts will be applied. This is a method of analysing and interpreting topics, ideas, and patterns of meaning that come up repeatedly across qualitative data (Braun & Clarke, 2022). The Thematic Analysis steps are:

   (i) Familiarisation – Began with note taking during the interviews. The notes, recordings and transcript were reviewed and written in Table 56, Section 7.3.

(ii) Coding – The answers are tagged with a code to identify those which are relevant to the reasons for this research (Section 7.0).

(iii) Theme - As data is coded, themes or patterns of meaning are looked for. The themes are match with the questions shown in Table 56, Section 7.3.

(iv) Theme Development – As themes are identified, two or more themes may show similarities. These may be combined to develop a new theme to replace the old one.

(v) Theme Refining – Eventually, the final themes begin to emerge, which starts the final stage:

(vi) Writing up – Themes can shift until the final report is completed.

7.2 Interviews

The interviews, after approval and consent from the HEI academics, are reproduced in this section. For comparison, the author has included The University of Derby's (UK) replies to the questions as if the lead academic had also been interviewed. A small introduction to each HEI has been included along with details of the interviewee (Table 51 - 54).

7.2.1 The University of Derby (UK) (HEI 1)

The University of Derby (UK), formally known as Derby Higher Education College is a public university in the city of Derby, UK. It became a university with the passing of the Further and Higher Education Act in 1992. Recognised for its teaching quality, it has a strong focus on applied learning. The 3 years BEng (Hons) Mechanical Engineering programme has a Foundation and Master's Year. Its student population ranges from 15,000 to 25,000, 67% full-time, 33% part-time. 90% of its students are from the UK. 10% International. 39% are male students, 61% female (The Complete University Guide, 2021).

7.2.2 The University of Wales Trinity Saint David (HEI 2)

The University of Wales Trinity Saint David (UWTSD) offers a choice of more than 300 employment focused courses across several campuses. 83% of students are full-time, 17% part-time. 43% of students are male, 57% female. Their programmes in mechanical engineering and automotive engineering range from Foundation Year, through BEng (Hons), up to master's level (The Complete University Guide, 2021)

Table 51 Interviewee Details (HEI 2)

Interviewee Details (HEI 2)	
Interviewee Name	Andrew Noble BEng (Hons) MSc
HEI Affiliation	University of Wales Trinity Saint David (UWTSD)
Job Title	Lecturer in Automotive Engineering
Specialism	Computer Aided Design. Structural analysis. CFD. Internal combustion engine component design.

7.2.3 Nottingham Trent University (HEI 3)

Nottingham Trent University (NTU) has over 33,000 students with 200+ undergraduate courses from accounting to zoology. There is a focus on student's future and careers, with every NTU course including employability support and work-related experience. 88% are full-time, 12% part-time.

Table 52 Interviewee Details (HEI 3)

Interviewee Details (HEI 3)	
Interviewee Name	Dean Burton BEng (Hons)
HEI Affiliation	Nottingham Trent University
Job Title	Lecturer in Mechanical Engineering
Specialism	Computer Aided Design. Automation Technology.

7.2.4 The University of Sheffield (HEI 4 & 5)

The university of Sheffield is a leading Russell Group university with over 30,000 students from 140 countries. It is committed to delivering life-enhancing research, innovation, and education that shapes the lives of its graduates and the world they live in. 64% of students are from the UK, 32% international.

Table 53 Interviewee Details (HEI 4 First & Second Year)

Interviewee Details (HEI 4 First & Second Year)	
Interviewee Name	Dr David Polson BE (Mechanical), BSc (Physics), CEng, PhD
HEI Affiliation	University of Sheffield
Job Title	Senior University Teacher in Mechanical Design
Specialism	• Responsible for research and implementation of a new process for the optimisation of building components and developing methods for calibrating building energy models. • He holds a doctorate in engineering and is developing interests around open-source hardware design and optimisation. • Communication of design through drawing, written prose and presentations, to the ability to work with uncertainty. • Believes firmly in life-long learning and has practised this in his own career and seeks to instil this in his students.

Table 54 Interviewee Details (HEI 4 Third Year)

Interviewee Details (HEI 5 Third Year)	
Interviewee Name	Dr Peter Mylon MEng PhD
HEI Affiliation	The University of Sheffield
Job Title	Senior University Teacher – Multidisciplinary Engineering Education
Specialism	Making and makerspace. Student-led learning. Mechanical design and prototype. Computer aided design (CAD).

7.3 Interview Notes

Table 55 is a summary of each interview, based on notes taken during the interview and interview recordings. These notes are a summary of the main points discussed during the interview.

Table 55 Interview Notes

Interview Questions	HEI 1	HEI 2	HEI 3	HEI 4 (First & Second Year)	HEI 4 (Third Year)
Describe the mechanical engineering design module logistics.	Average student numbers are L4 40, L5 45, L6 55. There is a strong international student body approximately 10-15% for each level. Female students are low at around 5% even though it is over 60% for the university. Part-time students around 8%	Classes are split up into clusters. Automotive and mechanical engineering are two examples. The automotive cluster is then split into automotive, motorsport, and motorcycle. Full time automotive student numbers: L4 55-60, L5 45-50, L6 around 40. Mechanical student numbers may be slightly higher. Part-time students around 5%. International students 3-4 per year. This does vary, some years it could be around 15. Females L6 2, L5 1, L4 2. Foundation year 7.	For HNC and HND around 70 students 98% P/T, 2% F/T. 90% male, 10% female. No international students, 100% national. Design classes can be split into mechanical and electrical.	Around 250 new students each year, this can be ±40. Now it's around 200, the number dropped down to 160 one year but now they average around the 200 per year. Overall, the university have around 850 undergrads and about 250-300 PhD students. About 40 MSD's. Part-time places are not offered. There may be a few students with extenuating circumstances just completing a year, these could be classed as part-time. Now there around 16-17% female. At a guess, around 25% would be international students. The university also run a separate aerospace (100's of students) and a separate general engineering (around 40), but no input into those.	In the final year it is a bit higher than normal, around 200 students. Very few are part-time, mainly full-time. Around 80% male and 20% female. Maybe 25-33% are overseas.
How are classes organised? **Individual or group work**. **Grading algorithm.**	The normal classes are for 2 hours lecture and a 2-hour tutorial. A lecture would be for around 30 minutes followed by demonstrations and examples. The pinch point for design classes is the necessity of using computer labs. The	Lectures tend to be in 2-hour windows. Due to the size of the computer labs, a class must often be split and teach the same lesson twice a week. Half an hour would be taught, then a demonstration of the application.	Average class size 17-20 but some classes can be as low as 3 but this is less common. Most work is carried out as an individual. Block delivery 2 hr presentation/discussion followed by 2 to 3 hrs problem solving. Working from home is not encouraged. There is no	Some lectures are shared with general engineering or aerospace engineering. These classes can run into 350 students. One lecturer had 850 students which was split into 3 cohorts. There are 2 lecture theatres which can hold up to 500, but they are in high demand.	The classes are not split. There are computer labs with dividers that can open out to give a double classroom. 40% of the module is online like flip-learning, quizzes, videos, Q & A. The time spent can vary, the students decide how long to spend online. They are supposed to do 10

	number of computers often require classes to be split. Some classes may be split three to four times which require the teaching to be repeated the same number. Mathematics is always challenging for students, so there is a weekly drop-in session with specialist mathematics lecturers available. Design in the early levels will be an individual task. In the final year classes are divided into groups.	Most lessons are split 50/50. That is 50% theory, demonstration followed by 50% application as a tutorial. There are weekly drop-in sessions for CAD, MATLAB, mathematics, and science.	grading algorithm but have seen a few examples. An appropriate one could save a lot of time especially if it was used in a spreadsheet.	A combination of individual and group work. The teamwork is important as you cannot work in industry unless as part of a team. The second reason is logistical, the amount of assessment work can be reduced. The grading is split between individual and group work.	hours per credit, and this is a 10-credit module. So, in total they should be doing 100 hrs, 12 hrs in class, the rest working in their own time. 60% is the design project side where the class is broken down into groups of 5 or 6 for around 1 hr per week. Have a few PhD students to support.
What would be a typical assessment design task? **Presentations**	The individual student assessment at level 4 would be mainly built around use of software (2D drawing, 3D modelling). This would be a 2 hr, in-class assessment carried out under examination conditions. At level 5 the individual student assessment will be on more complex design drawings. Application of appropriate standards. This would be a 2.5 hr, in-class assessment carried out under examination conditions. At level 6 the assessment would be conducted as a group exercise with all students expected to participate in the design of a given mechanical engineering complex component. The design task would be set in week one with the 12-week semester available to complete the task. A formal written report, model, calculations, group presentation to peers, and informal report would be required	L4 assessment would be on their basic skills using CAD software. Geometry, assemblies, basic drawings and drawing interpretation, lofting. Assessment is a 2-hr timed in-class assessment under exam conditions. L5 assessment is a 2hr in-class, timed assessment. L6 assessment would be more advanced features such as FEA, and software limitations. This would be a written report with software to effectively demonstrate the concepts. No use of presentations as part of the assessment process as the students are given an individual task, which they then hand in.	Assessment consists of a written report which may be split into two main tasks a design specification and a design report. The second part of an assessment could be a design exercise which would include a presentation. This would normally be presented by individuals. An early presentation could provide good insight into the design direction and provide confidence to the students. Grading is to the Pearson system of pass/merit/distinction. A popular assessment is to give an existing component to students and ask them to reduce the components mass while still maintaining the desired strength.	The assessment usually has an individual as well as a team element. This is to prevent students feeling that they settled with somebody in their team that wasn't very good. They feel they can still shine under those circumstances. Typically, a lesson runs for 1 hour twice per week. This is an average and can have peaks and troughs. The first year the students do an integrated project. The first project was to design a Gripper. This is good to get them thinking about the forces and bending stresses. They can carry out a reverse engineering on a cheap Gripper that was purchased. In the second semester the students complete a water bottle rocket. There are a series of Stage Gate Reviews where they provide a presentation on their design strategy, materials choice, and some analysis. In the Spring semester the performance of their rockets is	For the online part of the module assessment is mainly self-marking quizzes on Blackboard. There is a more advanced assessment which requires free text answers. The questions are longer, more complex. It's a problem-solving thing. For the 60% of the module there's 2 reports and an individual presentation. Having a presentation so early on in the design process could help to iron out problems before the students designs become very complex. An initial report is 20%, a final report that is 30%, a presentation /demonstration is 10%. This involves building a proof-of-concept model and presenting it to academics. An early presentation to peers could be interesting. Minimum pass mark is 40%.

				assessed. A field is hired out, with a landing strip in the middle. Some MATLAB code is used to determine the performance of the rocket. There is a day firing off rockets. Closer to the target, the better their mark. Pizza and sandwiches are provided. Invite the faculty. The plan in the future to include the aerospace guys to make it into a competition. Pass grade is 40%. Year 2 will be assessed by designing an electric bicycle. Next semester the students design a structure. This complements the design of a component as the component needs to be housed in something. The structure had to support a 20Kg weight but had a lot of restrictions on what the structure would look like. At the end of the year, everyone meets in the lecture theatre to try and break the structures. This year the structure is changing to a crane.	
Describe the main teaching methods. **Are students required to critique their design?** **500-word informal report** **Student critique.**	A group presentation during week four of the basic engineering design ideas. If the group has deviated from the design specification, then this provides an early opportunity to correct the path taken. The presentation was made to other students who were considered as one large group. The informal report was introduced to bring into the design process a way of reporting, informally the progress of the design.	The idea of using an informal report is good. Most written work is as a formal report. Any critique from students is good as it gets them to think and reflect. An informal report would have just key information. Managers want to know what you're doing, is it working, isn't it working, is it on schedule, what's the outcome going to be simple. A simplistic report is not a bad thing for students to get used to, because then they can be more concise and condensed	Standard teaching process of lecture, presentation of a problem, discussion, practical questions. Most of our student come from level 3 and so an informal report is the normal report writing they are used to. The challenge is to get them to write a formal report. Design is taught in the first year hence why the students are used to writing informal reports.	The module is run with a programme level approach. Design was integrated with Solid Mechanics and Production Mechanics. Year 2 the plan also to change to a programme level approach. This is taking an existing normal bicycle and modifying it. In preparation to designing the electric bike the students were asked to design a gear mechanism and a flat belt pulley system. They design the shafts and select the required bearings. Build a test	Usually, a front led presentation on things like how the project module works. A guest lecturer comes in one week. A Question & Answer where students can upload their questions and they can display them in class to answer later. The 5/6 PhD students and lecturer like to walk around, talking to groups and individuals, helping them understand the project. This morning wasn't a formal presentation, talking to the

	Most weeks would use the standard teaching method of lecture, demonstration, examples, practical. This would be followed by a tutorial to give the students an opportunity to practice what they have learnt. An individual critique is required around week 8. This is a balance of positive and negative things. Allows the student to show the depth of their understanding.	with their information. Instead of 3000 words give me one or two pages or four main points. Many of our students come through the vocational route and so are not used to writing such large, formal reports. When working at Samsung, often a progress report was required which could be skimmed in just 5 minutes.		rig to test the students designs. One lecture and one tutorial each week. They get the didactic learning in the lecture theatre and then they have exercises in the tutorial which follows the lecture. Some learning is put online for them to work through. There are workshop spaces students can use to build their structures. The areas are subcontracted out. It is called the Diamond. There is a similar thing to an informal report. In year one the students are taught to draw components. In year two they must assemble them which requires knowing how one component relates to another. They find it very difficult to know how to assemble their designs, how to lay it all out.	students, answering any questions, played a short, pre-recorded video. Informal report reminds me of applying for principal fellowship which required a Viva – A kind of structured conversation. This would depend on how many students you have. If it could be done this would allow the lecturer to pull out each individual contribution or understanding of the project. An individual Viva would be very labour intensive. This year a gate Review was introduced. Gate Reviews where the PhD helpers each spent about 10-15 minutes with each group, talking about the design and what each group had achieved. It wasn't marked but was mandatory. There was a kind of penalty if they didn't turn up or not engage with it. This was an attempt to give the students meaningful feedback. Found using GTA's better than staff as the message they give to students can be controlled better.
Is each year linked together throughout the programme?	Each module in each year was looked at to make sure that each level followed naturally onto the next level. Emphasis was placed on the basic engineering knowledge, taking every opportunity to build the knowledge, especially for our-full-time students. Direct entry students can be problematic as the exact content of their previous studies is not known. This is	Tried to maintain progression through the years. There were some difficulties with the Foundation year. 50% of the module is CAD. Direct entry to L4 may not have completed the required CAD, potentially their CAD skills could be zero, and so must be taught again. L5 builds on L4 assemblies for analysis within SolidWorks. L6 looks at more detailed simulations, FEA. This year I plan to teach kinematic	Modules are taught as stand alone, no integration. This is something that needs to change. Direct entry students may come from a totally different educational background. They sometimes lack required engineering knowledge that then must try and catch them up.	The university is in the process of changing these. The first year is now integrated. There are five modules, three of them are integrated with design. Two modules are like traditional hard science modules, the other three make up the Gripper and Water Bottle Rocket and all the supporting physics, solid mechanics, fluid mechanics, thermodynamics. In the	There is real push for programme level approach. Try to stop stand-alone modules, thinking, how does this work when going through the whole programme. For mechanical engineering, last year there was created a whole new first year which was meant to be more integrated. It's a bit like a problem-based learning sort of approach where they have a big project. They designed a water bottle rocket launcher,

	especially true for international students.	analysis linked to thermal conditions linked to structural studies.		second year there are two stand-alone modules. One module is a 10-credit module which equates to 100 hours. The third year is still under review. May not go down the route of integrating. An integrated design could be the design of a passenger vehicle or passenger ride. Something that is very industry focused. In the second year they do a group project. Industry partners come in. They are given a problem and go away to solve it as if they were consultants. The industrial partners keep coming back because it gives them a sense check on the decisions made. Sometimes the students come up with something that is innovative that they can run with.	lots of other theories fed into that. There is supposed to be a kind of thread running through the programme. They are currently redesigning the second-year design which will impact on the third-year module. It's a little bit delayed. Don't really get direct entry students, maybe the occasional one or two.
Are there any areas of design that students find particularly difficult?	Often students will fail to link all the different areas of a design. Trying to understand a problem as a whole, to see that a problem can be made up of many different facets. Areas such as FEA, materials, function, and assembly are not stand alone but are all linked together and affect each other.	The students are taught to use the software but probably need to go into the design process better. Don't teach this to the depth that it should be taught. Our vocational students tend to be more free thinking. They often find a better route to solving something in an abnormal way.	Design appropriate geometry to achieve the required strength. At HND level students may use optimisation methods. Students have too much freedom in their design. They require better and more constraints to increase the design difficulty and complexity.	The students are very good at solving well defined problems. If they are given say a cantilever, 1m long, weight at one end, made from this material, it has this cross-section and mass. Tell me the deflection they will have no trouble. But if asked to design a structure to support a mass they go weak at the knees. They have trouble going from an infinite design space to a solution. Poorly defined problems freak them out. They feel very stressed that their design solution is linked with their final grade, whether they are going to get a first and go off and work for Rolls Royce and be happy. An example is selecting a motor speed to design a	Mainly idea generation. Weighing up and considering ideas. What happens is most of the time they just come with an idea and then develop the design matrix backwards to show their idea was the best idea. A good method is the double diamond process which consists of divergent and convergent thinking. Market research into what you are going to design, then you hone into a design specification, then you diverge again as you develop design ideas. It's important not be too critical with initial ideas, allowing any ideas until you start to weigh them up.

				powertrain that need ratios for the reduction between the motor and fan. Their choice can be anywhere from zero to 3000. They just don't know where to start. They get quite stressed about it. If they are set a task to use trigonometry to find the height of a building, they stress over what size of building to use rather than worrying about the actual trigonometry.	
Do you use modelling software? **Advanced features**	SolidWorks updated each year with the latest version. Autodesk for 2D drawing. In the early years (L4 & L5) students are mainly learning the software, how each work to produce a model. Later advanced features are introduced such as FEA, Computation Fluid Dynamics, Parametric, Optimisation etc.	SolidWorks updated to latest version each year. Autodesk. Ansys for L6 structural analysis. It is planned to add surfacing as this is important for automotive engineering. L5 motion simulation for kinematic analysis and component interaction analysis and force transfers, motion loads. Like to highlight the limitations of SolidWorks, the bulk of the work is completed using Ansys.	SolidWorks. Advanced features at HNC could be FEA, at HND level it could be CFD.	Fusion 360. FEA is taught as part of their hard science module. Troubled with advanced features. Don't use parametric, animations or optimisation modelling. The expectation is for students to debug interferences. The university expect graduates to be able to use any modelling software.	Fusion 360. In the student's final project, they were required to do some Computer Aided Designs (CAD). In the first year the focus is completing 2D drawings. Concentrate more on Computer Aided Drawing and Computer Aided Manufacture (CAD/CAM) which allows students to produce the drawings and models and then to produce toolpaths for manufacture. Some students may choose to complete FEA or CFD, but the university don't expect it. Concentrate more on communication, producing good readable drawings and then communicating those drawings with the workshop for manufacture.
Do you observe any differences between teaching part-time and full-time students? **How does a placement year change full-time students?**	The basic engineering knowledge of part-time students is much better than full-time students. Part-time students are often better at problem solving. They tend to begin solving a problem quicker than full-time students. Full-time students will often catch up later with their problem solving.	Industry students tend to pick things quicker and are generally a lot more willing to put the time in to learn something. Tell the students; they will be taught the basics but if they want to get good then they need to spend time. The more time they put into it, the easier it will come to you.	Part-time students come to the university with varying amounts of industrial and manufacturing experience. Many students come from a non-engineering background such as A-level instead of a BTEC in engineering. These students require extra tuition on more basic knowledge in manufacturing.	Have very few part-time students. After year two they can go on a placement year. They come back after a year grown up. The return with a work ethic. They spend a year getting up for work in the morning and spending all day until 5 p.m. They do whatever is required. When they come back to university, they seem	Have very few students who are part-time. When full-time students return from a placement year there is a difference in how they approach real world problems. Did have a survey a few years ago of industry employees who said the students were very good at

	Realising the basic differences between part-time and full-time students allows us to apply a different teaching technique, a modified reverse engineering process also known as Blooms Taxonomy Reversed.	Historically, part time students coming from industry are used to using CAD, or if they haven't used it are working alongside people who use it, so they understand what the process is and what the requirements are. Many coming in this year have used Fusion 360 or basic things like Sketchup. This gives them a good understanding of the fundamental concepts of how CAD packages work. About 30-40% of our L4 students have used a CAD package before coming to the university.		to be focussed on what their careers will be like. Have developed a preparation for practical module due to feedback from students. They wanted something to help them polish their C. V's, get used to doing interviews, and other skills required to get employment. They get a chance to learn a new skill, maybe new CAD software, one guy was going into the army and so wanted to get fit, others spent time researching different industries such as aerospace.	theory but lacked common sense. Tried to solve this problem with students not doing a placement year by encouraging them to participate in Formular Student, Shell UK Marathon. Have around 20 different projects going on. Also have Makerspace to encourage students to complete practical work. I am not sure of students jumping to a full solution to a problem.
Discuss Bloom's Taxonomy Reversed and Reverse Engineering Method to assist with limited knowledge.	The knowledge gap identified in full-time students was reduced to 14% by changes to the curriculum. To assist students to understand some basic engineering problems which require knowledge a method of using Bloom's Taxonomy Reversed combined with Reverse Engineering has been developed.	As previously stated, students with an industrial background are quicker to pick things up. Anything that assists students to improve on their practical engineering has got to be a plus.	The need for extra tuition for students from a non-engineering background is a common factor. Bloom's is a favourite teaching method, used in nearly all lessons so to reverse it is an interesting concept. Looking forward to seeing how this develops.	After a placement year the difference is noticeable in the students. Anything that can bring students closer to industry methods must be a good thing.	Students are good at theory but lacked common sense. Placement years and competitions address this problem but to a limited degree. This method suggested may help to bridge the gap between full-time and part-time students' knowledge.
How do students carry out research? **Safe sources of data (SMALL CAPS).** **Questionable websites.**	Google is the main research method. This will usually bring up many answers to a design problem but many questions. Once a good web site has been found this can often be shared with other students. Library is not used much so it is often necessary to stipulate that in their final report, peer reviewed papers are used. Most part-time students will introduce company standards while full-time students will use national standards such as the British Standards.	Google and then random websites. Our library is across the way. Nobody deals with physical books any longer. Try to push students toward peer reviewed journals papers. This doesn't work that well with L4 students as journal papers are often incomprehensible to them. They tend to use websites which may not be correct to use in a formal report. This does give them a grounding	Google. Much research is carried out peer to peer. The library is not very industry relevant and is not up to date so can only assist students in their research to a limited degree.	First thing they do is go to the internet and do a Google search. They rely on sites like Engineering Toolbox. Years are spent trying to get them out of this habit. Encourage them to use textbooks. They don't come out of school using textbooks anymore. Encourage them to use academic journals. Each year the expectation is for them to use more academic papers, especially in their final year dissertation.	As an example, the students were asked to design a Ferris wheel. They had to decide on its location which required research. The research would be using Google. The sources found by students may not be particularly rigorous academically. They would often use Wikipedia articles and news sites. This is an area that needs to improve.

	Students can have difficulty differentiating between primary and secondary research.	that can be directed toward literature. SolidWorks has its own built in learning functions. There is an untold wealth of information online. If they have a problem, they can Google it and there will be a YouTube video to solve the problem.		A lot of them will fall back on YouTube videos. You can get good instruction on a lot of subjects, but this method may not be so good if you had to justify yourself in a court of law. Trying to teach them critical thinking.	
What standards are students expected to follow?	Have many Rolls Royce students who naturally use many standards from their company. Expect British Standards to be used, especially in the drawing. This would be BS8888.	Modern industry takes a different approach to how they do projects. They will use different approaches until they have 5 or 6 solutions to a problem. Then they will evaluate the solutions until one is favoured over the rest. This is an area the university needs to do more on.	Not usual for students to use a specific international industry standard but happy for a student to use a standard set by their company. British Standards are commonly used. Some students who already design in industry do so without producing a design specification or designing to a standard of any type.	For drawing it will be BS8888	In the students first year they are taught to draw to a standard. They are taught ethical considerations and importance of not committing plagiarism.
Is the students basic engineering knowledge at a reasonable level, any gaps found? **If gaps in knowledge are found, how are they filled?**	By the third year of a student's study at university their engineering knowledge has grown so that they can understand and apply advanced equations and methods in their designs. The difficulty was found in understanding more basic methods and techniques in engineering. This is especially true of our full-time students. As an example, students may design a pneumatic cascade system with maybe six to seven stages. This causes little problems. When they are required to assembly the whole system together, including mounting parts on the actuators, fixing valves and pipes together, this can cause difficulties as they may not be aware of the type of fixings available.	Student don't think immediately in first principles anymore. In a gearbox, you design the teeth profiles, you have got your meshing interface between gears. This is fine. How are you going to put the gears on the shaft? Is it going to be keyed? Is it going to be on splines or similar? Might calculate for example the reflective inertia but they will forget the basics. An example from last year. One module was looking at gearboxes in an automotive setting. They were perfectly happy with calculating gear ratios. They couldn't understand how to constrain the gearbox from turning due to the torque reaction. They didn't understand the basic requirement to balance the system.	Part-time students generally have a good basic engineering knowledge. Full-time students generally do not have as good a knowledge. Example – Students can select a bearing OK but have trouble deciding on the fit required. Sometimes the lecturer gives the students the fit, say H7 and then let them research what this means and how its applied.	Some students have never picked up a screwdriver while others have been involved in a race team. Gave the students a gas turbine to pull apart and then put back together. It was obvious they didn't have any idea what to do while others had no problem. Students can build their knowledge by joining a team on the Formular Student competition, Railway Challenge. Students that are motivated can use CNC mills and lathes, water jet cutters, CNC routers, 3D printers, and laser cutters.	In group work it is easy for a student to mask if they lack certain knowledge, allowing others to cover work they may not be able to do. Some of their numbers can be wildly off indicating they may not understand a topic as well as they should. Do they understand how big 1000N is for example. The ability to estimate stuff and come up with realistic figures is quite a basic sort of engineering skill.

As part of the design process, is reverse engineering taught?	Reverse engineering wasn't taught until it was realised the difficulties that some of our students have in understanding some of the simpler aspects of engineering. When appropriate, some of the methods that reverse engineering use have been applied to the design process to help direct a student's thinking, to help them understand better certain design methods.	Students are happy with the final equation to a problem but not going back to first principles themselves. They are happy to jump over these stages. They know the basic formular but have trouble linking them together to form the whole picture. Only teach reverse engineering in a small way.	A kind of reverse engineering is taught. The students can be given a component and set a task, maybe to reduce its mass while still maintaining the required strength. This requires a certain amount of working in reverse.	Have in the past had the student's reverse engineering a jet turbine engine. This year they were given a Gripper to reverse engineer.	Yes. In the first year it could be a hair dryer or a scooter. Do have a miniature jet engine which the students have to take apart. The students must draw them, decide on appropriate materials, try and improve the design.

7.4 Interview Summary

The interviews from Table 55 are summarised in Table 56.

Table 56 Interview Summary

<table>
<tr><th>Category</th><th colspan="5">Summary</th></tr>
<tr><td rowspan="5">Class logistics</td><td></td><td>Number</td><td>International</td><td>Female</td><td>Part-time</td></tr>
<tr><td>Derby</td><td>150</td><td>23</td><td>8</td><td>12</td></tr>
<tr><td>UWTSD</td><td>150</td><td>6</td><td>5</td><td>8</td></tr>
<tr><td>NTU</td><td>70</td><td>0</td><td>7</td><td>69</td></tr>
<tr><td>Sheffield</td><td>250</td><td>63</td><td>43</td><td>0</td></tr>
<tr><td>Class Organisation</td><td colspan="5">Two techniques used:
1) Small classes (<100) split into smaller groups and taught 3-4 times each week.
2) Large classes (>100) kept together but with increased number of teachers (including PhD students).
Each week 1-2 hr lecture followed by 1-2 hr tutorial.
Pinch-point is the size and availability of computer rooms.
Weekly drop-in sessions for maths, MATLAB, Science, CAD.
Combination of individual and group work.</td></tr>
<tr><td>Assessment Tasks</td><td colspan="5">Level 4 mainly use of 2D and 3D software. Development of geometric shapes. In house phase test or quizzes. Some HEI's require a higher level of assessment such as an integrated project and use of Stage Gate Reviews.
Level 5 more complex designs, application of standards. Formal Examination to design a component.
Level 6 group design activity, formal report, presentation, advanced features such as FEA and software limits, proof of concept models built.
An early presentation to peers was generally accepted as an interesting idea with possible benefits to all involved.
Assessment will have a group and individual element.</td></tr>
</table>

	Example assessment designs are a gripper, water bottle rocket, gearbox, and electric bicycle.
Teaching Methods	Standard per week presentation, demonstration, examples followed by questions. Alternatives are guest lectures, practical, Viva's, and pre-recorded video, individual critique. Tutorials provide students with practice. Design module is integrated with other modules to provide more detailed teaching. Some content is put online for students to look at later. Informal report – Good as it would be more concise. Some level 3 students have no problem with informal report. Use of PhD students for larger classes.
Linking of Years	Curriculum was reviewed so that each year's modules would complement the following year. Some HEI's taught modules as stand-alone. Basic engineering knowledge was specifically targeted, especially for full-time students. Direct entry students come from a variety of backgrounds and require catch up lessons.
Design Difficulties	Understanding a problem, seeing all the different facets to it. Understanding the design process. Designing appropriate geometry to achieve the required strength. Difficulty going from an infinite design space to a solution. Idea generation.
Modelling Software	SolidWorks. Autodesk. Ansys. Fusion 360, Advanced features vary between HEI's – FEA, CFD, Parametric, Optimisation, surfacing, motion simulation, computer aided drawing and CAM.

Part-time & Full-time Students	Basic engineering knowledge and problem solving of part-time students is better than full-time students. Apply modified reverse engineering process to engineering design process, also referred to as Reverse Bloom's Taxonomy. Students from industry pick things up quicker, more willing to put required time in. Most part-time students have no problem using Computer Aided Drawing (CAD) software. Students from a non-engineering background such as A-levels require extra tuition on more basic knowledge in manufacturing. Students returning after a placement year appear more grown up and acquired an improved work ethic. After returning from a placement there is a difference in how they approach real world problems. Encourage full-time students to compete in competitions requiring real world problems.
Research	Mainly Google then random websites. Library not used much. Try to encourage the students to use textbooks. Difficulty differentiating between primary and secondary research. Some sources may not be completely appropriate. Encourage to refer to Journal papers. SolidWorks has own built-in learning functions. YouTube video. Peer to peer.
Standards	Many students use the standards produced by their company. For drawing use BS8888. Industry may use several methods to produce a range of solutions. Then they will evaluate the solutions until one is favoured over the rest. British Standards. Often no standards used.

	First year taught to use correct drawing standards.
Basic Engineering knowledge	By the final year student knowledge of complex design issues is good. Basic methods and techniques students find difficult. Students don't think in first principles anymore. Part-time – generally have good basic engineering knowledge. Full-time student's knowledge is not as good. Some students have never picked up a screwdriver, others have been on a race team. Group work – Students can mask if they lack certain knowledge. Some numbers can be wildly off. Estimation skills are not realistic.
Reverse Engineering	Reverse engineering taught to assist students to understand more basic design concepts. Only taught in a small way. In a limited way – To re-engineer a component to meet a new criterion. Gave the students an example and ask them to pull it apart. In the first year.

7.5 Research Analysis

The interviews from Higher Education Establishments documented in section 7.3 and summarised in section 7.4 will now be analysed with reference to the five reasons for this research provided in section 7.0.

7.5.1 Research Reason 1 (section 7.0)

All three HEI's interviewed used the traditional method of teaching mechanical engineering design, weekly lectures, examples, question and answer, followed by a tutorial comprising practical questions for students to attempt. A proven and popular method used for many years in schools, colleges, and universities.

Normal class length for all HEI's was 1-2 hours lecture, 1-2 hours tutorial. The accepted hours per credit is 10. A module is 10-20 credits requiring 100-200 hours total time, most of which is completed by the students outside of a formal class.

Large cohorts of students (>150) are split by all HEI's into more manageable size, with classes being repeated each week. If the cohort isn't split, then it can be managed by additional teachers or PhD students.

Most HEI's use a combination of individual and group work. Group work is a requirement from industry, individual work makes for more accurate assessment of a student's abilities.

Most HEI's provide a weekly drop-in session to provide support in mathematics, Computer Aided Drawing (CAD), MATLAB, and science.

The number of full-time students is greater than part-time students in most HEI's. Part-time students prefer the Higher National Certificate (HNC) and Higher National Diploma (HND) route instead of a degree. Part-time students also prefer an apprenticeship, which are supported by industry and the UK government (HM Government, 2022).

The above methods used by the three HEI's provide confidence that there are no significant differences between their methods and those used at The University of Derby (UK). Any changes to The University of Derby's (UK) methods in aligning with industry should be transferable to other HEI's.

7.5.2 Research Reason 2 (section 7.0)

Full-time students have less basic engineering knowledge than their part-time colleagues. Full-time students are encouraged to participate in a range of practical competitions and after their second year to complete an industrial year placement.

If a design problem is fully defined to the students, they often do not have difficulty in determining a design solution. If not fully defined, students often have difficulty in understanding the problem and coming up with a design solution. The selection of the problem, and the number and type of constraints must be carefully selected by the lecturer to provide appropriate information for the students to complete the design task.

All HEI's stated that students use Google as their main search engine. Often students decide on a design solution and then carry out research to support their decision.

The issue of basic engineering knowledge has been identified by other HEI's along with the reliance of students on the use of Google for research. These two areas are part of the research of this thesis.

7.5.3 Research Reason 3 (section 7.0)

Lectures to explain principles and provide examples. Teaching is reinforced later with tutorials. Time between the lecture and tutorial allows the students to review the lecture and prepare questions for clarification of any principles or methods. Tutorials are used to reinforce the teaching by challenging the students to answer questions themselves with support from lecturers if required.

Drop-in sessions to support students in more challenging areas such as mathematics, MATLAB, science, and CAD gives students the chance to consolidate their learning before moving on to other topics.

Various assessments are used to check student's knowledge and understanding, ranging in complexity and degree of difficulty. Most HEI's use a combination of group and individual assessment to determine a student's abilities.

The methods, logistics, and pedagogical approach to teaching mechanical engineering design align very closely with those used at The University of Derby (UK) and are not specific to any one HEI.

7.5.4 Research Reason 4 (section 7.0)

Group work is accepted by most HEI's as necessary to design a complex mechanical engineering component. Group work is an expectation of industry along with the required skills to make it work successfully.

Presentations are used in all HEI's. The schedule can vary from very early in the design process to the end. Early presentations help correct any designs not staying within set design constraints. Later presentations assist in grading the designs by students explaining the design's ability to meet the required constraints.

Virtual or real prototypes are used to test a designs functionality, often linked with assessment of student's ability. The use of real prototypes is still a function of industry even though the method is used less due to virtual systems.

7.5.5 Research Reason 5 (section 7.0)

The basic engineering knowledge of students requires improving, especially for full-time students when compared to part-time. Those HEI's that have very few or no part-time students found that their full-time students, after completing an industry placement year, improved their basic knowledge and work ethics.

Use of an informal report was considered an interesting idea. An interview with each student would be better but practical considerations rule this out. Some students with previously low level of education found an informal report easy to write as this was considered normal.

Research using mainly Google was universal in all HEI's and causes issues when student's select a design solution and then use Google to justify it. The process requires reversing either at the first stage of the design process (conceive possible solutions) or in the research stage.

7.6 Chapter Summary

Mechanical engineering design is not a unique subject requiring a new pedagogical approach. The tried and tested techniques developed over decades in other practical subjects apply to mechanical engineering design.

The large range of subject areas that mechanical engineering design encompasses makes variations in teaching inevitable. These variations are only limited by the imagination of the teacher and students.

Research was dominated by the internet, Google being the preferred research tool of most students. This provides solutions to design problems. Students will often select a solution and then justify the selection later. Sometimes the solution is difficult for students to fully understand why certain design decisions were made.

The discussions on using an 'informal report' were all positive. Some students had no problems writing one as this was the method they used in previous courses. Others HEI's thought the idea to teach students to write succinctly was good.

All HEI’s confirmed differences between part-time and full-time students, mostly around degree of knowledge, work ethics, and application. The idea of using a reverse Bloom’s Taxonomy to aid in full-time students’ knowledge was found understandable and interesting.

This research has confirmed the above statements and provides confidence that the suggested changes to teaching mechanical engineering design that are being applied and proven successful at The University of Derby (UK), will also be applicable in other HEI’s if they wish to make use of them.

Based on the case studies of design methods in chapter 6 and the present teaching methods used by HEI’s in chapter 7 several incremental changes will be made to the way design is approached at the University of Derby (UK). These changes are recorded in chapters 10-13. To support the students through these changes support mechanisms have been developed and can be viewed in chapter 8.

CHAPTER 8

SUPPORT MECHANISMS

(Objective 4 Section 1.2.2)

8.0 Introduction

Industry has some advantages over academia. Design groups can be put together based on the strengths and weaknesses of the individuals. The experience of individuals can outweigh the inexperience of others and can even be used to encourage the inexperienced ones. The strength of the group is often greater than the strength of the individuals.

Within academia, the mechanical engineering experience of the individual student will either be very low or non-existent. This is because many students' past will only be school or university. If they are working, then it will probably be for only a short time. Due to the lack of experience, what support mechanism can be put in place to assist students in the design process?

8.1 Student Literature Review

All projects, if correctly run will require, in the early stages, a literature review. According to Library, (2019) a literature review is carried out for the following reasons:

- Provide a foundation of knowledge on a topic.
- Identify areas of prior scholarship to prevent duplication and give credit to other researchers.
- Identify inconstancies: gaps in research, conflicts in previous studies, open questions left from another research.
- Identify a need for additional research (justifying your research).
- Identify the relationship of works in context of its contribution to the topic and to other works.
- Place your own research within the context of existing literature making a case for why further study is needed.

8.1.1 Foundation of Knowledge

The first bullet point above, 'Provide a foundation of knowledge on a topic' is more difficult than it may at first appear. The knowledge gathered must be proven to be from a reliable source that can be reviewed and checked. If the knowledge base is not from proven, reliable sources then the whole project could be called into question.

The main source of knowledge for students is the World Wide Web (WWW). What mechanisms are there to help students identify reliable sources of information? This will be the focus of section 8.2.

8.1.2 Areas of Prior Scholarship

It would not be a good situation, after developing a design for a time to then find the design was not unique. Part of the literature review is to develop the breadth and depth of knowledge which would include any designs already available. Some areas of scholarship may be used in the new design justification. This would need to be acknowledged to prevent any plagiarism.

8.1.3 Research Gaps

During the literature review, gaps in knowledge may be found or questions may be left open from previous research. If these gaps are important to the new design, then they would require further research.

8.2 World Wide Web Information Reliability

As of 2018, there are over 1.8 billion websites in the world. Many of these are protected with free speech and anti-censorship laws allowing webpage owners to print anything they want, true or false. It is becoming ever more difficult to ascertain the reliability of webpages.

Using ‘Primary Source’ information should be a strong indicator that the webpage is reliable. ‘Primary Sources’ are sources of information from first-hand experience. The writer would be a witness of the event or be personally active in it. Opposite to ‘Primary Source’ information is ‘Second hand’ information, or hearsay. This source of information can be unreliable. Some good sources of ‘Primary’ information are:

- Journal articles.
- Books and book chapters.
- Some magazine and newspaper articles.
- Reports, such as from government agencies or institutions.
- Dissertations and thesis.
- Interview and speech transcripts and recordings.
- Video and audio recordings.
- Personal communications.
- Webpages. (Lee, 2013)

Out of the above list, students are most likely to use webpages as they are easily available, plentiful, make use of graphics, video, and animations. How can you check on the reliability of a webpage? Here are a few suggestions:

1. Look for sites from **secure** institutions. – The internet has many websites that were started a short time ago. What is wanted are sites associated with trusted institutions that have been around for a while and have a proven track record of reliability and integrity. Government agencies, non-profit organisations, foundations, or colleges and universities.

2. Look for sites that are **specialists** in their field. – A person wouldn't go to an auto mechanic if they broke a leg, and they wouldn't go to the hospital to have their car repaired. Look for websites that is a specialist in the kind of information you're seeking.

3. Steer clear of **commercial** sites. – Sites run by companies and business. These websites usually end in .com and are often trying to sell something. If they're trying to sell you something, chances are whatever information they're presenting will be biased in favour of their product. That's not to say corporate sites should be excluded entirely. But be wary.

4. Check the **age**. – An engineer needs the most up-to-date information available, so if a website seems old, it's probably best to steer clear. One way to check — look for a "last updated" date on the page or site.

5. Consider the sites **look**. – If a site looks poorly designed and amateurish, chances are it was created by amateurs. Steer clear. But be careful, just because a website is professionally designed doesn't mean it's reliable.

6. Check the **links**. – Reputable websites often link to each other. You can find out which other websites link to the site you're researching by conducting a link-specific Google search. Enter the following text into the Google search field, replacing "[WEBSITE]" with the domain of the site you're researching:

   link:http://www.[WEBSITE].com

   The search results will show which websites link to the one being researched. If lots of sites are linked to the site, and those sites seem reputable, then that's a good sign.

7. Avoid anonymous **authors**. – Articles or studies whose authors are named are often, though not always, more reliable than works produced anonymously. It makes sense: If someone is willing to put their name on something they've written, chances are they stand by the information it contains. And if you have the name of the author, you can always Google them to check their credentials.

8. Avoid **mind-set**. – Keep clear of sites with an obvious mind-set or bias to a particular make or brand. The site may have commercial links that could benefit the owners.

9. Avoid **purchased** sites. – Sites ending with .org or .net can be purchased and used by individuals and should be avoided. However, the domain .edu is

reserved for universities and colleges, while .gov denotes a government website. These sites should be safe to use (Rogers, 2019) (Ron, 2013).

To assist students to remember the above, the following acronym is suggested:

S	Secure
M	Mind-Set
A	Age
L	Look
L	Links

C	Commercial
A	Authors
P	Purchased
S	Specialists

The above acronym is not exclusive as there are other ways to check the reliability of a website. Over time, in industry, sources of information are built up that are from trusted proven sites. The same will happen over time with students. The above acronym should provide them with a starting point for increasing their reliable knowledge.

A resource area that is not provided by an academic but can be used to support their teaching is the use of personal laptops and hand-held devices. During a lesson, when an academic may be explaining a topic to the class it is often the case that students will check the data the academic provides, ‘live’ at it were. The students will provide any required update to the information being provided by the academic. This is a very good way of teaching and learning as students will take ownership of that information and will start to form a habit of double checking what is given to them from outside sources, i.e., the academic or websites.

8.2.1 World Wide Web Search Engines

When students are set a design task, it is natural for them to research solutions using a search engine. It is surprising how limited the WWW is when using a search engine. One of the most popular search engines, Google will only provide access to 4% of the WWW. This is known as the ‘surface web’, information search engines can access and is ‘visible’ to the mainstream public. 94% of the WWW is referred to as the ‘Deep Web’ where more private information is kept and is invisible to search engines. The ‘Deep Web’ is accessed routinely as you check emails, online bank statements, direct messages through social media and all sorts that are made private (Techwelkin, 2022).

The basic structure of the WWW is shown in Fig.54:

Content removed due to copyright reasons.

Figure 54 Surface Web (Techwelkin, 2022)

It is important that students do not confuse the Deep Web with the Dark Web. The Dark Web, as Fig. 54 shows, is an area of the internet that should be explained to students along with a warning to keep away from it.

How then do our students access the 94% of the WWW not visible in normal search engines? Academic information such as journal papers, reports, databases etc. are accessible usually once a person has created an account either as an individual or as a company. It is important that we encourage our students to use this part of the WWW. Provide examples in class and create accounts that students can use.

8.2.2 Predatory Journals

Hundreds of open access journals are being set up by reputable publishers, scholarly societies, and universities each year. A small number of pay-to-publish articles are appearing in journals. Some academic authors are being duped by submitting their research outputs to be published in these journals that do not have proper quality control or a peer review process. It is vital that lecturers warn students of the danger of using such poor-quality articles.

Some warning signs to look for:

- Board of Editors list shows that members are not recognised in their field or are affiliated with questionable institutions; however, this must be done with caution, as Board member names may be used without their permission.

- Journals with dubious addresses for their registered office.

- Unsolicited email or paper communication inviting publication in journals you don't know and have never heard of.

- Unsolicited invitations to conferences run by event managers, not professionals in the research area, often at attractive destinations.

(The University of Edinburgh, 2015)

8.3 Required Knowledge

Knowledge is key to learning. Many theories have been developed to enable students to gain this knowledge. These theories can be grouped within schools of knowledge. The three most common schools are:

8.3.1 Three schools of Learning

There are three schools of psychology that contribute to learning theory. Each looks at learning from a different point of view; they supplement rather than contradict each other and often overlap in practice.

School 1 – **Cognitive** looks at the thinking processes involved when learning takes place. The aim is to teach for understanding which requires that new learning is built on existing learning. Asking students challenging questions will help them make their own sense of what they are studying and enable them to make use of their learning in real life. This cognitive theory is called **constructivism**. To fully understand a topic, high order skills (see Bloom's Taxonomy in chapter 9) are required, such as analysis, synthesis and evaluation.

School 2 – **Behaviourist** ignore the thinking processes and look at how teacher behaviour and other external factors such as animal behaviour influence learning. Learners are motivated by an expected reward of some kind. The reward can be praise, attention, and other encouragement. Tasks are short and achievable so that learners can experience successful completion frequently.

School 3 – **Humanistic** has an interest in education as a means of meeting the learner's emotional and developmental needs. Emotional factors, personal growth and development are the highest values according to humanistic thinking and these are ignored in society. Education exists to meet the needs of the learners, not the other way round. Learners should be allowed to pursue their own interests and talents, to develop themselves as fully as possible in their own unique direction.

There are more learning theories that could be looked at, but most come under one or more of the schools mentioned above. As these schools overlap each other, in practice, they will all have relevance to this thesis. The most relevant, that will be argued later is constructivism.

8.3.2 Part-Time & Full Time Knowledge

During academic year 2014-15 students were tasked in the design module 6ME500 Advanced Engineering Design Modelling with designing a Road Re-Claimer. An interesting discussion was had between the lecturer and a student. The conversation began with the lecturer asking why a keyway with square ends was used to fix a gear to its driving shaft. A keyway would normally have round ends produced by a milling cutter during its manufacture. The student explained that after searching on the internet for ways to fix a gear to a shaft he came across a keyway with square ends. He considered that this would be a normal method of fixing the gear. The lecturer moved the conversation forward by asking what other methods of fixing the gear had the student considered. The answer was surprising, none. The student did not know of any other methods. The lecturer was concerned over the lack of knowledge of this student in basic engineering knowledge. Over the next few weeks, the lecturer had similar conversations with several students. Some displayed the same ignorance of basic engineering knowledge while others were opposite and displayed very good knowledge. The following year, 2015-16 the task was to design an Off-Road Buggy. During the semester, the lecturer found again, the degree of student knowledge on basic engineering varied greatly. Why were there such large differences in the knowledge of students?

Starting in academic year 2016-17 this apparent difference in knowledge was investigated. The following method was used:

1. Research ethical approval was requested and granted on 5th August 2016.

2. At the beginning of the Autumn semester, during the first lesson of module 6ME500 Advanced Engineering Design Modelling, students were invited to participate in a survey on Basic Engineering Knowledge.

3. The survey consisted of pictures of 50 common engineering components. From memory, students were asked to identify the components (Appendix 1).

4. Participation was voluntary and anonymous. Consent could be refused at any time.

5. The survey could be taken in-class during a lesson or anytime during the semester.

The survey was repeated for each subsequent academic year. The results are shown in Table. 57.

Table 57 Survey of Students Basic Engineering Knowledge

Academic Year	Student Total	Part-Time								Full-Time							
		Total Students	Average % Correct Total	Male	Average % Correct Male	Female	Average % Correct Female	International	Average % Correct International	Total Students	Average % Correct Total	Male	Average % Correct Male	Female	Average % Correct Female	International	Average % Correct International
2020-21	73	8	96	6	96	2	95	0	0	65	82	62	82	3	78	21	79
2019-20	111	47	89	39	89	8	87	0	0	64	75	61	75	3	80	29	73
2018-19	115	44	93	34	92	10	95	0	0	71	60	68	61	3	58	30	61
2017-18	113	40	92	37	92	3	92	3	93	73	55	68	54	5	55	22	54
2016-17	114	41	86	36	86	5	85	2	83	73	37	70	37	3	35	34	37

The results of the survey in Table 57 have been divided between part-time and full-time students. These two divisions were further split into male, female, and international students. An analysis of the results shows:

- During academic year 2016-17, out of 114 students, part-time students achieved on average 86% correct answers. Full-time students achieved on average 37% correct answers. This is a significant difference of 49%.

- With changes made (chapter 10-13) the difference in basic engineering knowledge was reduced to 14%.

- The difference in basic engineering knowledge reduced over subsequent years due to changes made and recorded in this thesis.

- There are no significant differences between male and female students.

- The number of female students, part-time and full-time is low, but reflects the national average of 12.37% (Women's Engineering Society, 2020).

- Most students taking the survey were aged between 20-21 which is the average age of students completing an under-graduate degree programme in the UK (HESA, 2021).

- International students are normally full-time due to UK visa requirements hence most years, the part-time recruitment is zero. The few part-time international students are due to repeating the year after failing two or more modules.

8.3.3 Reducing the Knowledge Gap

Many students will have little experience of practical engineering. Full time students will mostly come from completing their A levels at school or a Diploma at college. Part time students are mostly employed and so will be gaining experience, but this will still be very early on in their careers. The range of knowledge required by engineers is enormous. This can be seen by the range of different products produced by design engineers; these can be complex systems such as aircraft, satellites, automobiles, and computers; they can be simple designs such as kitchen utensils, sunglasses, lamps, and bottles. Of course, everything used today was designed, and so design engineers are required to have the necessary knowledge to produce reliable, functional, and cost-effective solutions. How can the gap between the knowledge students have and the knowledge they will require be reduced or filled?

The literature review (chapter 2) provides several suggestions to help fill the knowledge gap. After acknowledging that many degrees do not provide the knowledge required by engineers, even going as far as to say that knowledge is lacking, the review makes several suggestions. The recurring suggestions are:

1. Create a library of resources which would include more than just reference books, manuals etc. It would include things such as material samples, displays, engineering examples, manufacturers catalogues.

2. Students need to be taught how to set up their own enquiries and develop methods to solve problems.

3. Use of constructivism with open ended teaching.

8.3.4 Library Resources

Most universities and colleges have a traditional library made up of physical resources such as books, DVD's, catalogues, magazines, and newspapers. Most also have these things in digital form available for download. While these facilities are very good, they only address the lack of student knowledge to a limited degree. It is important that students are taught how to make the most of these resources. Induction onto a programme usually includes introducing students to the library resources and the systems in place to make the most from them. This is good, but sometimes an even more basic induction is required. In this internet age, students know how to use a computer and the induction will show them the systems in place to assist in this. Students also need basics in how to get the most from a book. Authors, referencing, editions, versions, ISBN number, doi number, content, preface, appendices, index, abbreviations and acronyms. It should not be taken for granted that students know what these things are, they should be explained.

The literature review takes library resources further. The suggestion is to increase the resources by including things such a material samples, physical and mechanical examples, demonstrations of engineering principles, collections of fixtures and fittings, bearing types, gear design etc. If the space is available, this resource would benefit all students.

It is planned to enhance the library resources at the University of Derby (UK) to include the above. This will be a large undertaking and may take months even years to achieve and will require continual updating.

2D drawing and 3D modelling are a very important part of the modern design process. In the first and second years of a degree, 2D drawing is taught. During the second year, basic 3D modelling techniques are taught, built on the techniques from 2D drawing. During the final year, as part of the resources previously mentioned, there will be a library of advanced 3D solid modelling techniques in the form of videos, tutorials, examples, and step by step instructions. Many of the more difficult advanced techniques will be demonstrated in class followed by a formative assessment carried out by individual students rather than working in teams. This will provide assurance that everyone can learn the advance techniques. This library will be continuously updated based on the requirements of the assignment design problem and student feedback on their requirements.

8.3.5 Student Research (Constructivism)

The library of resources mentioned above should assist students in their design process. The difficulty is that no matter how large this library becomes, it will never be able to cover every design possibility. The combination of resources required for each design could produce an infinite number of unique resouces. It is critical to teach design students how to develop their own resources and methods to solve problems.

In our early years students were often taught things by ‘rote’. Newton’s Third law. ‘For every action there is an equal and opposite reaction’ rolls of the tongue easily and can be learnt by children as young as four. This is learning without understanding, there is no depth to the understanding, so is often referred to as ‘surface learning’.

The author came across an example of this type of learning many years ago when he was teaching in a college. The class was engineering science and as part of a calculation the students were required to determine the cross-sectional area of a tube. It was important for the students to find the correct method for their-selves. All but one in the class was successful and achieved the correct answer. Without showing the student how to find the answer as it would be better for him to find it out himself, different suggestions were tried to direct the student to find the answer. Eventually it was necessary to show the student how to do it. The student summed up the situation when he said, 'but I have never been shown how to do that'. It is not possible to show students how to do everything as the options would just be too great. It is important to teach them the principles which can be used as building blocks for future projects. This is the principle behind constructivism (Petty, 2004)

Constructivism is where students construct their own meanings, usually out of their prior learning and experience which would also include any instruction they receive. This can be illustrated by a story called 'Fish is Fish' by Leo Lionni (Petty, 2004):

A little fish and a tadpole shared the same pond. They were great friends and played together every-day. One day the tadpole grew legs, and his tail began to disappear. Eventually the tadpole turned into a full-grown frog and left the pond. Days and weeks passed, and the little fish wondered where his old friend had gone. Then one-day the frog jumped into the pond and told his friend the little fish about all that he had seen. 'Like what?' the little fish asked. 'Like birds' the frog said. He went on to describe birds as having wings and two legs. Fig. 55 shows what the little fish pictured in his mind.

Content removed due to copyright reasons.

Figure 55 What the Little Fish Saw (Petty, 2004)

The little fish learned using constructivist methods. He used his knowledge gained through his experience to try and understand what a bird is. Unfortunately, his experience was limited, he saw a bird as a flying fish with wings and legs. This illustrates well how constructivism is applied but also shows how it can direct someone (the little fish) to the wrong conclusion (Johnson, 2016).

Successful learning happens by a process of individual hypothesis making where the student builds or constructs their own knowledge. What does it mean to fully grasp a new topic and be able to successfully use your learning? Benjamin Bloom an American educationalist developed what became known as Bloom's Taxonomy (Fig. 56), with a spectrum of skills or tasks.

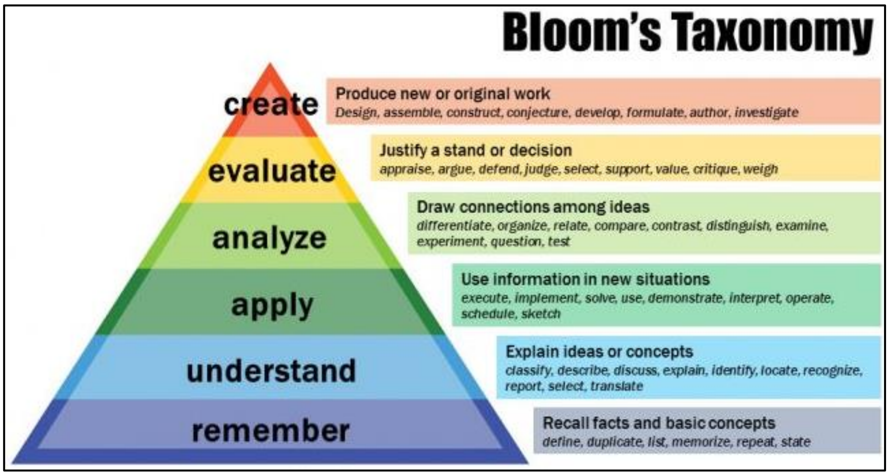

Figure 56 Bloom's Taxonomy (Armstrong, 2020)

Working through Bloom's Taxonomy from bottom to top. Each of the six sections are skills such as the ability to recall, explain etc. The first three sections, remember, understand, and apply are lower order skills. These skills can be taught directly but can be considered as the building blocks required to develop the higher skills required in real life and by designers.

Remember: State, recall, define, describe. An example given earlier was of Newton's Third Law which can be learnt by children as young as four.

Understand: Explain, interpret, classify, describe. The knowledge can be explained in terms of your existing learning and experience (see Fish is Fish above). You cannot understand something you do not know hence why 'remember' is required first. Understanding can only be fully achieved once higher-level skills are learnt.

Application: Apply, use, calculate, punctuate. Doing after being shown. A calculation can be demonstrated by a teacher and then a similar question is then attempted by the student.

The next three sections or skills are, analyse, evaluate, and create. These are higher order skills and are used in real life and require a student to make deep meanings and connections.

Analyse: Classify, compare, give reason, give causes and effects. This is breaking a complex whole into parts and then looking at the parts in some detail.

Evaluate: Solve a problem that is not routine. Write an essay, report, criticism, or argument. Design a leaflet, poster, presentation. Give constructive suggestions for improvements in a new situation or case study. Design a policy or strategy or device. Create a hypothesis. Create new ideas. Requires the student to decide how to do the task and must use whatever skills, knowledge, experience, and other learning that is relevant to the task.

Create: Make a judgement about an activity, policy, plan or argument, etc. such as an historical view or event, scientific experiment, economic policy, or mathematical solution. Comparing and contrasting two related ideas. Evaluation includes learners evaluating their own work while doing it, or after completing it. Evaluation usually involves giving strengths and weaknesses, arguments for and against, while considering evidence, bias etc.

8.4 Anderson and Krathwohl (Bloom's) Taxonomy Application

Bloom's Taxonomy has been updated many times. The latest is Anderson and Krathwohl (2001) making cognitive processes, when related to chosen instructional tasks, easily documented, and tracked and changed the original nouns to verbs.

8.4.1 Part Time Students

The application of Anderson and Krathwohl's Taxonomy will be made divided between part-time and full-time students.

Part time students are usually in appropriate mechanical engineering employment, hence why they are part-time. As such they are gaining experience from their work. This could be over several years. This experience will provide the knowledge and understanding that Bloom's suggest is required in the early stages of learning.

The last assignment for module 6ME500 Advanced Engineering Design Modelling during academic year 2019/20. The task was to produce a design for a worm and wheel. Table 58 provides the typical steps a student may go through:

Table 58 Anderson and Krathwohl's Taxonomy (Part-time Students)

Taxonomy	Application
Remember	A few may recall a worm and wheel from previous or recent experience. Some may recall parts of the worm and wheel, bearings, gears, keyways, manufacturing methods, materials, lubrication, casting etc.
Understand	A few will understand the principles behind the involute gear and gear development. Some may understand the different types of bearings and the type of loadings i.e., axial, thrust, or combination of both. Types of lubrication i.e., oil or grease, limitations in manufacturing methods such as casting, milling, and turning.
Application	Ability to put the above applications together in one assembly. Basic design completed with all major parts together and with complete or limited operation. Check 6 degrees of freedom have been met for each part and required inputs and outputs achieved.
Analyse	Review the parts individually to make sure they operate correctly, can withstand calculated forces, are lubricated appropriately. Make sure that the design meets all required specification.
Evaluate	To evaluate the design to determine if improvements can be made, new ideas considered, latest technology used.
Create	Based on the previous evaluation, create a new design of worm and wheel using possibly novel ideas, techniques, methods, assembly, manufacture, materials etc.

Anderson and Krathwohl’s practical application for part-time students as shown in Table 59 works well. This is because part time students are usually in appropriate work and have been building up their knowledge of basic engineering. They are not at the bottom of the taxonomy but have a head-start which gives them something to build upon. As their knowledge will not only be specific to the company they work for, but also general, they will be able to apply it in many applications and areas.

8.4.2 Full Time Students

The difficulty arises when turning to full time students. Most of these will have come from either a full-time college course or completing their A levels in school. They have not had the opportunity to build up relevant mechanical engineering knowledge. When faced with the worm and wheel design they are often not even at the bottom rung of Anderson and Krathwohl's Taxonomy. This problem is worse for students on direct entry into the third year of a degree programme as they will be coming from many different educational backgrounds that may not provide the degree of education students receive when entering a degree course in year 1. Without the required engineering knowledge and understanding students have difficulty interpreting the design challenge. They will not understand even the most basic design features. To illustrate, the gear, on the worm and wheel, will require fixing to a shaft. What methods can be used? Key and keyway, straight pin, tapered pin, circlip, coupling, shrink fit, brazing, welding, grub screw, split pin, and shaft shoulder are just some of the options available. Students need to know about each method, their strengths, and weaknesses to make an informed choice. They will naturally begin to research the options. Most will look to the WWW. The amount of miss-information available on the web makes it a dangerous place for students. Keys and keyways are sometimes shown on the www with square ends. This is possible to produce but would only be used if it was necessary to the design. If students apply the acronym SMALL CAPS (see section 8.2) this will help in their selection of information.

8.5 Reverse Engineering

The problem faced by full time design students; making sense of a design problem while having very little engineering knowledge is very similar to that faced by design engineers who are given a competitor's design and tasked with producing a version of that design for their own company. This is known as reverse engineering or product dissection.

According to Dieter & Schmidt, (2013), reverse engineering is the dismantling of a product to determine the selection and arrangement of component parts and to gain an insight about how the product is made. This is normally carried out using a physical artefact. The reverse engineering process includes four activities. Listed with each activity are important questions to be answered (Table 59).

Table 59 Reverse Engineering Stages

Stage	Activity	Questions
1	Discover the operational requirements of the product.	How does the product operate? What conditions are necessary for proper functioning of the product?
2	Examine how the product perform its functions.	What mechanical, electrical, control systems or other devices are used in the product to generate the desired functions? What are the energy and force flows through the product? What are the spatial constraints for subassemblies and components? Is clearance required for proper functioning? If a clearance is present, why is it present?
3	Determine the relationships between parts of the product.	What are the major sub-assemblies? What are the key part interfaces?
4	Determine the manufacturing and assembly processes used to produce the product.	Of what material and by what process does it appear that each part is made? What are the joining methods used on the key components? What kind of fasteners are used and where are they located on the product?

The operational requirements (step 1) are carried out when the product is fully assembled. After step 1 the product will require disassembly. It is a good idea to record as much detail as possible so that it will be possible to reassemble the product if necessary.

The reverse engineering process will show a design team what the competition has done. It does not explain why the choices were made. It is important that the assumption is not made that the product in front of them is the best designed product the competition could produce. Other factors may have influenced the design other than the physical description of the product, such as, cost, and national preference.

To be successful in reverse engineering requires a broad knowledge in multiple disciplines according to Wang, (2016). These disciplines are:

- Applying a knowledge of mathematics, engineering, and science in data analysis and interpretation.
- Using techniques, instruments, and tools in reverse engineering applications.
- Conducting appropriate experiments and tests to obtain the necessary data on reverse engineering.
- Identifying, formulating, and solving issues related to reverse engineering.
- Understanding legal and ethical responsibilities pertinent to reverse engineering.
- Assessing and evaluating documents and fostering attainment of objectives of a reverse engineering project.

8.5.1 Reasons to Reverse Engineer

Over time and due to developing technologies, there are several reasons why reverse engineering is used.

1. Legacy Components. – For components that were designed and manufactured years ago, there may not be any existing drawings, or existing drawings may not be complete in all the required information to manufacture.
2. Original Equipment Manufacturer (OEM) issues. – The OEM may no longer be trading or has lost the original drawings.
3. Design Development, Part Testing & Analysis. – Through 3D scanning a component can be analysed and remodelled.

4. Competitor Analysis. – To analyse a competitor's components to determine how and why it was manufactured.
5. Bespoke and Ancient Object. – Where there is only the physical component to gather data on or the component does not conform to standard geometric shapes. Reverse engineering using 3D scanning will make it possible to produce an accurate model.
6. Modern Manufacturing. – Modern methods such as Additive Manufacturing rely on reverse engineering.
7. Digital Archiving. – Museum pieces and historical artefacts can be captured through 3D scanning and the data can be held for future generations.

When students and design engineers are presented with a design problem, no matter what their previous experience has been, usually the first thing they will do is to look for examples of existing products. This helps them start the process of understanding the problem. Most reasons given above would apply.

8.6 Applying Anderson and Krathwohl's Taxonomy with Reverse Engineering

In Table 60, Designing a Worm & Wheel Drive System has Anderson and Krathwohl's Taxonomy in reverse order with some adjustments. Alongside the Taxonomy, are the main steps used in Reverse engineering. This method of supporting Full-time students will apply equally well with Part-time students. Using the example from above of the design for a Worm and Wheel.

Table 60 Designing a Worm & Wheel Drive System

Step	Student's Application	Anderson and Krathwohl's Taxonomy (2001) (Reversed Order)		Reverse Engineering (Dieter and Schmidt, 2013) (Normal Order)	
			Application	Activity	Questions
1	Carry out general research into solutions to the design problem	Create	Create a hypothesis as to why certain features were used in the design, decide on the benefits brought to the design. Why were materials used and what would be their main properties?	Research Internet, Library, Books, Technical Papers, Journal Papers.	
2	Compare & evaluate possible solutions	Evaluate	Evaluate different designs with each other to determine where improvements have been made, new ideas considered, latest technology used.	Discover the operational requirements of the products.	How does the product operate? What conditions are necessary for proper functioning of the product?
3	Carry out analysis of forces acting on individual components, How & why are parts assembled, discuss alternatives?	Analyse	Review the parts individually to make sure they operate correctly, can withstand calculated forces, are lubricated appropriately. Make sure that the design meets all required specification. Workshop visits, library of parts.	Examine how the product perform its functions.	What mechanical/electrical, control systems are used in the product to generate the desired functions? What are the energy and force flows through the product? What are the spatial constraints for subassemblies and components? Is clearance required for proper functioning?
4	Outline required assemblies and sub-assemblies, and detail possible methods used.	Apply	Ability to put applications together in one assembly. Basic design completed with all major parts together and with complete or limited operation. Check 6 degrees of freedom have been met for each part and required inputs and outputs achieved.	Determine the relationships between parts of the product. Decide on appropriate assembly methods with guidance from lecturer.	What are the major sub-assemblies? What are the key part interfaces? How are key parts assembled? Define appropriate assembly processes.
5	Review manufacturing processes and affect assembly and assembly components may have on method selection.	Understand	Based on research, review existing systems again and critically appraise their manufacturing and assembly potential.	Determine the manufacturing and assembly processes used to produce the product.	Of what material and by what process does it appear that each part is made? What are the joining methods used on the key components? What kinds of fasteners are used and where are they located on the product?
6	Use 3D solid modelling to apply assembly techniques and check detailed operation of design	Remember	A few will understand the principles behind the involute gear and gear development. Some may understand the different types of bearings and the type of loadings i.e., axial, thrust, or combination of both. Types of lubrication i.e., oil or grease, limitations in manufacturing methods such as casting, milling, and turning.		What type of fit is required? Will the assembly method allow correct transition of forces?

The above example, named Reverse Taxonomy, combines Anderson and Krathwohl's Taxonomy and Reverse Engineering. When correctly applied will assist Full-time students in the design process and their understanding of the problems to be solved. Full-time students would begin a design project by looking at complete systems and breaking them down into smaller components, trying to apply understanding and reason to each part.

8.6.1 Reverse Taxonomy Application

Staying with the above application of designing a Worm and Wheel and putting ourselves as an imaginary full-time design student:

1. Create. Use WWW to search 'Worm and Wheel'. Find as many examples as possible and try to determine their basic operation. What is the input and output? If these were reversed, would it still operate? What type of gears are used?
2. Evaluate. Compare the differences between the designs of Worms and Wheels. Why did the designer select one feature and another designer a different feature? What improvement or gain did the change achieve? What forces will be created in the designs and where may their maximum values be found?
3. Analyse. Break the Worm and Wheel in to its smaller parts. This system will probably have the following: wheel-gear, worm-gear, bearings, shafts, seals, and lubrication. Understand the purpose of each part, the forces acting through them.
4. Application. How are the individual parts assembled? What fixing methods are used? As an example, the wheel-gear is mounted on the shaft. What method is used to fix the axial load of the gear so that it does not turn on the shaft; splines and keyways are two popular methods. What, then stops the wheel-gear from sliding along the shaft; circlips, shaft shoulders are two popular methods. What type of bearings are used which will be determined by the loading the bearing is subjected to?
5. Understand. Putting the knowledge built up from the previous stages the design engineer should begin understanding the requirements of the Worm and Wheel. Details such as types of bearings, seals, circlips etc. can now be looked up in

commercial catalogues if they are standard parts or detailed drawings can be produced if a custom designed part. The individual parts can be modelled using industry standard software to confirm their correct operation.

8.6.2 Application to Module 6ME500 in Academic Year 2020/21

The design challenge for students on the 6ME500 Advanced Engineering Design Modelling module for academic year 2020/21 is to design a hydraulic engine lift. Students searching on the WWW will find examples to choose from. Fig. 57 is a typical design that students will find. What kind of questions should they be asking?

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Figure 57 Engine Hoist (Alibaba, 2023)

1. Create. What controls the lifting and lowering?
   Why is the arm adjustable?
   Why are the two front feet long?
   What is the purpose of the bracket at the end of the chain?
2. Evaluate. How will the engine weight be distributed during a lift?
   Why are two braces fixed on the top?
   Why are there 6 wheels?
3. Analyse. What type of hydraulic cylinder is used?
   What size bolts would be required, and which would have the greatest load?
   What type of hydraulic control system is used?
   How is the arm adjusted and then locked?

4.	Application	How is the metal tubing fixed together? What bearings will the wheels require? How does the geometry of the lift alter as the arm rises? What physical size will be required?
5.	Understand	Does the design meet fully the design specification? Will it meet or exceed the customer's expectations?

Full-Time students will require assistance in answering of the questions in section 8.6.2 above. They must be guided, using the principles of Reverse Engineering and Reversed Taxonomy. This will reduce the knowledge gap, but more was required.

8.7 Earlier Modules

It would make little sense to try and reduce the knowledge gap of Full-Time students only in the final year of a degree. Modules taught in Foundation and years 1 and 2 were studied. Were there opportunities to increase the knowledge of Full-Time students from the first day they started their studies at university?

All modules were reviewed with a view to adjusting the curriculum to increase their basic engineering knowledge. Several adjustments were made to different modules and implemented from academic year 2017-18. This will be an ongoing process, repeated each year.

8.8 Chapter Summary

Table 58 shows the basic engineering knowledge of Full-Time students when compared with Part-Time students reduced from 49% in academic year 2016-17 to 14% in academic year 2020-21.

Changing the curriculum in modules taught earlier in the degree programme and applying the principles of reverse engineering alongside reversed taxonomy have both improved the library of knowledge of Full-Time students. A 14% difference is still significant but much better than the 49% when the problem was first identified. To assist full-time students to reduce the gap even more, this thesis suggests the application of Bloom's Taxonomy Reversed.

CHAPTER 9

NATURE OF BLOOM'S

(Objective 4 Section 1.2.2)

9.0 Introduction

Bloom's Taxonomy has been used in teacher education for many years and has been updated many times. It has been translated into 22 languages and is the most widely applied, and most often cited reference in education (Forehand, 2005). This chapter will look at some of these updates to determine if they can better be used in the Reversed Bloom's Taxonomy being developed in this thesis.

Bloom developed three Educational Objectives or domains, knowledge-based goals (cognitive), skill-based goals (psychomotor), and affected goals which relate to moods, feelings, and attitude. To illustrate the difference between the three Educational Objectives. A student may be required to select an appropriate bearing for a design. Knowing the different types of bearing would be a knowledge-based goal, correctly fitting the bearing, would be a skills-based goal, and caring that the correct bearing is selected is an affected goal as the student values, attitude, or interests can be affected by the course. This thesis, in part, is researching the knowledge-based goals.

9.1 Bloom's Taxonomy (1956)

During a 1948 Convention of the American Psychological Association, discussions led Benjamin Bloom to spearhead a group of educators with the task of classifying educational goals and objectives (Forehand, 2005). Benjamin Bloom, Max Englehart, Edward Furst, Walter Hill, and David Krathwohl published, in 1956 a framework for categorising educational goals: Taxonomy of Educational Objectives. This became known as Bloom's Taxonomy. Taxonomy was a word that Bloom selected and is synonymous with 'classification'.

The framework consisted of six major categories: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. These categories are often depicted as a stairway. Students are encouraged to climb the stairway leading to a higher level of thought. Each level is subsumed by the higher levels. It is assumed that a student working at the 'application' level will also have mastered the material at the 'knowledge' and 'comprehension' level (Forehand, 2005). Knowledge was required first, after which 'skills and abilities' could be developed. Knowledge was considered as 'simple' with each category increasing in complexity.

The six categories (nouns) in detail and applying each level of expertise to the example used earlier of selecting/fitting a bearing is shown in the box.:

Knowledge – Recalling subject specific information and more general universal information. Recalling methods, processes, patterns, structures, settings.

Identify some bearing types. Recall previous use and terminology.

Comprehension – An individual knows what is being communicated. Can use the knowledge without necessarily relating it to other material or seeing its fullest implications. Some interpretation and extrapolation.

Knows roller bearings are better in some circumstances than plain but not why. Can interpret and extrapolate data from sources but does not fully comprehend the data's full implication.

Application – Being able to deal with an idea or event, particularly a concrete situation.

Can select a bearing type based on forces acting on it (axial/thrust). Forces are determined from the design. Consider methods to mount bearings.

Analysis – Breaking down ideas into a hierarchy is made clear. Relationship between ideas is explicit.

Identify different bearing types based on their loads and application. Comparison of bearings, Strengths, and weaknesses. Comparison of different mounting systems. From experience, recall previous use.

Synthesis – Taking individual elements and parts and putting them together to form a whole.

Can link bearing types, forces acting on bearings, application of bearings. Possible bearing combinations are considered. Possible mounting methods selected.

Evaluation – Making judgments about the value of material and methods for a given purpose.

Determine correct bearing to use and make a judgement that selection is correct. Gather and apply external evidence to base judgement on. Selected mounting system correct and fit for purpose.

9.2 Anderson and Krathwohl Revised Taxonomy (2001)

In the 1990's, a former student of Bloom's, Lorin Anderson led a team to update the taxonomy, hoping to add relevance for the 21st century and make it more dynamic. In 2001, the group of cognitive psychologists, curriculum theorists, instructional researchers, and testing and assessment specialists published the revision. The changes were in three categories: terminology, structure, and emphasis (Irvine, 2017).

9.2.1 Terminology

Instead of 'educational objectives' which were nouns, they used verbs or 'action words' to describe the cognitive processes (Armstrong, 2010).

The six categories (verbs) in detail are (Forehand, 2005):

Remember – Recognising, recalling relevant information from long-term memory.

Understand – Constructing meaning from oral, written, and graphic messages through Interpreting, exemplifying, classifying, summarising, inferring, comparing, explaining.

Apply – Carry out or using a procedure through executing, implementing.

Analyse –Breaking material into constituent parts, determine how the parts relate to one another to produce an overall structure. Differentiating, organising, attributing.

Evaluate – Making judgements based on criteria and standards. Checking, critiquing.

Create – Putting elements together to form a coherent or functional whole. Generating, planning, producing.

Table 61 provides a comparison between the original 1956 Bloom's Taxonomy and the revised 2001 version.

Table 61 Terminology Changes

Bloom's 1956	Bloom's 2001
Evaluation	Creating
Synthesis	Evaluating
Analysis	Analysing
Application	Applying
Comprehension	Understanding
Knowledge	Remembering

9.2.2 Structural Changes

As with the original 1956 version, knowledge is the basis of the six categories. In the revised version, knowledge was broken down into a separate taxonomy. The four types of knowledge are:

Factual – knowledge of terminology and specific details and elements.

Conceptual – Knowledge of classifications and categories, principles and generalisations, theories, models, structures.

Procedural – Knowledge of subject specific skills and algorithms, subject specific techniques and methods, criteria for determining when to use appropriate procedures.

Metacognitive – Strategic knowledge, knowledge about tasks including appropriate contextual and conditional knowledge, self-knowledge.

The four types of knowledge, combined with the revised six cognitive processes helps produce a grid (Table 62 Revised Bloom's Taxonomy) which provides 24 separate cells. Table 62 was produced by Oregon State University and has hyperlinks for each of the 24 cells containing definitions and examples (Fisher, 2005).

Table 62 Revised Bloom's Taxonomy (Fisher, 2005)

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9.2.3 Changes in Emphasis

Bloom's Taxonomy is used by a far larger audience than the author's ever considered possible. The revised Taxonomy was intended for a much larger audience. The emphasis was placed on a more authentic tool for curriculum planning, instructional delivery, and assessment (Forehand, 2005).

9.3 Marzano and Kendall Taxonomy (2007)

Marzano and Kendall's taxonomy consists of 6 levels of difficulty. Each level of difficulty is sub-divided into process (Table 63).

Table 63 Marzano and Kendall Taxonomy

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(Marzano and Kendall, 2007)

9.4 Use of Bloom's Taxonomy

Bloom's Taxonomy provided educators with their first systematic classification of the process of thinking and learning. The six hierarchical categories each requiring achievement of the skill or ability before the next, more complex, one. Blooms provided the measurement tool for thinking.

Bloom's Taxonomy was designed as a one-way street. Students begin at the bottom category (knowledge or understanding) and work their way up. With the growing use of the internet, students searching for solutions to a design-problem often find themselves looking at a complex design solution without the required knowledge and understanding. The students have turned Bloom's hierarchy upside down or reversed it. This is more noticeable in full-time students as they lack the required underpinning knowledge.

9.5 Application to Thesis

The three taxonomies reviewed above all follow a similar pattern, a hierarchy of learning, but each has a different emphasis. The original Bloom's (1956) used nouns to describe its educational goals. Anderson and Krathwohl's (2001) revised theory used verbs. Marzano and Kendell (2007) combined these two theories into a more comprehensive theory that would be of use to a much larger audience.

All three taxonomies reviewed could be used by this thesis. Anderson and Krathwohl (2001) with its use of verbs most meet the needs of this thesis as it best fits the requirements of design engineers during their training and once qualified, in industry. Learning is a hierarchical process, building on previous knowledge. Design engineering is also hierarchical, building on known knowledge, methods, and designs. The methods used to teach engineering design to students will also be used once these students become qualified design engineers.

The breaking down of knowledge into four areas, factual, conceptual, procedural, and metacognitive will also assist this thesis in understanding the category of knowledge that full-time students appear to lack during their studies.

The original Bloom's theory (1956) and all subsequent updates use a hierarchy of knowledge. To develop a deeper understanding of a problem/issue/concern it is critical to build the understanding gradually. To completely understand something at one level before deepening that understanding to a higher level. This thesis agrees with these findings and does not look to develop its own Taxonomy of Learning and will leave this development to the specialists in those areas.

This thesis has identified a lower level of mechanical engineering knowledge in full-time students when compared with part-time students (see chapter 8). This lower level of knowledge leads students to search for complete complex design solutions on the internet without having the required knowledge to understanding them fully. By applying Bloom's in a different way, in a reversed direction, like reverse engineering, this thesis suggests that teaching of design to full-time students can be improved and help them overcome the difficulty having a lower level of mechanical engineering knowledge.

CHAPTER 10

INCREMENTAL CHANGES

COMPLEXITY

PREVIOUS ASSEMBLY

(Objective 4 Section 1.2.2)

10.0 Introduction

Different aspects of the design process are taught at various stages throughout the three years of a BEng (Hons) Mechanical Engineering degree. Following the suggestions from Bloom, Anderson & Krathwohl, Marzano and Kendall (chapter 9), the underpinning knowledge required to design successfully are taught throughout this time (chapter 8).

During the last year of the degree, students are expected to design a complex component and use all the knowledge and skills acquired in the previous two years to produce a design appropriate for the task. For the University of Derby (UK) this task is accomplished in module 6ME500 Advanced Engineering Design Modelling. For reasons set out in the thesis introduction (chapter 1) this module is not fit for purpose and requires changing to bring it in-line with modern design used in industry.

These changes will be introduced incrementally for the following reasons:

- Observe the effect of the changes on academic attainment.
- Provide specific feedback from students.
- Minimise any negative effects on the module.
- Gather feedback from industry professionals on the direction the module is taking.

Most of the incremental changes to the way design is taught, recorded in this and the next three chapters are already being employed in various academic institutions. Some changes are unique to this research and academia but are used by industry. It is not required that these changes be proven as most are already being used by industry, only that the changes work with students. This will be checked by surveying the students and checking the module results do not change significantly.

The latest forecast is that UK's engineering employers will need to recruit 182,000 people with engineering skills each year until 2022 (CTP, 2018). The estimates vary, but all official government data shows significant growth in the engineering sector.

One estimate is that one in six engineering employers found it hard to fill vacancies ranging from craft, technician, professional and managerial occupations. Design engineers have been found especially difficult to find and recruit (Department for Education and Employment, 2000). Industry is looking for graduates with the core skills of mathematics and science, enhanced with a firm grounding in the engineering design process (Newman & Whattley, 2003). Where will the engineering sector find these engineers?

To support industry, it is necessary for colleges and universities to train future design engineers. This requires a close collaboration with industry (Back & Sanders, 1998). Many graduates think that their university education did not prepare them for their current job (Sounding Board, 2015) (Johan, 2015). The methods taught in academia should match, as close as possible those methods that industry use, to be as realistic as possible. At the same time, colleges and universities must use a system that allows assessment of a student's ability to design.

10.1 University of Derby (UK)

The University of Derby (UK) is in the process of change, to update their methods of teaching mechanical engineering design so that upon graduation their students will have the tools and knowledge to allow them to begin their careers as mechanical engineer designers in industry.

Final year students on the BEng (Hons) Mechanical Engineering program are required to complete module 6ME500 Advanced Engineering Design Modelling. This requires meeting two criteria:

- Apply and critically evaluate the design intent and full parametric in assembly and use of complex modelling techniques.
- Design, model and analyse a component using FEA tools.

From criteria 1, what does 'complex modelling techniques' mean? During the 2014/15 academic year this term was accepted to mean, by The University of Derby (UK), the design of a Road Re-Claimer (Fig. 58). This machine removes the top surface of a road in preparation for a new layer of tarmac to be laid. During the following academic year, 2015/16, this was to design an Off-Road Buggy (Fig. 59) which is used for driving around sand dunes for pleasure. The designs for each included the chassis, suspension, steering, engine, gearbox, differential, and brakes. Each student was to design the whole vehicle.

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Figure 58 Road Re-Claimer (Lectura Specs, 2023)

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Figure 59 Off-Road Buggy (Beyaz Gazete, 2021)

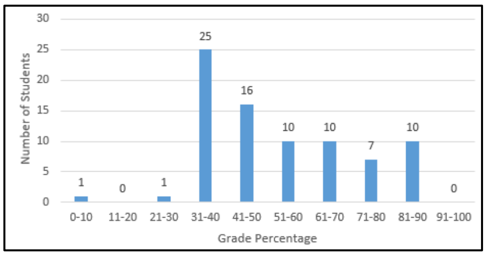


Figure 60 6ME500 Results 2015-16 (Sole, 2023)

A precise definition for ‘complex modelling techniques’ is yet to be developed. The closest term to it is ‘complex system’. This is a system comprised of a (usually large) number of (usually strong) interacting entities, processes, or agents, the understanding of which requires the development in the use of new scientific tools, nonlinear models, out of equilibrium descriptions and computer simulations.

A complex system should not be confused with a complicated system. An architect may design a complex building which is multi-functional but at the same time is not complicated.

The design of Figures 58 and 59 are complex and complicated. Industry would design these using a team of experts each concentrating on their speciality. From a basic sketch to a completed product could take around three years. Japanese car manufacturers are trying to reduce the time to 2 years. To expect students to do the same in 12 weeks is nonsensical.

When the grade profile for the 6ME500 module was examined for the 2015-16 academic year (Fig. 60) a high proportion of students achieved a grade between 31-40%. This was because many of these failed their first attempt and achieved the minimum 40% on their second attempt.

Student feedback was that in the allocated time, there was too much work to realistically complete. Most effort was used in producing a model with little time or thought to the quality or practicality of the design. The models produced were complex but were not designs that could be manufactured or capable of operating correctly.

Looking at the grade profile statistically, the distribution should ideally be a normal curve with standard deviation, shaped like a “Bell Curve” which the distribution in Fig. 59 does not meet (Teacherhead, 2013).

To closer parallel the industry process, it was decided to make the module assignment less complicated while maintaining the required complexity. By reducing the quantity of work, the quality would be to a higher standard.

10.2 Step 1.

From academic year 2016-17 the assignment was to design a lathe gearbox. To make the task less complicated, only three speeds were required, the torque was kept low, thus only spur gears would be required (Fig. 61). Detail in the assignment was kept to a minimum and so that students would make their own independent

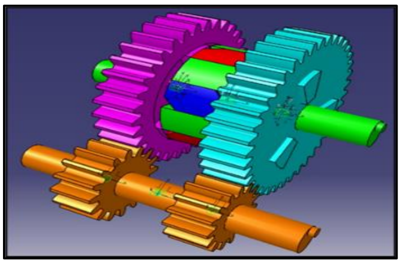


Figure 61 Lathe (Shopping, 2023)

enquiries. The students would develop novel solutions to the task (Junginger, 2007) (James-Gordon & Bal, 2003). The grade profile for academic year 2016-17 is shown in Fig. 62.

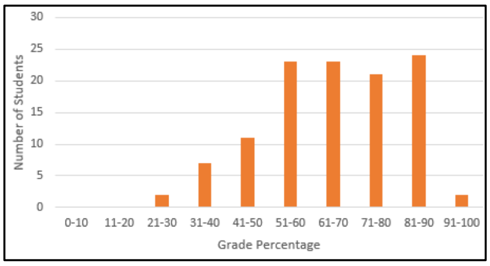


Figure 62 6ME500 Results 2016-17 (Sole, 2023)

The most significant result produced by step 1 above was to produce a grade profile that statically is closer to the normal curve with standard deviation. More students passed the assignment at the first attempt and had higher grades. Greater emphasis was placed on producing a working design that was backed up by application of science principles.

The solutions presented by the students were imaginative and detailed. Their reports show significant improvement in understanding of the engineering science behind their designs, material selection and design intent.

10.3 Step 2.

Large, complex designs can take years to bring to market. An example is the Boeing 777 commercial airliner. From the first component to be designed until first flight was over 16 years. To try and reduce this time the concept of concurrent engineering (Chen, 1998) was developed. In the case of the Boeing 777, manufacture began while parts of the aircraft were still being designed. Conversely, the design of many parts required them to fit existing parts produced earlier (Sabbach, 1996) by other design engineers. Many components once designed will then undergo many modifications, additions, and upgrades throughout their life. A vast amount of time is spent by design engineers working with existing components.

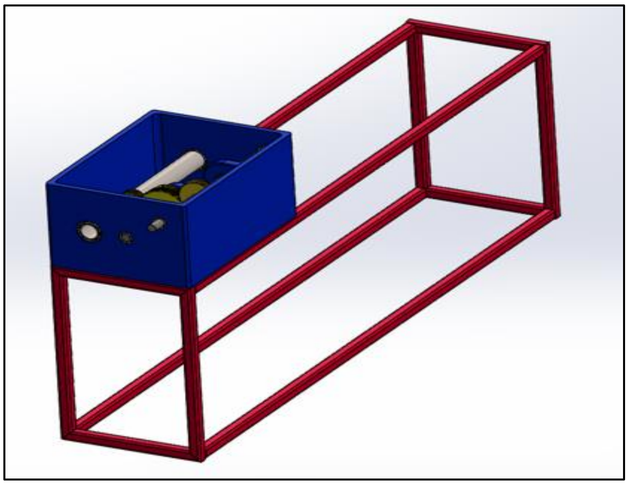


Figure 63 Partially Completed Lathe (Sole, 2023)

Rather than students start the design process with a clean sheet, they were given in academic year 2017-18, a partially completed centre lathe with a simple three speed gearbox based around the previous year's assignment (Fig. 63). The task was to design a pulley drive system and emergency brake mechanism. They could not alter the existing design unless they could present to the lecturer a compelling argument to do so, they could only add to it. Some specifications were provided such as motor power, motor speed and belt types. Apart from the constraints already mentioned, the design task was to be as open ended as possible to provide students with the widest opportunity to develop novel ideas (Burghardt & Hacker, 2004). Bloom's (chapter 9) suggest this method of learning, building on previous knowledge and designs will produce strong cognitive skills that will benefit the design engineer in the design process now and the future.

The grade profile for academic year 2017-18 is shown in Fig. 64. The grades were lower when compared to the previous year, but the normal curve with standard deviation was maintained. Anecdotally, the students found the task of designing to an existing part (the partial lathe) much more difficult than starting with a blank sheet. Most of the designs were sensible, novel, practical and were backed up with good application of applicable engineering science principles.

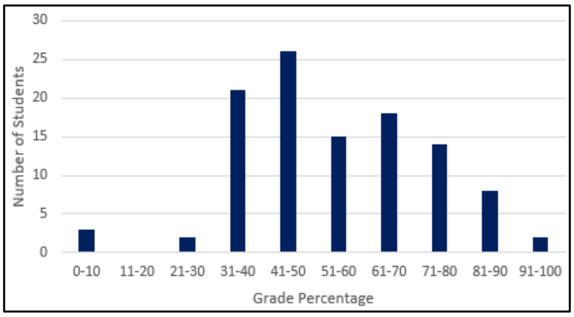


Figure 64 6ME500 Results 2017-18 (Sole, 2023)

The above changes were not to make students better design engineers but were to provide them with a much more realistic idea of the kind of design processes and systems they can expect after graduation and when they begin their careers in industry. Hopefully, their employability as design engineers will be improved.

10.4 Surveys

At the end of academic year 2016/17 and 2017/18 the students completing the 6ME500 Advanced Engineering Design Modelling module completed a survey. During academic year 2016/17 the assignment was simplified to single complex component, either a lathe gearbox or the differential on a car. During academic year 2017/18 a single complex part was still required, the drive mechanism and brake for a lathe. Instead of starting with a clean sheet the students were given a lathe gearbox and their designs had to connect to the existing gearbox.

A comparison of the survey results between these two academic years follows:

- **The Design Task was Easy**. The task was considered harder in academic year 2017/18. This was mainly due to having to design to an existing part.
- **The Design Task Encouraged me to Think on New Topics**. No change between the two years.
- **The Existing Lathe Model Made my Design Task Easier**. Could not compare with last year as the Assignments were different.
- **The Library Facilities Contributed Significantly to my Design Knowledge**. No change between the two years.
- **Fellow Students Helped in my Understanding of Design Problems**. No

change between the two years.

- **This Design Task Would be Better Completed as a Group Activity**. Both years were close but there is a slight increase in the number of students for year 2017/18 who disagreed with this. Students generally do not like group work. Their main concern is all group members completing an equal amount of work and grades being fairly administered.
- **Social Media was Used to Assist in this Design Task**. A significant increase In students who disagree with this statement. This is a surprise as students generally, prefer to use social media of their choice but most preferred not to share their thoughts and ideas with others in the class.
- **All of Your Design was Completed in the University**. No change between the two years.
- **Modelling Software Made the Design Task Easier.** No change between the two years.

10.5 Chapter Summary

For industry to maintain its competitiveness, many new mechanical engineers are needed each year, many of these will be design engineers. Many design engineers come straight from colleges or universities.

To train design engineers so that they can leave a college and university and be of maximum benefit to industry in minimum time, their training must reflect the needs of industry. The University of Derby (UK) is in the process of changing their assessment methods to closer match the requirements of industry.

The first two steps to reduce the gulf between the industry design process and that taught in academia have been made. An improved grade profile was noted that was closer to the normal curve with standard deviation. These results provide confidence that the changes made have benefited the students. The methods employed by The University of Derby (UK) have moved closer to the methods of design used by industry but without reducing or harming the grade profile. This process is not designed specifically to improve grades but to improve the methods used to teach and assess the University of Derby's (UK) mechanical engineering design process. If the grades of students do improve, then this is an added benefit.

The survey results were mostly as expected. The students found the task harder in academic year 2017/18 as they were having to design to an existing part. The preference to not using social media was a surprise.

As the title of this paper suggests, this is the first part of the process. Other changes will be required which future papers will be detailed.

The changes discussed through this chapter were validated, first by implementing them in a class of students studying their final year of a BEng (Hons) Mechanical Engineering degree. The implementation was successful providing confidence that the changes worked in a classroom session and did not have any detrimental effects upon the teaching and learning of the class. This was clearly indicated when students completed the surveys at the end of the semester. Secondly, these changes were discussed in interviews (chapter 7) with specialist lecturers teaching design at other HEI's in the UK. No issues or problems were highlighted and many of the ideas were viewed in a very positive way.

CHAPTER 11

INCREMENTAL CHANGES

GROUP WORK

(Objective 4 Section 1.2.2)

11.0 Introduction

Chapter 6 was a detailed investigation of the methods and techniques used in designing a component or system as used by the mechanical engineering industry. The methods and techniques had these things in common:

- A systematic approach.
- Time limited.
- Group activity.
- Use of specialists when considered necessary.
- Required constraints.
- Produce prototype (literal or virtual).
- Testing and evaluation.
- Consideration of manufacture and production.

To achieve the aim of this thesis, it would be good to incorporate as many of the above into the design process used by universities and colleges. This chapter will investigate each of the above and determine if they can be incorporated into the 6ME500 Advanced Engineering Design Modelling module as taught at The University of Derby (UK).

11.1 Group Activity

11.1.1 Advantages

What are some advantages of group working in industry and the benefits for students in education? The following is a list of the skills that group working will help to develop and which are transferable to employment.

- The ability to listen to others and evaluate different points of view. There may be some conflict, but once resolved, can lead to all following a common direction.
- More expertise is available in a group due to the variety of backgrounds

and experiences. Two heads (or more) are better than one and allow the sharing of ideas.

- Efficiency is improved when individuals in a group each work on an aspect of the design and then bring all the group ideas together.
- The development of cooperation and planning skills.
- The development of leadership and shared leadership skills.
- One member's weakness may be another member's strength.
- The ability to work on large and/or complex projects.
- Ability of several people to detect flaws about a solution or ideas. This helps eliminate errors and mistakes that an individual may overlook.
- The ability to work with individuals from a range of cultures and backgrounds.

(University of Auckland, 2018)
(Chris, 2015)

Group work is active. Students who are not willing to contribute in a classroom are more willing to contribute in small groups. Groups tend to support each member by peer-tutoring. A group can bring out much more in an individual when each member provides their part of the 'jigsaw'. (Petty, 2004)

The famous saying: 'the sum of the whole' from group work, 'is greater than the parts of the individual members'. When a group works well together it is more productive than the same number working as individuals.

11.1.2 Disadvantages

In industry the most important outcome of group design is the final product. In academia the important outcome is the final design along with individual input. The individual input to the task requires a grade. A grade that applies to the whole group would not be fair to apply to all the individuals of that group.

Petty, (2004) highlights some of the difficulties when using group work:

- Groups can go off in the wrong direction.
- Due to the different personalities within a group, differences of opinion can arise.

- More time planning and organising rather than completing the task.
- Groups can be hijacked by a determined individual.
- Some group members can become passengers. They rarely do what the group requests but reap the benefits and accomplishments from the entire group.

(University of Auckland, 2018)

(Chris, 2015)

The above difficulties can be addressed by correct class management and using appropriate assessment techniques.

11.1.3 Assessing Group Work

The dilemma that needs to be addressed is how to assess an individual's work while that individual is part of a group? It is important that the process be transparent, which means students must know what will be assessed and how it will be carried out. Frykedal & Chiriac, (2011) provide some interesting suggestions:

- Walk round and observe who was active in tasks and working well in the group.
- Assess group presentations and implement an individual assessment.
- A collectively produced assignment should not be assessed individually since it creates competition among students.
- Assessment of group work could be undertaken with help from students through self and peer assessment.
- Assessment from outside a group (by the lecturer) can be complemented by assessment from within the group (peer assessment).
- Logbooks provide a strategy to assess from within the group. The purpose of logbooks were to continuously write down and reflect on the group process to have a basis for the assessment.

11.1.4 Peer Assessment of Group Work

Meaningful assessment requires honest and critical feedback. Many students are reluctant to provide this information on their peers. The quality of peer assessment can be compromised by friendship, age, gender, ego, or self-esteem. To prevent bias, anonymity is required. With modern computer systems this is not a difficult task to achieve. One such is WebPa which is an open-source online peer assessment tool created by Loughborough University (WebPa, 2019). This allows students to give each in the group a mark based on individual efforts. A difficulty can arise if students think they are being marked subjectively by their peers, for example if one person falls out with the group but still does their part of the overall work. To avoid such problems clear marking guidelines must be prepared for the students so that there is no ambiguity about how they are being assessed.

Anonymity was also found to improve students' performance in peer assessment; anonymity does not necessary lesson students' perceived pressure and tension in peer assessment (Li, 2017).

The Business and Technology Education Council (BTEC, 2019) provide the following guidelines on assessing group work:

- Group work should only be used where one or more learning outcomes of the unit indicate that they might be appropriate.
- Learners should be informed, in detail and in advance, of the basis for assessment of group projects, including the methods to be used to measure the extent of individual contributions.
- If the group project requires skills or judgements beyond those required for the subject (peer assessment) then adequate training should be provided.
- If there is peer assessment of the contribution of the learners to a group, then the process for collecting feedback should be confidential between the individual learner and the assessor. If peer assessment includes the measurement of the contribution, the method should be clear and simple to use.
- A common group grade must not be assigned to all members of the group. Individual contributions should be measured and graded against the learning outcomes, the assessment and grading criteria.
- Evidence of observation of presentations and discussions (with peers, with assessors etc.) should be detailed and mapped to criteria to provide evidence of achievement of individual contributions.
- It is good practice to encourage learners to reflect on what they have learnt from the group work experience and produce a written evaluation.

- Feedback can be directed to the group with reference to individual contributions and achievement.

This chapter has been looking at peer assessment where students assess their fellow students in working as part of a team. This is encouraged by Race, (2001) who agrees with many things already cited. He goes on though, to make an interesting observation: 'peer assessment can provide greater validity of the assessment for some kinds of assessment, for example that relating to presentations, performances, practical competences. Group-based assessment can extend the range of assessment to include cooperative and collaborative skills. Race recommends that peer assessment of presentations be used along with self-assessment using the same criteria used for peer assessment. An interesting idea.To help convince students that the self-assessment and peer assessment is as valid as the 'real' lecturer assessment, race explains the need to clearly link the assessment with the learning outcomes of the module or programme. ArchMiller, (2017) introduces the reader to a method to maintain validity of the marking. The paper suggests having one paper in each group be peer assessed by someone outside the group as well as the lecturer also to review the assessment on another paper in each group. A calibrated rubric with examples was to be used for the assessment.

An area of group work that is of concern to students and their lecturers is the problem of 'free riding' and the difficulties of sorting out fairly the contribution of each group member. The only people who know what the respective contribution is, are the group members themselves (Delaney *et al,* 2013). If a group decides to 'carry' passengers, there is not much a lecturer can do about it. Sometimes, when students are not happy with a 'bystander', they are still reluctant to 'shop' the offenders and often unite to present a picture of agreement on the contribution of each group member. Race, (2001) make the following suggestions.

- Individual face-to face oral exams (or viva) either with the whole group, or with individual members.
- Provide the overall mark for the group work to the students and ask them to distribute it among the group members. Some groups will differentiate their contribution, others will divide it equally.

- How much of the mark the students are allowed to distribute will need to be decided? This is called the differential.
- Award a mark for the product of the group and ask the group members to peer-assess an additional mark for their contribution.
- Award an equal mark to each group member for the product of the group task, then add individual assessed tasks for each member of the group.

Much of what has already been written, Delaney *et al,* (2013) agrees with but goes on to make some interesting suggestions:

- Multiply the group mark by an individual weighting factor derived from the assessment criteria completed by the student's peers.
- Multiplying the group mark by the number of students in a group and ask the students to distribute the marks between themselves. Example, if the lecture awarded 70% for a group project, and if there were 5 in the group then an allocation of 350 marks would be given to the group members and they would then decide how the 350 marks would be allocated.
- A group mark plus or minus a mark for contribution using set assessment criteria.
- A combination of a group mark (the final output) and a mark for group work (The process) derived from peer assessment criteria, with the split not necessarily being 50/50.

Delaney *et al,* (2013) continues by criticising the most common method to adjust group work. This method consists of adjusting the group mark for each individual group member based on an assessment by their peers. Four different methods were assessed but each had things in common; each peer assessment was completed in hard copy; each used a point allocation system to distinguish the performance of group members; and each had 'contribution' as one criterion for assessment. The concern was the over emphasis on contribution. Each model looked at appeared to be an effective reward/punishment mechanism. This works and encourages individuals to participate in group work, but the suggestion is for a more prescriptive criteria for assessing students' teamwork skills. An opposite view was suggested by Sridharan *et al,* (2018). This was that peer assessment based on a survey with five criteria should be used. The criteria were:

- Completed his/her work in a timely manner.
- Provided constructive feedback to you on time.
- Guide the team to move forward by providing novel ideas.
- Made a quality contribution to the assignment.
- Behaved in a professional manner by treating team members respectfully.

These are very similar to the criteria used in the previous chapter. The ‘provide constructive feedback to you on time’ appears to be more for student/lecturer arrangement rather than peer to peer.

Heathfield, (1999) identifies two problems his students showed concern over first, fair allocation of grades for group work assessed items and second, student preparation for group work. The fair allocation of marks for each individual group member was to be achieved by adjusting the individual marks according to the contribution made to the group. The group should undertake peer assessment themselves using five indicators to measure individual contributions. These include regular attendance at group meetings, contribution of ideas for the task, reading and researching material for the task, organising, and analysing the material, as well as practical contribution to the product.

Lam, (2008) places strong emphasis on the importance of formative assessment. This should provide regular feedback to improve student learning, based on peer and self-assessment by students themselves and supplemented by lecturer guidance provided at the critical stages of briefing, sketch design and detail design. Compulsory formative assessment can be adopted to ensure students attend all feedback sessions to make the most of formative assessment.

11.2 Implemented Changes

For the 2018-19 academic year the main change to the assignment for module 6ME500 was the introduction of design as part of a group. A choice of two designs was offered 1) a mechanical screw jack for mechanical engineering students or 2) a car jack for motorsport students.

As part of the assignment the students were expected to select within their groups which of the two designs they were going to attempt. They also had to complete the following:

- A 10-minute group presentation on their basic design concept, specification and calculations.
- Carry out FEA on one part.
- Write a formal report of 4000 words.
- Complete a confidential report on each member of their group.

At the start of the semester, after the students were told that the module was to be a group activity several students raised concerns over individuals doing their fair share of the work and the final grades for individuals reflecting accurately the work and effort they put into the design. At the end of a twelve-week semester each individual student was asked to complete a survey on working within a group. This survey was to be used to address these concerns. The results can be seen in full in Appendix 3.

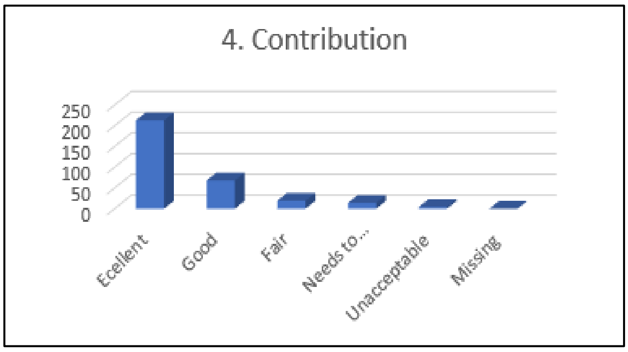


Figure 65 Student Survey - Contribution (Sole, 2023)

The main concern of students over group work was the contribution made by individuals. The results in Fig. 65 clearly show that most students (281 out of 318) thought the contribution of their peers was either Excellent or Good. The remaining 37 students thought the contribution was fair to missing. This is still a significant number which will need to be addressed.

The survey also asked the students to answer 5 questions. The questions and a summary of the student's replies is given below (Multiple student answers shown in brackets)

1. **Describe any communication problems within your group or describe how well members of your group were able to communicate with each other.**

<u>**Replies**</u>

Regular texts.

Use of Onenote (x2).

Regular chats on facebook (x2).

Met as a group many times each week other than planned lecture times.

No problems (x26).

Team of international students each speaking a different language. No failure in communication (x3).

Communication was perfect (x2).

Communication through phone, email, meetings.

Use of Whatappgroup (x9).

Minor problems at the start of the design as the design changed and wasn't communicated. Other than that, the team worked well.

Online dropbox used to collaborate files.

Maintained phone, text and skype communication.

Easy to communicate through social media channels.

Sometimes difficult to organise due to hectic weekly schedules and some non-attendance (x2).

Many clashes between group members.

Difficult to have good communication when separated from each during the day.

Communication started well, Emails exchanged, numbers given. As the weeks went past, group members stopped turning up for meetings.

The semester started with slow communication as none had ever worked together but all fell into a good rhythm.

<u>**Summary**</u>

Most students had no communication problems. Nearly every group used different social media platforms to maintain communication. A few difficulties were encountered in the first few weeks, mainly students finding how to work as a group and language difficulties with international students.

2. **Did you meet outside of class to establish goals and stay in tune with each other?**

<u>Replies</u>

Produced a project plan every week (x16).

Yes (x28).

Met 3 times.

No (x8).

Yes, every two days (x3).

Yes, every day (x2).

A few times (x8).

Frequently (x7).

Group members would not turn up at meetings (x2).

More meetings rather than just meet during lectures.

Not a lot.

Goals were established; however, members of the group were not in tune.

Not required to meet.

<u>Summary</u>

Most groups met outside of lecture times. At least 67 stated that they met differing amounts each week. Only 12 individuals said that they did not meet up outside of lecture time.

3. **What worries you the most when working in groups?**

<u>Replies</u>

Having the choice of who to work with in a group.

Having to carry someone (x46).

No problem with people pulling their weight (x9).

Lack of communication (x2).

Some dropping out (x4).

Sharing of information.

Different ideas from members can lead to a project becoming inefficient.

Due to different abilities the report may not flow.

Working on a group design that could be improved.

Not getting along or getting my views across.

Unfair grading from others (x3).

Producing work that does not match the groups criteria.

Having a team that has no interest in the project.

Lack of communication and initiative during meetings.

The different ideas.

Design.

That my work knowledge isn't up to standard.

Missing out stuff in the assignment.

Personality clash (x2).

Getting everyone in the same place at the same time.

Fear of people not doing enough.

Nothing.

Others not completing what they are asked.

Group members not taking responsibility and letting the group down.

Duplicating work.

If everyone will meet the deadline and have enough time to discuss before submitting.

People are different with different backgrounds and knowledge.

Not being listened to or feeling able to contribute enough to the success of the project.

Lack of effort and motivation from other members.

Summary

The greatest worry of group work was members of the group not doing their fair share of the work. 47 students expressed concerns even though 10 stated this was not a problem in their group. Quite a few expressed concerns over different problems with working with others, such as personality clashes, members dropping out etc.

4. **Did you think you did your fair share?**

Replies

Yes (x72).

Yes, but sometimes colleagues need help in their parts.

I did contribute quite fair, although I could contribute a bit more (x3).

The work was shared equally.

Struggled to contribute using SolidWorks, I did contribute more with research/CES/report writing (x2).

I believe some people could have done more work.

Doing all calculations and FEA analysis I do believe I have done more than others.

No, less than others.

More than.

Two people did not pull their weight and did the bare minimum.

Summary

The majority thought they had done their fair share (72).

Individuals did admit they could have done more. Others were concerned they had not done enough.

5. **Did others do their fair share?**

Replies

Yes (x59).

Majority of the group did.

Some did, some didn't (x2).

Some work submitted to the group was not feasible and needed to be re-modelled / re-written.

Yes, except for one (x4).

I believe some people could have done more work (x5).

Not everyone.

Mostly (x3).

Summary

The majority (59) agreed that everyone did their fair share. A very small minority thought a few group members could do more.

11.3 Grading Algorithm

At the end of the semester, each group would hand in their design model which included FEA, parametric design, and optimisation. Along with the model they provided a written report detailing decisions made as to design specification, hand calculations ideally based on two different mathematical methods which corroborate the FEA results, material selection, manufacture, cost, and research. The model and report were graded according to the grading rubric from the module criteria (Appendix 4). 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. Everyone was expected to participate in the presentation and answer questions from their peers and lecturer. The presentations were on the progress each group had completed on their designs up to this point, and then described future planned activities. Most groups chose to give their presentations using PowerPoint. Some brought examples that had been specially manufactured using additive manufacturing methods. 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 grade was not based on the designs as they were still in their early stages. 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 (Shenke *et al, 2021).*

The grading algorithm is shown in Equation 1.

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

Equation 1 Grading Algorithm

In practice, each member of the group would start with the same grade. This grade would then be adjusted to show the different amount of work individuals had completed based on the group peer assessment.

A difficulty arose from the Individual student work from the weekly Peer Review. How would absence be treated? If a student missed a week, the other group members would record, correctly, that their input was zero. This input could only apply to their missing the lesson for that week and would not include any work they may have done elsewhere, outside of classroom time. Unless a student missed many weeks it was decided to ignore individual absences of 1 week.

Another area of concern raised by students was the group size. A maximum of five was set, but it was left to the individual students to make their groups up. Some groups had only two. Students asked if group size was considered during grading as individuals in smaller groups would do more work than individual students in larger groups. As group size was the choice of the students, it was not considered in the grading.

11.3.1 Group Work Peer Assessment

At the end of 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'.

11.3.2 2018-19 Grades

The grade profile for academic year 2018-19 is shown if Fig 66. When compared to the previous year, 2017-18 the grades are higher and follow the normal curve with standard deviation better. The main influence on this is the introduction of group working. For most groups, the sum of their parts has proved to be better than the individual parts.

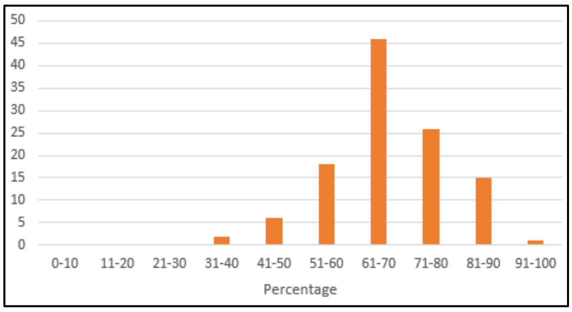


Figure 66 6ME500 Grades 2018-19 (Sole, 2023)

11.4 Chapter Summary

Working in groups to utilise 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 within the groups.

The changes discussed through this chapter were validated, first by implementing them in a class of students studying their final year of a BEng (Hons) Mechanical Engineering degree at The University of Derby (UK). The implementation was successful providing confidence that the changes worked in a classroom session and did not have any detrimental effects upon the teaching and learning of the class. The students clearly indicated this in the surveys they completed at the end of the semester. Secondly, these changes were discussed in interviews (chapter 7) with specialist lecturers teaching design at other HEI's in the UK. No issues or problems were highlighted and many of the ideas were viewed in a very positive way.

CHAPTER 12

INCREMENTAL CHANGES

ISSUES RAISED

(Objective 4 Section 1.2.2)

12.0 Introduction

The academic year 2018-19 saw several changes to the design module 6ME500. The assignment gave the students a choice of designing either a mechanical screw jack or a car jack for use in motorsport.

The biggest change was designing as part of a group. Students do not like working in groups. Their biggest concern is some members not doing their fair share of the work, and individual grades not matching the individual work input. The students selected the individuals to make up each group, and each group decided which design to attempt.

As part of a group, they were expected to give a presentation of their designs. This was early in the semester, week 4 so the designs would still be very early in their development, but would include the design concept, specification, and any calculations. This would receive an individual grade.

The students were requested, at the start of the semester, to let their lecturer know, immediately, if there were any problems within the groups. At the end of the semester the individual students were to complete a confidential report on each member of the group. The results are shown in chapter 11.

This chapter will look at any issues raised during the academic year (2018-19) and will seek to address them by making changes based on the research carried out in the literature review in chapter 2 and the research into assessing group work in chapter 11.

12.1 Issues Raised During Academic Year 2018-19

As previously mentioned, students were concerned that individuals in their groups 'pulled their weight' by doing an equal amount of work, and then received an appropriate grade. This was in fact, their greatest concern. The weekly log which all groups completed, some better than others, highlighted some very minor issues but nothing of significance. The survey completed by individuals at the end of the semester were mostly good. Only one group reported that they were not happy with the quantity and quality of the work completed by other members. It was explained to the students at the beginning of the semester, that to be able to adjust an individual grade based on the feedback received from their peers it would be necessary to see a pattern of weekly log reports to back up the survey at the end of the semester. As this did not happen, no action was taken against the accused students.

12.1.1 Weekly Log.

The weekly log will be redesigned to give greater priority to the work of individuals and any possible problems or difficulties. The importance of the weekly log will be emphasised to the students throughout the semester.

Each group received a group grade based on the report and model presented at the end of the semester. Each individual received a grade based on their presentation skills and the percentage of work reported in the weekly log. This system worked well but was not perfect. For the presentation, a maximum grade of 10% was available. The grade based on the weekly log was mostly around the 5% mark. When a comparison was made between the possible individual mark of 15% and the work individuals were doing as reported in the weekly log it was clear that the potential 15%-mark adjustment did not reflect the difference in work that individuals were completing.

12.1.2 Share of Marks.

The marks available for individual work was increased to a maximum of 30%. The 10% marks available for the presentation will stay the same. Another 10% will be available to individuals for completing a 500-word interim report and a final 10% for individuals producing an audio Powerpoint presentation with a maximum 5 slides and 10 minutes.

The SolidWorks models produced by the groups varied greatly. Some were detailed, well thought out and should function correctly. Others were quite simple designs, with little detail and were questionable as to their functionality.

12.1.3 Fully Defined

All SolidWorks models must be fully defined. This is a term used in SolidWorks. It means that all dimensions are recorded and come from a known datum. In a sketch, the drawn line will change from blue to black to denote it is fully defined. If parts are mated together to form an assembly, then the mates must also be fully defined. If a model is not fully defined then SolidWorks can produce errors, especially when trying to mate or join parts together.

12.1.4 SolidWorks Library of Parts.

Industry make use of all the tools available to it to help the designer get the best from there modelling. SolidWorks uses a library feature of standard parts that can be selected by the user. Typical parts are screws, bolts, nuts, washers, bearings, cir-clips, pins etc. Once a part is selected, its size is adjusted by the user to the requirements of the design. Once the size of the library part has been adjusted to the required size, it can be saved as a copy. SolidWorks also has a feature called 'Pack and Go' which will take all the related files for a model design (parts, assemblies, drawings, references, design tables, design binder content, decals, appearances, scenes, and simulation results) and gather these together into a folder or zip file. This system saves time for the designer who is not required to create these standard parts (SolidWorks, 2023). Use of any library parts, whether from SolidWorks or any other source will be allowed in the student's designs.

12.1.5 Group Size

The class was divided into groups of 4 or 5. The individuals making up a group were selected by the students. The selection process gave no surprises as most groups were made up from individuals that knew each other or in the case of part time students were work colleagues. In most cases this caused no problems. A few groups formed with less than the required 4. Some started with 4 but then reduced in size for various reasons. Some students complained that the smaller groups (less than 4) had more work to do per individual than the lager groups. If the group size reduces during the semester through no one's fault, then this will be considered during marking and the final grade for the group work will be adjusted.

12.1.6 Report Size.

The word count for the final report was set at 4000 ±10%. This is the same amount as previous years and is set by the universities standards committee. Most groups did not achieve this goal. With no penalty incurred if not met, many groups did not make a serious attempt to achieve it. Report size in industry is important as there is often not enough time to read very large reports. Large reports tend to deviate from the main topic and important issues, or points can be missed. It was also noted that some groups tried to circumnavigate the report size by putting text in the report as an image. Word processors will not count this in the word count. Excessive use of appendices, which are not added to the word count were also used. It was made clear in the assignment that a penalty will be incurred for breaking the 4000 ±10% word count including the use of methods to circumnavigate the requirement. Students need to develop the skills required to write accurately and succinctly.

12.1.7 Group Working Report

A successful product in industry is one that the consumer likes and so purchases and recommends it to others. The increase purchase of the product will be reflected in increased profits. The closes students get to this is the grade that their work receives. A difficulty in group work is that if all the students receive the same grade, then individual effort, or lack of, is not reflected in the grade. This can demotivate students or even encourage some student to 'freeload' or do the minimum work they can get away with. Last year (2017-2018) students were asked to complete a weekly report detailing the work everyone had completed and what percentage effort the group considered individuals contributed. This was put into an algorithm so students would understand how their individual grade was calculated. 75% of the grade was from the work completed as a member of the group, 25% from individual contribution. For this year (2018-2019), the contribution from individuals was increased to 30% and was derived from three separate inputs 1. Group presentation where everyone receives their own grade, 2. A 500-word report providing a rationale of their designs and an update on their designs, 3. A 5-slide Powerpoint audial presentation. The rest of the marks would come from the group report and 3D model. The grading algorithm from last year was updated and can be seen in Equation 2.

$$\left(\begin{bmatrix}\textit{Each group member}\\ \textit{receives the same grade}\\ \textit{from Report and design Model}\end{bmatrix}+\begin{bmatrix}\textit{Individual grade}\\ \textit{from}\\ \textit{presentation}\end{bmatrix}+\begin{bmatrix}\textit{Individual grade}\\ \textit{from}\\ 500\ \textit{word report}\end{bmatrix}+\begin{bmatrix}\textit{Individual grade}\\ \textit{from}\\ \textit{Powerpoint}\end{bmatrix}\right)\times\begin{pmatrix}\textit{Individual student work}\\ \textit{from weekly Peer}\\ \textit{Review}\end{pmatrix}$$

Equation 2 Grading Algorithm

12.1.8 Word Count.

As mentioned earlier, it is important for students to develop the skill of writing to specified word counts. The assignment requested a word count of 4000 words, ±10%. The assignment provides a list of the sections that would count toward the word count.

The reports were uploaded for marking using software called Turnitin. This software is designed to check for plagiarism. It was found that when the reports were downloaded to be marked, they each had three different word counts:

1. Total word count of every word in the report irrespective whether they were included in list of sections to be included in the word count.
2. A lower word-count once sections were removed that did not count toward the word count was subtracted.
3. A total word count from Turnitin which was substantially higher than the two-word counts mentioned above.

Some reports used images which included large amounts of text as a means of reducing the word count. Turnitin does not count images as text.

This issue will be addressed during the next academic year 2019-20.

12.2 Chapter Summary

The changes detailed above were implemented as part of the incremental changes to the 6ME500 design module. At the end of academic year 2018-19 an assessment based on student grades, lecturer input, student feedback from a confidential survey and student personal feedback given confidentially to the module lecturer.

The grading algorithm was updated to include changes to the marks available for individual work which will allow greater area for differentiating between individual students. The group size was increased to provide a larger diverse group profile.

The changes discussed through this chapter were validated, first by implementing them in a class of students studying their final year of a BEng (Hons) Mechanical Engineering degree at The University of Derby. The implementation was successful providing confidence that the changes worked in a classroom session and did not have any detrimental effects upon the teaching and learning of the class. This was corroborated by students in the surveys completed at the end of the semester. Secondly, these changes were discussed in interviews (chapter 7) with specialist lecturers teaching design at other HEI's in the UK. No issues or problems were highlighted and many of the ideas were viewed in a very positive way.

CHAPTER 13

INCREMENTAL CHANGES

500-WORD REPORT

5-SLIDE CRITIQUE

CUSTOMER SPECIFICATION

(Objective 4 Section 1.2.2)

13.0 Introduction

The academic year 2019-20 was the final year to introduce incremental changes to align as close as possible the design process used in academia with that used in industry.

13.1 Assignment

The assignment set for academic year 2019-20, working in groups of 4 to 5, mechanical engineering students were to design a mechanical worm and wheel while the motorsport students were to design a worm and sector (Fig 67 and 68)

Content removed due to copyright reasons.

Figure 67 Worm and Wheel (Roll Tex, 2023)

Content removed due to copyright reasons.

Figure 68 Worm and Sector (CBT, 2023)

The design criteria were kept to a minimum i.e., outside dimensions, input torque, gear ratio, and number of starts. This was to provide the students with maximum flexibility in their designs.

During week 4 the groups gave a 10-minute presentation of the basic design concept, specification, and calculations to their fellow students. All groups were considered combined into one large group to share ideas and thoughts. This received an individual mark based on the student's presentation skills.

In week 7 a 500-word report by each student was produced explaining the rationale behind their design and providing an update on the projects progress. The students received an individual mark.

In week 12, a Powerpoint presentation was completed and receive an individual mark. This was to describe the main calculations used.

Also, in week 12, a formal report (4000 words) and fully defined model would be marked as a group activity.

Once the module was completed, the students completed a confidential report on working in a group.

13.2 Incremental Changes

13.2.1 500-Word Report

Design projects in industry can run for a few weeks into years. Throughout this period, it is normal for the design team to regularly report back their progress to the customer or manager. This can be completed formally for long projects and often informally for short ones. Informal feedback can take the form of a simple conversation. As the projects encountered in academia are usually short (12 weeks for The University of Derby (UK)) it was decided that, individually, each student would report back on progress made informally. This would be a 500-word report explaining the rationale behind their design and providing an update on the projects progress. The format and detailed content were left to the individual to decide.

13.2.2 Individual 5 Slide Powerpoint with Audio Overlay

A difficulty encountered with group work is that individuals will volunteer to work on an area that they are naturally comfortable with. The areas individuals volunteered for first were 3D modelling, calculations, materials, and report writing. While concentrating on their preferred area they would neglect the other areas as individuals in the group would be working on them. It was decided that at the end of the semester, everyone would hand in a 5-slide Powerpoint presentation based on the calculations used throughout the design project. Calculations were selected as this was one of the harder areas of the project and so one of the least volunteered areas.

It was not possible to implement the audio overlay as planned as many students did not have access to the necessary hardware (microphone). The planned audio was added to the Powerpoint slides as notes.

13.2.3 Customer Specification

The last change was to select a design project that had a 'real world' customer specification. The customer could be an industry specialist, in which case the customer specification would probably be good; but it also could be from an amateur where the customer specification may be inaccurate or even have parts that could be wrong. It was decided to provide a customer specification that was small (only 4 criteria) but that could, arguably be wrong in places.

13.3 Group Feedback

After the 12-week semester was finished, students were asked to complete a confidential survey on the success or not of working in a group. The full results of the survey can be viewed in Appendix 3.

The main concern of the students, as in previous years was the level of contribution from individuals in the group. As in previous years this did not pose a significant problem as can be seen in Fig. 69. Over 200 students considered the contribution made by their peers was 'Excellent'. Another 40 considered the contribution of peers as 'Good'. Students did voice concern over two individuals they considered did not do their fair share. This was investigated and the attendance of one was found to be 52%. The marks of the two students were adjusted down to reflect their lack of contribution.

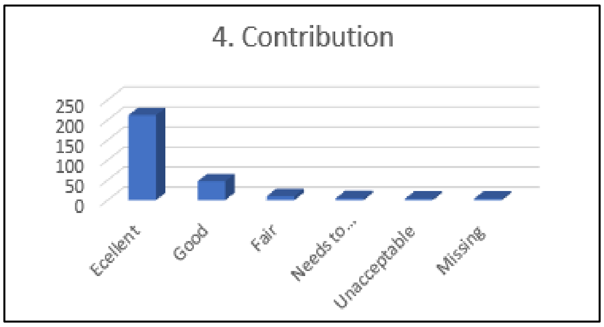


Figure 69 Student Survey - Contribution (Sole, 2023)

The survey also asked students to answer 5 questions. The question and a summary of the student's replies is given below (Brackets indicate number of multiple students replying):

1. **Describe any communication problems within your group or describe how well members of your group were able to communicate with each other.**

   <u>Replies</u>

   Communicated well with each other.

   Communication was generally good (x26).

   Absence from lectures by other group members made communication difficult at times (x3).

   Communicated mainly by arranging meetings at weekends (x5).

   Communicated via a Group Chat (x9).

   Used Email and Whattsapp (x5).

   Meetings at home.

   N/A (x3).

   Facebook / iMessage group.

   Group communications throughout.

   Some people did not entirely listen during group discussions.

   No problems (x3).

   Used a variety of platforms well.

   Managing communications outside of the university was hard.

   Managed files through Onedrive.

   Team folder set up in Microsoft Teams.

   One member not replying to emails or telephone.

   Used Microsoft Share Point.

Summary

Of those that replied, 26 said communication was good. 20 students said they used some form of social media to maintain communication. Very few comments that any difficulties were had in communicating with each other.

2. Did you meet outside of class to establish goals and stay in tune with each other?

Replies

Yes (x22).

Did once or twice a week (x11).

Met in the initial weeks. Later meetings were less regular.

Regular scheduled meetings (x5).

No (x4).

A few meetings were held at key points of the project.

Used social media to discuss the progress of the project (x5).

Had a couple meetings outside.

No physical meetings other than before a lecture.

Stayed late each day to set clear actions.

Summary

Most students (42) who replied to the survey said they met regularly outside of class. 4 had no meetings, 5 also had no meetings but used social media to maintain communication.

3. What worried you most when working in groups?

Replies

Conflict within the group.

A member doesn’t contribute (x25).

Out of individual control (x6).

Nothing (x3).

No, I find it comforting to work in a group (x2).

Choosing the right group members.

That a voice would be overshadowed and ignored.

Leaving all the work until the last minute.

Work being done to a level that was below what I would expect of myself.

Getting left out of work, not enough to go around.

People actioning tasks.

People's capabilities (x2).

Disagreeing.

Lack of teamwork.

Getting a time that suits everyone set up (x2).

Running out of time.

Lack of interest or communication.

Cooperation of each member.

Ensuring the vision and collective direction is clear and understood by all.

Letting others take their preferred roles, leaving me in a role I am uncomfortable with.

Some members cannot be relied on to be responsible for a section of work.

Having work not being used or doing all the work.

The unreliability of other members.

Summary

The concern of a large proportion of students was a member not contributing (25) even though many stated that this did not happen in practice. Most other remarks were expressing concern of their own contribution being listened to and practical problems of setting up meetings and group communication.

4. Did you think you did your fair share?

Replies

I believe I did contribute although I should have done more (x2).

Yes (x45).

More than my fair share (x3).

Summary

The majority thought they had done their fair share (45). Two individuals admitted they could have done more.

5. Did others do their fair share?

Replies

Yes (x46).

Some did some didn't.

Mostly yes (x5).

Summary

No issues were raised over the work of other team members.

13.4 2019-20 Grades

The grade profile for academic year 2019-20 is shown in Fig. 70. When compared to the previous academic year 2018-19 the grade profile is very similar and follows the normal curve with standard deviation better. The concerns most students have about group work, for the second year in a row are proved unfounded.

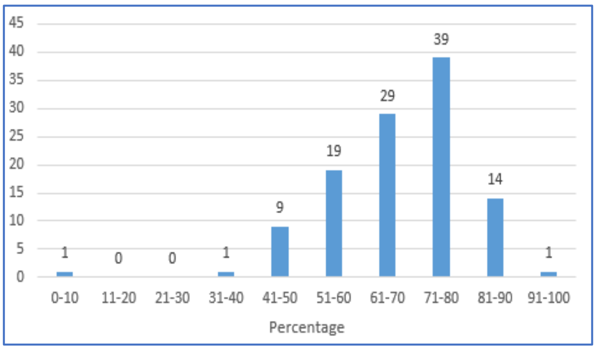


Figure 70 6ME500 Grade Profile 2019-20 (Sole, 2023)

13.5 Chapter Summary

The changes made to the design module 6ME500 during academic year 2019-20 brought the design process in academia closer to industry methods. There were no significant problems with the changes except the audio overlay which was replaced with notes added at the bottom of the slides.

CHAPTER 14

DISSEMINATION

(Objective 5 Section 1.2.2)

14.0 Introduction

An important part of this thesis is to disseminate the information, data, and findings to a wider audience of specialists in the field of engineering design. This will provide confidence that the research, interpretation, and application has been carried out appropriately and is accepted by industry and academic specialists.

The first stage in the dissemination process will be through two supervisors appointed by the University of Derby (UK) to oversee the PhD. These supervisors already have a PhD and a proven track record in appropriate research. With their assistance and guidance, the conference and journal papers are checked for accuracy of information and academic rigour.

Stage two was to present completed papers at selected design conferences. These papers, containing the main findings from the PhD, after being reviewed and approved by the PhD supervisors are then sent to the conference organisers to be peer reviewed. The review is anonymous to try and prevent bias. Once reviewed, and accepted, the papers are presented at the conference followed by a question-and-answer session. This session provides more feedback on the findings of the paper.

Stage three was to build on the conference papers by re-writing some of them into Journal papers. The anonymous peer review for journal papers is carried out with a much higher degree of criticality and rigour and are disseminated to a much wider audience of industry professionals.

Another aspect of dissemination is the building up of a network of colleagues from the same engineering design field. These colleagues get to listen to you, and you get to learn from them. This provides a wealth of specialist knowledge that can be applied to the research.

In chapter 15, the main learning outcomes from this thesis were disseminated to industry specialist. There responses are very detailed and helpful, hence why it has been given its own chapter.

The next section provides a summary of the conference and journal papers. This will include the paper title and abstract, any addition to knowledge, conference details, links to thesis section(s), paper reference, and any other appropriate information.

14.1 Completed Dissemination

<table>
<tr><td>Conference:
Engineering and Product Design Education (E&PDE19)</td><td colspan="2">E&PDE 2019
Conference 12th and 13th September 2019
Workshop 11th September 2019</td></tr>
<tr><td colspan="2">Paper Title:
No paper presented at this conference.</td><td>Date Presented/Published
Conference 12/13 September 2019</td></tr>
<tr><td colspan="3">Paper Abstract:
N/A</td></tr>
<tr><td colspan="3">Attendees/Reviewers/Committees
Representatives from education and industry with an interest in design education. The international scientific review board was made up of 111 members. 44 doctorates and 43 professors. 71 were international members. These were all from academia or industry.</td></tr>
<tr><td colspan="3">Contribution to Knowledge:
N/A</td></tr>
<tr><td>Paper Reference:
N/A</td><td colspan="2">General information:
First design conference attended.
Began networking and gaining insight on the research carried out by others in the same field as the research for this PhD.</td></tr>
</table>

Conference:

Engineering and Product Design Conference (E&PDE20)

Paper Title:

The Challenges of Teaching Design in the 21st Century, The Age of the Fourth Industrial Revolution

Date Presented/Published

11th September 2020

Paper 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 Third 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 in the future?

Attendees/Reviewers/Committees

Representatives from education and industry with an interest in design education.

The international scientific review board was made up of 111 members. 44 doctorates and 43 professors. 71 were international members. These were all from academia or industry.

Keynote speaker was Maiken Hillerrup Fogtmann, a senior design manager at LEGO Education that provides hand-on Science, Technology, Engineering, Arts, and Mathematics (STEAM) solutions for students and teachers.

Contribution to Knowledge:	
1. 90% Virtual teamwork, 10% face-to-face. 2. Grading algorithm for group and individual work. 3. Information source acronym.	
Paper Link: Link to Conference Paper	**General information:**

<table>
<tr><td colspan="2">Conference:
Festival of Learning – The University of Derby (UK)</td><td>UNIVERSITY OF DERBY</td></tr>
<tr><td>Paper Title:
Mechanical Engineering Design at the University of Derby (UK)</td><td colspan="2">Date Presented/Published
21st July 2021</td></tr>
<tr><td colspan="3">Conference Theme
Role of arts and culture in the work of a Civic university; A look at Derby CAN (Creative Arts Network), S.H.E.D. (Social Higher Education Depot) and Youth Future Leaders, projects that have changed the lives of young people, communities and artists in the city. The event will also feature the work of the Opportunity Area Inclusion Programme, which aims to increase the capacity and capability of mainstream schools to provide effective inclusion interventions and support vulnerable students.</td></tr>
<tr><td colspan="3">Attendees / Organisation
University of Glasgow, Adult Learning Australia, Guangzhou Open University, Harvard Kennedy School New England Alumni Association, The Centre for Haishan Research of National Taipei University, as well as many cities and municipalities.</td></tr>
<tr><td colspan="3">Contribution to Knowledge:
N/A</td></tr>
<tr><td>Paper Link:
N/A</td><td colspan="2">General information:
A presentation to an invited audience on latest teaching methods used for teaching design at The University of Derby (UK).</td></tr>
</table>

Conference: International Conference on Engineering Design (ICED21)	ICED 21 GOTHENBURG 16-20 AUG

Paper Title: Design Education – A Reversed Method to Fill an Information and Knowledge Gap Between Full-time and Part-time Students.	**Date Presented/Published** 16th – 20th August 2021

Paper Abstract:

Teachers in schools, tutors in colleges, and lecturers in universities are all required to have specific teaching qualifications. As part of the qualification, it is normal to study tried and tested pedological theories. Some examples are Bloom's Taxonomy, Constructivism, and Experiential Learning. This paper identifies a gap in the information and knowledge required of student design engineers studying on a full-time course, when compared to part-time students. To redress this gap, it is suggested that no new theories are required but just a new method of applying an old theory, the application of Bloom's Taxonomy in reverse alongside reverse engineering. An example of applying this method to a class of design engineers in their final year of a BEng (Hons) Mechanical Engineering is provided.

Attendees/Reviewers/Committees

The scientific committee was made up of 415 members, 34 from the UK, the rest international. The organising committee was made up of 14 members from Chalmers University of Technology in Gothenburg and the Department of Industrial and Materials Science. Also engaged with them were the Department of Technology Management and Economics and the Swedish Product Development Academy. The Programme committee was made up from 8 members from Chalmers and Strathclyde universities.

Keynote speaker was Professor Marco Cantamessa at the Department of Management and Production Engineering of the Politecnico di Torino, where he teaches Management of Innovation and product Development.

Contribution to Knowledge:	
1. Survey of basic mechanical engineering knowledge 2. Reverse Engineering and Reversed Bloom's Taxonomy	
Paper Link:	**General information:**
Link to Conference Paper	N/A

Conference: Engineering and Product Design Conference (E&PDE21)	
Paper Title: Mechanical Engineering Design, Does the Past Hold the key to the Future.	**Date Presented/Published** 8th – 10th September 2021

Paper Abstract:

Industry design of a complex product has always required a cross-disciplinary team of experts. Is it possible to mimic these teams in academia when training the design engineers of the future, and what disciplinary skills will they possess? The exceptional collaboration potential provided by the internet means industry experts can work as a team, and at the same time, reside anywhere in the world. What are the capabilities of teamwork when the team members may never see each other for real? Though a physical prototype is sometimes required, most prototypes are designed and created in the virtual world using 3D modelling. The model can be tested, checked for accuracy, have materials applied, and be created parametrically which allows the product's geometry to be reset to different sizes by the designer. Collaboration, effective communication and 3D modelling make it possible to design intricate and complex designs remotely. It is right to congratulate ourselves on the complexity of modern design and how clever designers have become, designers must not lose sight of past achievements. Design has become more complex in this modern age, but it would be incorrect to say that complex design did not exist in times past. Before the internet, aircraft were built, global communication systems existed, men went to the moon. What can be learned, if anything, by looking at the methods used to design complex products in the past? How can design engineers apply what they learn from the past to the future?

Attendees/Reviewers/Committees	
Representatives from education and industry with an interest in design education. The international scientific review board was made up of 111 members. 44 doctorates and 43 professors. 71 were international members. These were all from academia or industry. Keynote speaker Christian Bason, CEO of the Danish Design Centre. He is a leading international authority on design, innovation, and leadership in business and government.	
Contribution to Knowledge: 1. Requirements for hand-calculations 2. Group work - Regular meetings, allocation of responsibilities	
Paper Link: Link to Conference Paper	**General information:** N/A

Journal Paper: Design & Technology – An International Journal	Design and Technology Education: An International Journal
Paper Title: Mechanical Engineering Design, Learning from the Past to Design a Better Future	**Date Presented/Published** February 2021

Paper Abstract:

The economic importance of design, and design engineers to the success of a company has led to the exponential growth in the demand for qualified design engineers. To fill this demand, colleges and universities provide the best training available so that, after graduation these engineers will provide significant input from the first day of work. Today is known as industry 4.0 or the 4th Industrial Revolution, where computer power rules and takes on greater tasks, freeing up time for the design engineer to design more and more complex designs.

Sometimes, it is good to stop, and take a breath to review our practices and remind ourselves of things that may have been forgotten. It is true that designers can design complex mechanisms and systems, in times past many of these would not be possible. But what can be learned or be relearned of good practice by taking a journey through some of the design methods from the past. This paper will travel back to the 2nd century BC and look at cutting edge water pump design and the importance of a good literature review. It will highlight a serious gap in knowledge when comparing full-time and part-time students in our modern age. Airship design will be reviewed, the R100, R38 and R101 to remind us of the need to cross check design calculations. Looking at the beauty of Concorde design will remind us of the requirement in any design of good planning and regular meetings. This journey will finish by looking at the design process of the Boeing 777 commercial airliner, one of the first designs to use Computer Aided Design (CAD) and Computer Aided Manufacture (CAM). The use of Design Build Teams (DBT) with cross-disciplinary experts who can reside anywhere in the world will be considered. The reviewed historical examples may at first glance appear happen-stance but are in fact linked, and demonstrate a continuing growth in the ability, knowledge, complexity, and techniques of engineering design.

This step back in time will remind teachers of some basic principles when teaching design to future design engineers. Designs have become more complex in this modern age, but it would be incorrect to say that complex design did not exist in times past. Before the internet, aircraft were built, global communication systems existed, men went to the moon.	
Editors and Readers Provides a broad and inclusive platform for all aspects of Design and Technology Education and Technology Education in primary, secondary, and higher education sectors, initial teacher education (ITE) and continuous professional development (CPD). The mission is to publish high quality research, scholarly and review articles at the leading edge of development theories and practices of Design and Technology Education that increases insight, support understanding and add to global discourse.	
Contribution to Knowledge: 1. Importance of sketching 2. Requirements for hand calculations 3. Design teams	
Paper Link: Link to Conference Paper	**General information:** N/A

Conference:

NordDesign 2022

Paper Title:

Sustainable Design: When to Use a Virtual or Real Prototype to Most Benefit Your Students?

Date Presented/Published

16th – 19th August 2022

Paper Abstract:

After reviewing the main environmental areas of concern today, this paper will focus on waste management within the area of sustainability. For many years, as part of the design process, physical prototypes were necessary. This was in order to prove a design‘s functionality and safety. They were expensive, time consuming and, by todays standards wastful. Often, once production began, they were scrapped. The necessity of a physical prototype outweighed all environmental considerations. In the 21st century, with the growth in Computer Aided Engineering (CAE), physical prototypes have nearly been replaced with virtual prototypes. The evidence is overwhelming as to the benfits of virtual prototypes to designers, designs and the environment. This paper will research and identify an area where physical prototypes are still beneficial, that of educating design engineers. A survey of mechanical engineering students over 5 years will identify a significant difference in the basic engineering knowledge of full-time engineering students when compared with their part-time colleagues. The use of physical prototypes can help reduce this difference. This paper argues that physical prototypes, under certain conditions, can reduce waste and still be sustainable.

Attendees/Reviewers/Committees

54 International reviewers from universities, Institutes of Technology, Polytechnics, and Design Schools. Keynote speaker was Toke Malm, design engineer at Dyson, UK. Past five years has worked on New Product Innovation with James Dyson the company founder.

Contribution to Knowledge: 1. Virtual and physical prototyping requirements 2. Survey of basic mechanical engineering knowledge	
Paper Link: Link to Conference Paper	**General information:** N/A

14.2 Knowledge Gained

The conference papers, presentations, and journal papers in this chapter are the results of five years research, application, testing, and trials. Learning at the early stage of this thesis may have been superseded by more informed learning later. Some things tried in the classroom may work in practice, better than other things. Here is a chronological list of the things learnt over the last few years, based on the above papers, starting from 2019.

14.2.1 Engineering and Product Design Education Conference 2019

- Importance of design and design engineers to the financial health of a company.
- Difficulty of recruiting good design engineers.
- Today, is the fourth industrial revolution (Industry 4.0) where design methods are led by computer systems.
- Modern design is a team approach as many different skills are required.
- Design teams can often be physically together, as in small companies, but are more often working virtually, based all over the world.
- Sharing of design ideas and close links with the customer are essential.
- The needs for design engineers and the criteria that academia work to will never be 100% matched.
- Developing a grading algorithm to grade individuals when working as a team.
- Development of an acronym to guide students when research on the internet.

14.2.2 Festival of Learning 2021

- The lack of full-time student's basic engineering knowledge when compared to part-time student.
- Development of a theory based on reversing Bloom's Taxonomy to help address the identified knowledge gap.
- Benefits and limitations of 3D modelling software especially when used in teaching design.
- Application of Reversed Bloom's Taxonomy and theory of Reversed Engineering.

14.2.3 International Conference on Engineering Design 2021

- Research into basic engineering knowledge between full-time and Part-time students with survey results conducted between 2016 and 2021.
- Further development of theory based on Reversed Bloom's Taxonomy and Reversed engineering with practical application of students.
- Correlation of theories developed from Bloom's Taxonomy.
- Table comparing Reverse Bloom's Taxonomy and Anderson and Krathwohl's Taxonomy written in 2001.

14.2.4 Engineering and Product Design Education Conference 2021

- Most design is innovation rather than invention.
- Calculation of forces in design is critical and should be validated with recalculations using different methods.
- Boeing 777 was first complex design to use computer software to produce 3D components and assemble them together as a virtual prototype.
- Computer modelling can reduce errors in design, such as interferences by up to 95%.

14.2.5 Design & Technology – An International Journal

- Looking to the past to remind ourselves of good practice. Philo's and Hero's force pump example of innovation and benefits of sketching in early design and the need for a thorough literature review.
- Airships R100 and R101 very good example highlighting the importance of calculations in design.
- Tragedies of the airships R38 and R101, both designed by the same team who put little emphasis on calculations.
- Concorde is an excellent example of international teamwork in an age before the internet made virtual teamwork extremely easy.
- Reminded again the benefits of computer modelling in design and the enormous benefits. Example of Boeing 777.

14.2.6 NordDesign 2022

- Importance and necessity of sustainability in design.
- Physical prototyping has nearly been replaced with virtual prototyping.
- Virtual prototyping brings many advantages to the design engineering and helps reduce waste.
- Physical prototyping can still bring short and long-term benefits to engineering design students.

14.3 Peer Validation

The conference and journal papers listed above (section 14.1) were peer reviewed and accepted as correct and accurate by industry experts and academics.

The conference papers, after passing the peer reviews were presented at the conference. After the presentations, the author was questioned by industry experts and academics to clarify any uncertain points from the presentation or paper. This process adds confidence that the papers are correct and accurate.

A journal paper requires a much higher level of scrutiny by peers and industry specialists and so provides a very high level of confidence in the papers being accurate and correct.

Table 64 lists the contribution to knowledge that was included in the conference and journal papers.

Table 64 Contribution to Knowledge

Grading algorithm for group and individual work.
Information source acronym.
Survey of basic mechanical engineering knowledge.
Reverse Engineering and Reversed Bloom's Taxonomy.
Group work - Regular meetings, allocation of responsibilities.
Design teams.

14.4 Chapter Summary

A combination of examples from the past, combined with modern-day examples from industry have built up a detailed picture of the requirements to design a complex component or system in this modern age. Reminders to be thorough in calculations, benefits of teamwork, theory to assist full-time students build basic engineering knowledge, benefits of 3D modelling software along with some limitations, importance of a thorough literature review. This knowledge, when combined, will enable the University of Derby (UK) to teach future design engineers ready for the challenges in this 21st century.

CHAPTER 15

INDUSTRY VALIDATION

(Objective 6 Section 1.2.2)

15.0 Introduction

The changes made to teaching mechanical engineering design at The University of Derby (UK) require to be validated. This was achieved in three parts.

1. Changes were introduced systematically and incrementally into the classroom (chapter 10–13) and the results monitored to determine their effect upon teaching and learning and student grades. Feedback was gathered from students using Module Evaluation Questionnaires and the National Student Surveys.

2. The methods developed to teach mechanical engineering design were disseminated to a wider, professional audience. This was through peer reviewed conference and journal papers (chapter 14).

3. An overview of the methods used to teach mechanical engineering design were sent to industry specialist and their comments invited as to how applicable the methods were to those used by industry.

15.1 Industry Validation Method

The research methodology selected for the required industry validation was based on the model Saunders Research Onion (Saunders *et al,* 2019) and will use an interpretivism epistemology, emphasis on qualitative analysis over quantitative, deductive from general to specific changes in teaching methods. Action research of the specific issue around teaching mechanical engineering design using industry methods, and cross-sectional time as this validation will be reviewing the change in methods up to this point in time.

15.2 Documents Supplied to Industry Design Specialists

An overview of the design module as taught today was provided to the industry design specialists. These documents covered practical aspects of teaching design such as class organisation, presentations, communication skills (Table 65) and pedagogy such as group working, number and type of lessons, student support, informal and formal report writing (Table 66) of the design module. Comments were invited on how well or not design at The University of Derby (UK) matched the requirements of industry. The replies are provided verbatim in Appendix 5, followed with a detailed analysis, and where appropriate future application.

Table 65 Module 6ME500 Advanced Engineering Design Modelling - Practical Application

No	Application	Rationale
1	Design assignment complexity	The design assignment (a complete vehicle) was not realistic for a 12-week semester and was reduced to a **manageable size.** This year (2021-22) the design challenge is to design a miniature gearbox and attach it to a small electric motor (supplied item). This will fit inside a car wing mirror to allow the mirror to be adjusted.
2	Work in groups of 4/5 week 1	A large proportion of complex design is completed by Design Groups. **Group work** is required more and more by industry. The design module 6ME500 lends itself very well to be completed as a group.
3	Groups to be formed by student's week 1	Preferred option was to assign students to groups based on their strengths. This had a few difficulties: • Many students are direct entry to the final year of the degree, their strengths were unknown. • Logistical difficulties – student body is made up of full-time, part-time, some sharing accommodation, international working from home, and motorsport. Assistance to join a group was provided by lecturer if required.
4	Group presentation week 4	A **group presentation**, very early in the design process was given by each group. This gave: 1. The group clearly understood the design challenge and to redirect if required. 2. To check the design groups were working well together. 3. To grade their presentation skills. 4. All groups were considered as one large group for the sharing of initial ideas. 5. Provide confidence for each group to hear and see the work of others.

5	Informal individual report week 8	To check individual students' **communication skills**. This is equivalent of updating managers on the progress of the design, informally and verbally. To carry this out verbally, logistically was not possible. The verbal changed to written as this would also provide required proof.
6	5 Slide critique week 12	At the end of the design challenge, this gives individual students an opportunity to critique theirs and the groups work. This will hopefully be a balanced **critique** of strengths and weaknesses.
7	4000-word formal report week 12	All individuals in the group are to participate in writing this report. Individual input is decided by the group. Content to be student decided but expect to have at least specification, calculations which corroborate the FEA results using ideally two different mathematic methods, materials, assembly, 2D drawings.
8	SolidWorks model week 12	A **fully defined** model to include parametric, FEA, materials, optimisation.
9	Grading algorithm	The distribution of grades between individual and group work was determined using a simple algorithm.

Table 66 Module 6ME500 Advanced Engineering Design Modelling – Pedagogical Application

No	Application	Rationale
1	General	The students will be supported for **1 hour per week face to face lesson** followed by a second **1 hour, invitation only** to groups for a face-to-face session with the lecturer. **2 Hours pre-recorded** session updated each week to match design requirements and students identified needs. Most of the work will be completed **virtually** with students arranging meetings as required. Differentiation - Support for full-time students required as their basic engineering knowledge when compared with part-time students is significantly less. Application of 'reverse engineering' techniques found useful and is a developing theory. Lecturer available by email 7 days a week to answer any questions.

2	Design challenge complexity	Earlier design challenges were asking students to do too much within the 12-week semester. Because of this they spend 90% of their time modelling. The 4000-word formal report was squeezed in at the end. The **reduced complexity** allows the time to be spent on checking the designs functionality, meeting the specification, researching, calculating, and working on the 4000-word report.
3	Work in groups of 4/5 week 1	Students to be guided in working in groups and any conflict management that may be required.
4	Groups to be formed by student's week 1	Groups will naturally be made up between friends. This can have some advantages but may also mean that some specialist areas (materials, calculations, 3D modelling) may be weak for some groups. Students to be supported by providing **tutorials** (pre-recorded, live sessions, written) in specialist areas throughout the semester. **Group meetings** with lecturer to try and identify any areas where support may be required.
5	Group presentation week 4	Required presentation skills demonstrated by lecturer from week 1. Lecture on presentation skills and their grading.
6	Informal individual report week 8	Writing **concise and accurate**. Ability to explain clearly, and unambiguously complex design issues.
7	5 Slide critique week 12	Application of **critical thinking skills** on own and group members contribution. Critique on design, what they think went well, what could be improved.
8	4000-word formal report week 12	Requirements of **formal report writing** (abstract, contents, citation and references, bibliography etc). Writing concisely, and ability to display and use data accurately.
9	SolidWorks model week 12	Pre-recorded videos of advanced SolidWorks. Opportunity to attend level 5 SolidWorks class to cover the basics (if required). Tutorials available for advanced SolidWorks features. Class demonstration to answer any student questions.
10	Grading algorithm	This was determined, originally by research followed by minor adjustments until the correct balance between individual and group work was determined.

15.3 Industry Specialist Replies

The verbatim replies from Industry Specialist on the information provided in Tables 66 and 67 are in Appendix 5.

15.4 Analysis

The comments from the industry design specialist generally agreed with the practical and pedagogical decisions made when teaching design at The University of Derby (UK). The comments from each industry design engineer will now be analysed in detail.

John Sulley - Rolls-Royce Associate Fellow, Nuclear Component Design & Performance.

1. **COMMENT.** ‘The key thing is the design thinking behind the modelling. In Rolls Royce they have separate designers and modellers. Your different approach should help produce designers, not CAD modellers’.
   ANALYSIS. The emphasis was switched from the model to the design, presentations, working as a group and producing a detailed professional report. The 3D model is still required and is an important part of the assignment but has been given a lower priority. The aim is not to produce CAD modellers, our aim is to produce designers. The emphasis of the design model is now correct.

2. **COMMENT**. ‘Fully support group working. Getting it into their psyche that design work most commonly involves a joint effort’.
   ANALYSIS. Student’s dislike group work. They are concerned primarily that some members of a group will ‘coast’ and not do their fair share of the work. In practice, by far most students participating in group work have a positive experience. Industry’s demand is for group work. Groups in industry are formed based on individual expertise. This is difficult to achieve in academia as individual expertise may not be known. Students generally form their own group. Individuals in the group usually select which area of the design process

they are comfortable completing. They are, in fact, volunteering as the expert in that field, thus mimicking industry very closely.

3. **COMMENT**. 'I think your critique week is very important. The key thing is students being able to take constructive feedback and develop. A good suggestion was Always Assume Positive Intent'.

   ANALYSIS. It is important that students can accept and give constructive feedback. This is a very important so that students can develop their skills and grow as a design engineer. Part of constructive feedback involves honest self-reflection which will decide how they apply that feedback. Students at The University of Derby (UK) are tasked with producing a 5-slide critique using Microsoft Powerpoint. In describing the critique, it is important to make it clear that this is not a negative thing. It should be a balance between 'things that went well' and 'things that didn't go as well as expected' The suggestion of 'Always Assume Positive Intent' will be used next academic year as it is catchy but makes the point very well.

4. **COMMENT**. The report must show 'have they fully captured the requirements' and 'have they demonstrated they have met the requirements'.

   ANALYSIS. The first part of this comment, 'have they fully captured the requirements' is dealt with in two ways. Very early in the design process, (week 4) students give a group presentation on their design ideas to their peers. Even though their ideas are in their infancy, it is good to check that their understanding of the design problem is correct and started out on the correct course to solve it. Any corrections required at this stage are easy to make compared with further down the design process. Secondly, in week 8 individual students are expected to provide a 500-word informal report updating the customer (university academic) on the design process. This provides time to make any adjustments, if required to the design.

   The second comment, 'have they demonstrated they have met the requirements' is satisfied with the main emphasis being on the 4000-word report handed in during week 12. This report is to provide evidence that the design requirements have been met. This is then backed up further by the 3D model which will demonstrate the operation or function of the design.

5. **COMMENT**. 'The most important thing a designer should have, is grasping the concept of parameter variation and positioning parameters away from 'cliff-edges' in performance'.

   ANALYSIS. Part of 'have they fully captured the requirements' (see comment 4 above) is to decide what Factor of Safety (FOS) is required. A part for an aircraft may require a very small FOS to keep the design mass to a minimum. Opposite to this may be a design for a lifting device (forklift, crane) which will require a much larger FOS. It is important that designers understand how close or far from the 'cliff-edge' they set their designs. Get it too small, and a design may fail in service prematurely, too large and costs could spiral. To make this even more difficult, some designs may have parameters that vary, which will make the 'cliff-edge' vary. This subject is covered in class, but it may be beneficial to review this coverage to determine if it is adequate or requires improving. Some practical examples will assist students to understand the issues involved.

Muhammad Ahmad Majeed khan - Design Engineer

1. **COMMENT**. 'Maximum support is provided'.

   ANALYSIS. The time allocated to lectures and tutorials is under constant review. Some topics require and are given more time. Students can request one-to-one teaching if they find a topic difficult to grasp. It is important to get the balance between supporting students and providing them with the tools to complete their design assignment.

2. **COMMENT**. 'Idea of working in groups is excellent'.

   ANALYSIS. Group work is generally disliked by students but loved by industry. Modern design requires many areas of expertise that would be near impossible to find in one person. Working in groups makes this possible. For group work to be successful, students will require learning more skills, sometimes referred to as 'the softer skills': Group management, conflict resolution, people management, work allocation, criticism of self and others, leadership, planning etc.

3. **COMMENT**. ‘I would rather have chosen groups myself’.

   ANALYSIS. Students selecting their own group is popular and usually involves friends selecting friends. This doesn’t necessary mean that a strong (in terms of expertise) team will be formed. However, the team probably will be strong working together. Groups formed in industry would normally be based on individual expertise. A student may be expert in certain areas but generally, stronger groups will be formed based on friendship rather than expertise.

4. **COMMENT**. 5-Slide critique, ‘Very good in my view’.

   ANALYSIS. The taking and giving of criticism is important for the personal development of students. It is also a good thing when directed at the design. It may be necessary to direct students on appropriate criticism so to achieve the greatest benefit to them and the design.

Reece Matthews - Design Engineer and NVQ assessor Rolls Royce.

1. **COMMENT**. ‘Overall, I think the scope of the module looks good, and I believe there is a good combination of individual and group work to challenge the students in a project representative of industry’.

   ANALYSIS. The scope of the module was difficult to get right as the balance between individual work and group work required a few trials until it was correct. This is an ongoing consideration as different design challenges will require slight changes in the scope. It is important for students to learn how to prioritise not just the workload but what to leave in and what to leave out, the scope. This scope is shown most in the 4000-word report which could easily be much bigger. The challenge is to write succinctly and to the point, a professionally written, technical report.

2. **COMMENT**. Suggest ‘DfX (Design for Manufacture/Assembly/Lifecycle). Ask the students to initially design for a specific production quantity (low volume) then as part of the formal report ask how they would adapt the design for mass production’.

ANALYSIS. A good suggestion that will be added to the assignment for academic year 2022/23. The 4000-word report should still detail the low volume design as it is important for students to demonstrate their understanding of the design problems and how to solve them. Adding a section on things to consider when designing for high volume will make it possible for students to demonstrate their understanding of issues high volumes will raise.

3. **COMMENT**. 'I believe the interim report should be verbal and should be audio recorded as evidence'. This will address a 'shortfall on students softer communication skills…this is a key skill students will need to bring into the workplace'.

   ANALYSIS. This is an interesting suggestion. The interim report is the 500-word individual, informal report written for week 8. It is academia's equivalent to an informal conversation with an employee's line manager, bringing them 'up to date' on the progress of the design. Academia requires this 'conversation' to be recorded in some way as marks are awarded to individual students. The informal report causes interesting reactions from students as they are taken outside their comfort zone. They are used to formal reports, informal needs to be learnt. The suggestion that this be recorded is good and would be the preferred option as it is closer to the informal conversation required. The logistical aspect of recording is difficult as most years the module attracts over 80 students. To carry out over 80 recordings within a 12-week semester would require too much time that should be spent on the design.

4. **COMMENT**. 'Need to ensure that face-to-face aspect is maintained as physical meetings if possible as this builds key softer skills which online meeting does not develop'.

   ANALYSIS. Throughout the semester regular group meetings with the lecturer are arranged at least twice, more if any issues are raised. Each week, two hours are scheduled as face-to-face with the lecturer. Individual meetings can be arranged at the request of students. Physical meetings with individual students are important as softer skills can be developed, any issues or concerns dealt with. It is also important that students develop the ability to work on their own initiative either as part of a group or individually. The balance of how much individual support is not correct now and needs to be addressed. Individual students require more one-to-one assistance. This will be reviewed for the next academic year.

5. **COMMENT**. 'Who do the group present to in the 'group presentation'? This presentation should be made to peers as well as assessors to allow students to experience and learn from their peers' shortfalls'.

   ANALYSIS. The group presentation in week 4 is made to the lecturer and peers. At the presentations end, peers are encouraged to ask questions and discuss any thoughts they may have. This is followed by questions from the lecturer. Even though the presentation is early in the semester and progress in the students' designs may be limited, an opportunity to redirect the design path, if required, can be made. This is often accomplished by the discussion between the group and peers, with little intervention from the lecturer. This is a very successful learning opportunity for the students.

6. **COMMENT**. 5-Slide critique week 12. 'Agree, ensure that the students critique their approach as well as outcome'.

   ANALYSIS. The critique by the students was a general critique, leaving them to select the critique areas. Most critiques did cover the approach and outcome, but it will be good to mandate this for future students.

7. **COMMENT**. SolidWorks model week 12. 'Optional exercises should be given along with pre-recorded videos so students can assess their competence before deciding whether optional classes are necessary'.

   ANALYSIS. Pre-recoded videos have an advantage that students can access them at a time that is convenient to them and can be paused at any time allowing students to attempt the next part of the exercise. It will be logistically possible to provide optional exercises live in class if the complexity of the exercise was monitored as live SolidWorks can be a very time-consuming exercise.

8. **COMMENT**. Work in groups of 4/5 Week 1. 'Students should set themselves individual roles within the team, each with their unique accountabilities) project manager, Sub-System Leads etc)'.

   ANALYSIS. This is a good suggestion. Most groups select a group leader and volunteer for areas they are confident to complete. Accountability is an area that hasn't been considered so far. What type of accountability and how they would be administered is something that requires exploring? This could cause more problems than it solves but is worth investigating.

9. **COMMENT**. Group presentation. 'Frame this around the standard design structure. This presentation should be focused on 'Understanding Requirements', students should be encouraged to keep things holistic at this stage, focusing on functionality and not jumping to solutions. Presentation should be timed to align with this stage in the programme'.

   ANALYSIS. Students are subject to jumping to conclusions even though the design is at a very early stage. Some will have decided the whole design without any research, consideration of requirements, group discussions on other possibilities. This should be a time of considering all possibilities no matter how 'mad' they may at first appear. At week 4 the emphasis will be on a holistic approach rather than final designs.

10. **COMMENT**. Informal Individual report. 'Why would verbal not be possible? Within industrial NVQ, audio recorded 'Professional Discussions' are key required evidence. Students assigning themselves roles would be beneficial here as each student would need to put a different slant on their report (avoid plagiarism)'.

    ANALYSIS. This is an interesting suggestion, carrying out 'Professional Discussions'. May be difficult with student numbers but will be looked at. One possibility would be to get other lecturers involved in the discussions which would make this logistically possible. The 'soft skills' in communication could be encouraged.

15.5 Chapter Summary

The changes made to the design module 6ME500 taught on the final year of the BEng (Hons) Mechanical Engineering Degree Programme were made based on research into the methods favoured by industry. These changes worked well with very little adjustment required.

Three industry design experts have reviewed the module from two different stand points 1) practical changes and 2) pedagogical changes. Overwhelming agreement from all three specialist that the module is fit for purpose and the methods used coincide with those used by modern industry.

Some suggestions have been made which will be reviewed and where possible implemented. The practical aspects of instigating some methods due to the class size may be an issue. The above comments have added to the body of evidence that this module is fit for purpose and is aligned very close to the methods used in industry.

CHAPTER 16

ADDITION TO KNOWLEDGE

(Objective 4 Section 1.2.2)

16.0 Introduction

The addition to knowledge can be divided into two distinct areas. The first area is focussed on all practical aspects of teaching a class of mechanical engineering design students. These changes were researched by examining industry practice and applying them to real classes of students studying a BEng (Hons) Mechanical Engineering degree. These changes were validated by industry experts as being appropriate. The second addition to knowledge was addressing a knowledge shortfall found in full-time students, a practical example of how this works is provided. Validation of this second area was through interviews with academic subject specialists in mechanical engineering design.

16.1 Practical Aspects

In chapter 6, research was undertaken on the methods used by industry to design complex mechanical engineering components. These methods were critically reviewed to determine if they can be applied in academia. Industry design aim is to produce a functional, cost-effective design. Academia has the same design aim but has the additional requirements of assessing a student's design ability whilst maintaining a record of the assessment.

The practical changes in themselves are a synthesis of existing knowledge, that when applied together, and in a design context, become unique (Table 67). Many of the practical changes are already used either by academia or industry. However, some have been developed specifically for this research such as; webpage acronym; 500-word informal report; curriculum design; and grading algorithm.

Table 67 Practical Changes

Practical Method	Explanation
Group presentation	This is early in the design process. Transparent discussion between groups is encouraged, checking that the design is following the expected design constraints. Groups can compare basic design ideas for future development. All groups considered as one large group for sharing of ideas.
Group design	Most complex design is completed in groups to maximise specialist skills. Groups in industry would be formed depending on the design requirements and on the strengths of individuals. Students self-select members as strengths of students often not known (direct entry) by lecturer.
Webpage acronym	An acronym was developed to assist students to determine if a webpage was appropriate to use.
500-Word informal report	Equivalent to an informal chat with a superior on progress of the design. A report was selected due to practical limitations of carrying out an actual interview and a means of recording the assessment & providing feedback.
Library of knowledge	To assist student to build their basic engineering knowledge, a library of parts and materials has been established. This will be a continuous process.
Curriculum design	The curriculum through the three-year degree was reviewed to identify areas in the modules where basic engineering knowledge could be improved.
Grading algorithm	A grading algorithm was developed specific to the new features developed in this thesis. Weighted grading for group and individual work included.
5-Slide critique	After completion of a design, the process is critiqued by the students to enhance the process and improve future iterations.

16.2 Knowledge Shortfall

A knowledge shortfall was identified in chapter 8 which mainly applied to full-time students. In section 16.1 Practical Aspects to changes were made to partially improve the basic engineering knowledge of full-time students, 1) development of a library of knowledge and 2) review of the curriculum to improve their basic engineering knowledge.

During face-to-face lessons the lack of students basic engineering knowledge was witnessed by the author when simple design decisions were made incorrectly. Many times, the cause of these incorrect decisions was identified as the incorrect use of internet search engines, the most popular being Google (chapter 7 interviews with HEI's). The use of a Webpage acronym (section 8.2) should improve the situation.

Students require a method in which decisions involving basic engineering knowledge can be resolved by applying sound mechanical engineering design theory. The addition to knowledge will be known as 'Bloom's Taxonomy Reversed' and will be explained with an example in the next section.

16.2.1 Bloom's Taxonomy Reversed

Students on a BEng (Hons) Mechanical Engineering degree, final year, at the University of Derby (UK) were tasked with designing a lathe gearbox. The assignment provided details on design constraints, scope, input, output, and hand-in requirements etc. What follows are the typical steps students took to design the gearbox.

Step 1 - Research

The main research by students was carried out using Google. A basic design specification was completed starting with constraints listed in the assignment with additions from students through basic searches of individual words. Boolean searches using operators such as AND, OR, and NOT tended not to be used.

Of the gearboxes searched, many were too complicated, some too simple. Eventually students will find gearboxes that appear to meet the assignment specification (Fig.71).

Content removed due to copyright reasons.

Figure 71 Typical Lathe Gearboxes (Pro Engineer (2023), The Home Shop Machinist (2023), Freepic (2023))

Step 2 Calculations

Based on research in Step 1, a basic layout of the gears and initial calculations can be completed. These initial calculations are often put into a spreadsheet so that different configurations can be tried until an appropriate result is found that satisfies the design specification. The list in Table 68 is typical of the parameters applied in the initial calculations. Each may require several permutations before an appropriate result is found.

Table 68 Initial Calculations

Gear ratio	Shaft diameters
Gear teeth profile	Input/output speed
Input/output torque	Holding torque
Backlash	Bearings
Operating temperature	Loading

Step 3 Design Decisions

Decisions are required in several areas; each will require research to determine an appropriate solution. These may include the following (Table 69).

Table 69 Design Decisions

Materials	Lubrication system
Change mechanism	Maintenance
Assembly	Manufacture

Step 4 Model

A model will be created by the student's using 3D modelling software. Some typical examples are shown in Fig. 72.

Content removed due to copyright reasons.

(Pinterest, 2022)	(CGtrader 2023)	(GrabCad, 2023)

Figure 72 Lathe Gearbox Models

Step 5 Knowledge Shortfall

The 3D models created in Step 4 can be produced by commercially available software. The basic gearbox is produced in the above models with all the main parts assembled, but much important detail is missing. Some of the missing detail is shown in Fig. 73.

Content removed due to copyright reasons.

These gears are mounted using splines. What type of splines and would these be acceptable on the student's new design?
The bearing shows no method of fixing. Will axial movement be fixed or free?

The smaller of the two gears appears to have an insert. Is this so the gears can move along axially?
Are the gears fixed radially but with axial movement?
The roller bearing shows no type of fixing.

One gear looks like it may have a key in the gear but there doesn't appear to be a corresponding key in the shaft.
The other gears and bearing appear not to have any fixings.

Figure 73 Missing Detail (Excel, 2022) (Grabcad, 2023) (Cgtrader, 2023)

How are the gears and bearings to be fixed to the shafts? What would be the preferred method? The choice is rather large as shown in Table 70.

Table 70 Gear Fixings

Key and keyway	Circlip	Coupling
Splines	Shaft shoulder	Collar
Pin	Split pin	Sleeve
Dowel	Bearing	Pressed
Heat shrunk	Set screws	Tapered pin

The originally researched gearboxes (step 1) often do not show this detail. If it is shown, it may not be applicable to the new gearbox design. 3D modelling software allows the user to easily assemble a gearbox because it allows the user to simply 'mate' parts together i.e., simply say to the software, 'fix this part to this part' and it is done, without any reference to how it is done. Basic engineering knowledge is required.

Step 6 Bloom's Taxonomy Reversed

Bloom's Taxonomy has been updated many times over the years and is detailed in chapter 9. The latest widely cited version is Anderson and Krathwohl's (2001). This thesis will refer to all versions of the Taxonomy as Bloom's as this is probably the most well-known version.

The usual application of Bloom's Taxonomy begins at the simple 'Remember' and builds in complexity through 'Understand, Apply, Analyse, Evaluate to Create'. Student's using the internet to research a design problem reverses this process because they start with the finished complex design. Using the latest version of Bloom's Taxonomy in reverse, going from a complex system (Create) to a simplified one (Remember) will help students with limited engineering knowledge decide the best possible options for a given problem.

This method also aligns very closely with an adapted Reverse Engineering method. Table 61 provides a comparison between the Reverse Engineering method and Bloom's Taxonomy Reversed method.

In Table 71 is an example of applying Bloom's Taxonomy Reversed to the design of a lathe gearbox. Please note the following:

- Most students do not have difficulty with more complicated design decisions highlighted in section 16.2.1 step 2 and 3.
- The difficulty comes with the simpler decision such as the method to fix the gear to a shaft. This difficulty arises from a lack of basic engineering knowledge.
- The possible methods can be found in the library of knowledge being built up in the University of Derby (UK).
- Applying Bloom's Taxonomy Reversed and combining with a Revised Reverse Engineering will guide students in making the best possible decision.
- Reverse Engineering is usually applied to a complete system (in this example, the whole gearbox). In this application, it is applied to only a small part of the system, in the case, fixing a gear to the shaft.

Table 71 Application of Bloom's Taxonomy Reversed

Complex Design Problem	Reverse Engineering (Bloom's Taxonomy)	Application
	Library of knowledge. (Create) Identify possible fixing methods for the gears, their strengths, and weaknesses.	
	Operational requirements. (Evaluate) Understand the purpose of each part and how it interacts with other parts.	Determine from input through to output the path the applied torque follows.
	How is the operation achieved? (Analyse) Individual parts roll in overall operation.	Identify radial and axial movement for correct operation for each gear (six degrees of freedom). Determine materials and force flow through all parts.
	Relationship of parts. (Apply) Order of parts to assemble, fits.	How are assembly and subassemblies achieved? Select appropriate fixing method.
	Manufacture. (Understand)	What processes are required for manufacture/production?
Basic Design Problem	**Review. (Remember)**	Review all decisions based on a overview of design.

16.3 Chapter Summary

The methods highlighted in Steps 1 to 6 are not specific to this example and can be applied across many different designs and HEI's.

The internet is a very powerful tool that aids mechanical engineering design in ways previously not thought possible. It is important when using the internet to teach, that students are made aware of its limitations and how to overcome them.

The webpage acronym (section 8.2.1) should assist students in their webpage selection. The more reputable a webpage, the more refutable its data and information will be.

While students are still building their basic engineering knowledge, applying Bloom's Taxonomy Reversed will help students to make better design decisions. Even once their basic engineering knowledge has reached a good level, this method will still apply as engineering is such a vast field, making it impossible for anyone to know everything.

CHAPTER 17

CONCLUSION

17.0 General Conclusion

Mechanical engineering design is constantly evolving due to the influence of many different areas, computer technology being a prime example. A computer at home or sitting at a desk at work was unheard of within the authors lifetime, but today is considered normal. Even the physical size and processing power (or more precisely, the lack of processing power) of the earliest computers is something difficult to understand unless you lived through it. The speed, memory, screens, pointing devices, storage and the internet have given design engineers today the ability to design collaboratively anywhere in the world. Their complex designs are modelled in 4D software which includes functionality. Prior to these technological advances it was still possible to design complex things. Concorde and the Apollo space missions are two examples, but the cost of errors, the requirement to produce many expensive prototypes made these programs extremely expensive and time consuming. The savings modern computer software could have brought to these two programs in terms of design would be in the £millions and maybe even £trillions. The next generation computers are being developed as this thesis is being written. Alongside this technological development is software development. 4D software with its functionality may develop in areas not even thought of at present. Due to the development of the computer, design of complex components and systems has changed. Parts are modelled using 3D computer systems, the parts are assembled into a virtual prototype. Manufacture, production, planning, and costing are all part of Computer Controlled Engineering.

This thesis has brought design education as close as possible to the approach used by designers in modern industry. As exemplified by computers above, this is ongoing and dynamic process. As educators it is important to keep on adapting to these changes, accepting new ideas and ways of working and teaching.

17.1 Specific Conclusion

The development of teaching design was split into two specific areas, (1) organisation and (2) teaching theory. These two areas are not mutually exclusive but developed together over a 6-year period.

17.1.1 Organisation

At the beginning of this thesis, six years ago, the organisation & therefore the quality of students on the final year of a BEng (Hons) Mechanical Engineering degree was poor.

The assignment task, set in the design module required the design of a complete vehicle which included suspension; steering; chassis; engine; gearbox; differential; brakes; body. This would normally have taken a design team around two years to complete. Individual students were allowed a semester of 12 weeks. The assignment task was reduced to a design of a complex part that was a manageable size and could be completed within the timescale.

The assignment required calculations of forces to determine stresses and corroboration of those forces using SolidWorks software, the size of the assignment meant it was not possible to calculate for all parts. Calculations to determine if a design is fit for purpose are now given much more importance, but due to the limited time, are not expected for each part of the design, only for those deemed most functionally important.

The balance between modelling and report writing were changed, the emphasis was put on the 4000-word report which justified the design decisions made. Rather than students spending most of the time modelling, they now had time to develop the details of their designs and produce designs that could be manufactured.

Group working is a challenge to students, generally they prefer not to do it. Industry prefer group working as they appreciate the required skills in modern complex designs can normally only be found in a group of highly skilled design engineers. Some individual work was accepted to allow students to have some individual expression.

17.1.2 Teaching Theory

There are many teaching theories in use today. This thesis did not plan to comprehensively review them all as this would be beyond the scope of a PhD. When teaching design to the final year, students on a BEng (Hons) Mechanical Engineering Degree tried and tested pedagogic theories were applied. The combination of the theories will be different to anything tried before and will be unique to the module used to teach design.

During teaching of the design module, a difference in the mechanical engineering design knowledge was noted between full-time and part-time students. Over a period of years this was reviewed with the aid of a survey carried out by the students to determine their level of mechanical engineering knowledge. A large difference in knowledge between part-time and full-time students was found. This knowledge gap was addressed by looking back over the first two years of the degree programme and looking for ways that the curriculum could be improved. A new theory was developed. It was noted that students using the internet would research complete complex systems. Because of their limited knowledge they had difficulty understanding the design intent. By applying a combination of Reverse Engineering and Bloom's Taxonomy (reversed) this limited knowledge could be addressed and the student's knowledge improved when compared to their part-time equivalent students.

Throughout the time students are in education they accept as normal the requirement to produce formal written reports. This design module has a 4000-word report. A different type of report was introduced, an informal one. This was to portray the equivalent of updating verbally to a company's managers how the design was progressing, informally. This, students found most challenging, it took them out of their comfort zone.

17.2 Validation

The research carried out in this thesis has been validated as accurate and applicable in four different ways.

All research was based on peer reviewed conference and journal papers. Any books were from reputable sources and accepted by industry and academics as accurate and reliable. Website selection was limited to sites that could be verified by industry specialist.

The author had two supervisors who are both experienced researchers with a PhD. All research carried out under their guidance was checked to the highest standards of accuracy and reliability.

The main findings of the research were written in conference and journal papers which were peer reviewed by industry and academic specialist. The conference papers were presented at conferences. After the presentation, the findings came under scrutiny by industry and academic specialists.

The methods to teach design and align The University of Derby (UK) with industry methods were scrutinised by industry specialists and found to be very close to the methods used by industry. The University of Derby (UK) will be preparing students ready for design in industry.

17.3 Academia Recommendations

The methods and systems used by industry to design mechanical engineering components are constantly changing. As these methods and systems change, so must the methods and systems used by universities and colleges to train future design engineers. It is essential that universities and colleges keep pace with industry so that graduating design engineers will be able to significantly contribute to the design process from their first day in industry. The benefits to a company of good design were shown to be vast (chapter 1).

If a company employs good design engineers, the possibility of large benefits, both financially and reputationally are possible. This has created a very competitive market for graduate engineers in the UK and worldwide. By applying the research-informed teaching in this thesis, universities and colleges will be training future design engineers to enter this competitive market as a very strong contender. This will also improve the reputation of the university or college.

Based on the research in this thesis, the following steps are recommended for universities and colleges to take to achieve the close alignment with industry methods and systems, applicable to 2023.

1. Begin the creation of a library of knowledge. This will consist of those items expected in a library such as: books, magazines, journal articles, conference papers, newspapers, DVD's, CD's etc. but with the addition of physical engineering materials, sample mechanical fixture and fittings, DVDs of machining, samples of mechanical stock items, bearing etc. This step is placed first as it will probably take the longest to achieve before it becomes useful to students basic engineering knowledge. Do not assume students will know of the existence of this resource or how to use it. Introduce this to them at the earliest opportunities and provide examples how it can be used.

2. Review assessments. It is critical the assessment is detailed enough for students to understand the design problem and complex enough to meet the learning outcomes of the programme. It must be possible to complete the design within a set timeframe. The design challenge could be a new, unique design solution or a redesign of an existing component. Introduce the following assessment methods into the assignments:

(i) Most complex mechanical engineering design is a group activity. It is important to assess the students work as part of a design group and individually. The grading algorithm will assist in this task by allocating marks for group and individual work. If the students are well known to the academic, then group creation would be best completed by the academic who would consider the strength and weaknesses of each group member. If the students are not known to the academic, then allow them to select their own group members.

(ii) The design groups, at an early stage of the design (week 4) present their initial design thoughts to their peers in a formal group presentation. At this stage there is a collaborative culture between design groups. All groups learn from each other. Any designs not following the assessment brief correctly can be easily adjusted. Any mistake at this early stage will have a minimum effect upon the design project.

(iii) During week 8 each individual student to present a 500-word informal report on the progress of the design. This would be equivalent to an informal conversation with a manager, updating them on progress made. Some students may choose to write this as an actual conversation.

(iv) Provide an individual critique on the final design solution (week 12). How well did the final design meet the assignment brief? During the design process, what could have been done better? Limit the size of the critique. Five sides or slides is recommended.

3. Explain generally, the process of applying Bloom's Taxonomy in reverse. Provide examples of the reverse logic this uses, detailing the required steps to develop a solution. Look out for areas during the design process where student may appear to struggle with understanding or selecting part of a design solution. Assist them by applying Bloom's Taxonomy Reversed by directing them to a solution with application of appropriate questions. This application of Bloom's Taxonomy Reversed will be a detailed explanation of the design problem.

By applying the above to the teaching of mechanical engineering design in a university or college, the graduate design engineers will be better equipped to enter the competitive market and make a valid contribution to the design process from day one.

17.4 Future Development

This thesis along with its accompanying research was completed in 2023. To keep the teaching of design up to date will require constant changing, constant updating. One of the main drivers of change in design is computer systems. While they continue to develop so will design. This is the beginning of the journey with no destination.

Some of the teaching and learning theory was based around Bloom's Taxonomy (chapter 9) and its newer versions such as Anderson and Krathwohl (2001) and Marzano and Kendall (2007). There are other theories that could be investigated such as The Teach Thought Learning Taxonomy, UbD's Six Facets of Understanding, The Taxonomy of Significant Learning, Webb's Depth of Knowledge Framework, and The SOLO Taxonomy (Teachthought, 2022). These are just a small sample of alternative theories that should be explored. Most are a development of Bloom, but some may bring new ideas that could be applied to teaching design.

REFERENCES

Ackermans, K. Rusman, E. Nadolski, R. Specht, M. Brand-Gruwel, S. (2019) *Video or Text Based Rubrics: What is Most Effective for Mental Model Growth of Complex Skills Within Formative Assessment in Secondary Schools?* Journal of Computers in Human Behaviour. https://doi.org/10.1016/j.chb.2019.07.011.

Aggarwal, S. McCabe, L. Aggarwal, A. (2010) *Small to Medium Businesses Routes to Market Study.* [online] Available from: https://www.smb-gr.com/wp-content/uploads/2010/pdfs/Routes_to_market_study.pdf [Accessed 2 June 2021].

Alibaba. (2023) *New Model Heavy Duty Steel 2 Ton Position Hoist*. [online] Available from: https://www.alibaba.com/product-detail/Heavy-Duty-Steel-2-Ton-Position_1600629870003.html [Accessed 10 September 2023].

AMN Quality Solutions (2023) *Manual or Automated? How to Choose the Right Type of Assembly for Your Production Needs.* [online] Available from: Manual or automated? – How to choose the right type of assembly for your production needs (linkedin.com) [Accessed 23 September 2023].

Anderson, L, W. Krathwohl, D. (2001) *Bloom's Taxonomy Revised.* [online] Available at: http://www0.sun.ac.za/ctlresources/wp-content/uploads/2018/11/Anderson-and-Krathwohl.-2001.-Extract-from-A-taxonomy-for-learning-teaching-and-assessing-a-revised-Blooms-Taxonomy.pdf [Accessed 4 March 2021].

Aniwaa, (2022) *The Marketplace for Additive Manufacturing Solutions.* [online] Available from: https://www.aniwaa.com/ [Accessed 17 August 2022].

Antony, J. Antony, F. (1998) *Teaching Advanced Statistical Techniques to Industrial Engineers and Business Managers.* Journal of Engineering Design, 9:1, 89-100 doi 10.1080/095448298261688.

Anwer, N. Mathieu, L. (2016) *From Reverse Engineering to Shape Engineering in Mechanical Design.* Journal of CIRP Annals – Manufacturing Technology doi: 10.1016/j.cirp.2016.04.052.

ArchMiller, A. Fieberg, J. Walker, J. Walker, H. (2017) *Group Peer Assessment for Summative Evaluation in a Graduate-Level Statistics Course for Ecologists.* Assessment & Evaluation in Higher Education, 42:8, 1208-1220, doi: 10.1080/02602938.2016.1243219.

Armstrong, I. (1981) *Design for Production.* Journal of Industrial Management & Data Systems, Vol. 81 Iss 9/10 pp. 2-4 doi: 10.1108/eb057207.

Armstrong, P. (2010) *Bloom's Taxonomy. Vanderbilt University Centre for Teaching.* [online] Available from: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/ [Accessed 1st August 2021].

Armstrong, P. (2020) *Centre for Teaching – Bloom's Taxonomy.* [online] Available from: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/ [Accessed 3rd April 2020].

Aromaa, S. Vaananen, K. (2015) *Suitability of Virtual Prototypes to Support Human Factors/Ergonomics Evaluation During the Design.* Journal of Applied Ergonomics doi: 10.1016/j.apergo.2016.02.015.

Ashley, S. (1995) *Cutting Costs and Time with DFMA.* [online] Available from: CuttingtimeandcostwithDFMA.pdf (mit.edu) [Accessed 22 September 2023].

ASQ (2023) *How to Build a House of Quality with Technical and Competitive Benchmarking.* [online]. Available from: https://asq.org/quality-resources/house-of-quality [Accessed 17 September 2023].

Aziz, A. Islam, S. (2022) *Impact of Mixed Pedagogy on Engineering Education.* Journal of IEEE Transactions on Education, Vol. 65. Ni. 1. February 2022.

Back, W. Sanders, S. (1998) *Industry Expectations for Engineering Graduates.* Journal of Engineering Construction and Architectural Management, Vol. 5 Iss 2 pp. 137 – 143 doi: 10.1108/eb021068.

Bailey, D. (2022) *Manufacturing After Brexit.* [online] Available from: https://ukandeu.ac.uk/manufacturing-after-brexit [Accessed 14 August 2022].

Barbosa, G.F. Carvalho, J. (2014) *Guideline Tool Based on Design for Manufacturing and Assembly (DFMA) Methodology for Application on Design and Manufacture of Aircrafts.* Mechanical Science and Engineering 36. 605-614.

Baroutian, S. Kensington-Miller, B. Wicaksana, F. (2016) *Bridging Theory with Real World Research Experience: Co-Teaching Engineering Biotechnology with R & D Professionals.* Journal of Education for Chemical Engineers. doi:10.1016/j.ece.2016.05.002.

Barraclough, P. Wahlberg, A. Freeman, J. Watson, B. Watson, A. (2016) *Predicting Crashes Using Traffic Offences. A Meta-Analysis that Examines Potential Bias Between Self-Report and Archival Data.* PLoS ONE 11(4) Journal.

Barsalou, M. (2020) *A DFMEA by Any Other Name.* Journal of Quality Progress. Vol. 53, Iss. 6, (Jun 2020), 42-45.

Bartolomei, J. Miller, T. (2001) *Functional Analysis Systems Technique (F.A.S.T.) as a Group Knowledge Elicitation Method for Model Building.* United States Air Force, Wright-Patterson AFB.

Battaia, O, Dolgui, A. Heragu, S. Meerkov, S. Tiwari, M. (2018) *Design for Manufacture and Assembly/Disassembly: Joint Design of Products and Production Systems.* International Journal of Production Research. Volume 56, 2018. Issue 24.

Becker, R. Grzesiak, A. Henning, A. (2005) *Rethink Assembly Design.* Journal of Assembly Automation, Vol. 25 Iss 4 pp. 262-266 doi: 10.1108/01445150510626370.

Behm, M. Culvenor, J. Dixon, G. (2014) *Development of Safe Design Thinking Among Engineering Students.* doi: 10.1016/j.ssci.2013.10.018.

Berbegal-Mirabent, J. Gil-Domenech, D. Riberio-Soriano, D. (2020) *Fostering University-Industry Collaborations Through University Teaching.* Journal of Management Research and Practice, 18.3 263-275, doi: 10.1080/14778238.2019.1638738.

Bertoni, M. Bertoni, A. (2019) *Iterative Value Models Generation in the Engineering Design Process.* Design Science, 2019, Vol.5.

Beyaz Gazete (2021) *Spor/Sade Modifiye Edilmis Araclar.* [Online] Available from: https://beyazgazete.com/fotogaleri/spor-4/sade-modifiye-edilmis-araclar-tum-fotograflar-12088/buyuk-fotograf-15/?pcount=50 [Accessed 10 September 2023]

Blakeley, S. (2022) *Epistemology Examples & Types.* [online] Available from: https://study.com/learn/lesson/epistemology-examples-types.html [Accessed 3 July 2022].

Blizzard, J. Klotz, L. Pradham, M. Dukes, M. (2012) *Introducing Whole-System Design to First-Year Engineering Students with Case-Studies.* International Journal of Sustainability in Higher Education. doi: 10.1108/14676371211211854.

Blum, S. (2019) *The Pedagogy of Design and Technology at Xavier University of Louisiana, New Orleans.* ITM Web of Conferences 27, 02001 (2019). https://doi.org/10.1051/itmconf/20192702001.

Boothroyd, G. Dewhurst, P. Knight, W. (2011) *Product Design for Manufacture and Assembly.* 3rd Edition. CRC Press.

Boothroyd and Dewhurst (1984) *Design for Assembly: Selecting the Right Method.* Machine Design. Penton/IPC Education Division.

Borrego, M. Douglas, E. Amelink, C. (2009) *Quantitative, Qualitative, and Mixed Research Methods in Engineering Education.* Journal of Engineering Education. January 2009.

Brad, S. (2008) *Complex System Design Technique (CSDT)* International Journal of Production Research, 2008, 46 (21), pp.5979-6008.

Brahimi, H. Dweiri, F. Al-Syouf, I. Khan, S. (2013) *Cooperative Education in an Industrial Engineering Program.* 6th International Forum on Engineering Education. doi: 10.1016/j.sbspro.2013.10.760.

Brand, B. (2020) *Integrating Science and Engineering Practices: Outcomes from a Collaborative Professional Development.* International Journal of STEM Education 2020 7:13 https://doi.org/10.1186/s40594-020-00210-x.

Braun, V. Clarke, V. (2022) *Thematic Analysis: A Practical Guide.* SAGE Publications Ltd. London. ISBN 978-1-4739-5323-9.

Brown, G. (2019) *Is Assessment for Learning Really Assessment?* Front Educ. 4:64. doi:10.3389/feduc.2019.00064.

BSI. (2022) *What is a Standard – Benefits.* [online] Available from: https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/about-standards/what-is-a-standard-benefits/ [Accessed 28 December 2022].

BTEC. (2019) *Assessment Strategies.* [online] Available from: https://qualifications.pearson.com/content/dam/pdf/btec-brand/V727c3_BTEC_Assessment_strategies_factsheet.pdf [Accessed 24 February 2019].

Burghardt, M. Hacker, M. (2004) *Informed Design: A Contemporary Approach to Design Pedagogy as the Core Process in Technology.* The Technology Teacher.

Capobianco, M. Joyal, H. (1996) *Practical Strategies for Incorporating Professional Development Experiences in the Classroom*. Journal of Science and Children.

Career Transition Partnership (2017) *Industry Sector Guide – Engineering, May 2017.* [online] Available at: https://www.ctp.org.uk/assets/x/53116 [Accessed 23 May 2017].

Caulliraux, A. Bastos, D. Araujo, R. Costa, S. (2020) *Organisational Optimisation Through the Double Diamond - Applying Interdisciplinarity.* Brazilian Journal of Operations & Production Management, Vol 17, No. 4, e2020917. https://doi.org/10.14488/BJOPN.2020.025.

CBT (2023) *Worm and Sector Steering*. [online] Available from: https://carbiketech.com/worm-and-sector-steering/?utm_content=cmp-true [Accessed 10 September 2023].

Certification Course (2023) *Six Sigma certification Course.* [online] Available from: http://www.sixsigmacertificationcourse.com/house-of-quality-hoq-qfd/ [Accessed 11 November 2023].

CGTrader, (2023) *Lathe Headstock Gears.* [online] Available from: https://www.cgtrader.com/3d-print-models/hobby-diy/mechanical-parts/lathe-head-stock-gears [Accessed 9 January 2023].

Chaharbaghi, K. (1990) *Using Simulation to Solve Design and Operational Problems.* International Journal of Operations & Production Management, Vol 10 Iss. 9 pp. 89 – 105 doi: 10.1108/01443579010006163.

Chan, Lai-Kow. Wu, Ming-Lu (2003) *Quality Function Deployment: A Comprehensive Review of its Concepts and Methods.* Quality Engineering, 15(1), 23-35 (2002-03).

Charyton, C. Merrill, J. (2009) *Assessing General Creativity and Creative Engineering Design in First Year Engineering Students.* Journal of Engineering Education.

Chen, C. Wu, J. (1994) *CAD/CAM Systems Integration: An Integrated Surface and Volume Feature Modelling Scheme.* Journal of Integrated Manufacturing Systems, Vol 5 Iss 4/5 pp. 22-29 doi: 10.1108/09576069410069512.

Chen, K. (1998) *Integration of Design Method Software for Concurrent Engineering using Axiomatic Design.* Journal of Integrated Manufacturing Systems, Vol. 9 Iss 4 pp. 242-252 doi: 10.1108/09576069810217847.

Cherrafi, A. Garza-Reyes, J. Belhadi, A. Kamble, S. Elbaz, J. (2021) *A Readiness Self-Assessment Model for Implementing Green Lean Initiatives.* Journal of Cleaner Production. 309. https://doi.org/10.1016/j.jclepro.2021.127401.

Chiarini, A. Baccarani, C. Mascherpa, V. (2018) *Lean Production, Toyota Production System and Kaizen Philosophy.* The TQM Journal. Vol.30. No. 4. 2018. pp. 425-438.

Chiang, W. Pennnathur, A. Mital, A. (2001) *Designing and Manufacturing Consumer Products for Functionality: A Literature Review of Current Function Definitions and Design Support Tools.* Journal of Integrating Manufacturing Systems, Vol. 12 Iss 6 pp. 430-448 doi: 10.1108/EUM0000000006108.

Childs, P. (2018) *Mechanical Design Engineering Handbook.* Butterworth-Heinemann. Second edition. ISBN 978-0-08-102367-9.

Choi, Y. Song, E. Oh, E. (2015) *Effects of Teaching Communication Skills using a Video Clip on a Smart Phone on Communication Competence and Emotional Intelligence in Nursing Students.* Journal of Psychiatric Nursing 29, (2015) 90-95.

Chris, Joseph. (2015) *7 Pros and Cons of Group Work.* [online] Available at: http://www. josephchris.com/7-pros-and-cons-of-group-work [Accessed 30 September 2018].

Chua, C. Lye S. (1998) *Parametric Design Modelling of Drinking Bottles.* Journal of Integrated Manufacturing Systems, Vol 9 Iss 2 pp. 99 – 108.

Coen, K. Katz, R. (2015) *Teaching Mechanical Design Practice in Academia.* CIRP 25th Design Conference Innovative Product Creation. doi: 10.1016/j.procir.2015.01.043.

Collins (2023). *Definition of 'more/greater than the sum of its parts'.* [online] Available from: https://www.collinsdictionary.com/dictionary/english/more-greater-than-the-sum-of-its-parts [Accessed 17 September 2023].

Collins Concise Dictionary. (1999) *Collins Concise Dictionary.* Harper Collins Publishers, Glasgow. 4th Ed. ISBN 0 00 472257 4.

Concept Draw. (2023) *How to Create a House of Quality Diagram.* [online] Available from: https://www.conceptdraw.com/examples/house-of-quality-visio [Accessed 10 November 2023].

Conforto, E. Amaral, D. (2016) *Agile Project Management and Stage-Gaye Model – A Hybrid Framework for Technology-Based Companies.* Journal of J. Eng. Technol Manage. 40(2016) 1-14.

Comacho, B. Alexandre, R. (2019) *Design Education: University-Industry Collaboration, a Case Study.* The Design Journal, 22:sup1, 1317-1332. doi:10.1080/14606925.2019.1594958.

Creative Industry Supply. (2022) *Understanding the Toyota Production System.* [online] Available from: Toyota Production System (TPS & Lean Manufacturing) | Creative Safety Supply [Accessed 27 December 2022].

CTP. (2018) *Industry Sector Guide – Engineering – May 2017*. [online] Available at: https:// www.ctp.org.uk/assets/x/53116 [Accessed 23 May, 2017].

Curtis, W. Murphy, M. Shields, S. (2013) *Research and Education.* Foundation of Education Studies. Taylor and Francis Group.

Das, S. Bourell, D. Babu, S (2016) *Metallic Materials for 3D Printing.* Materials Research Society. Vol. 41. October 2016. doi .org/10.1557/mrs2016.217.

DeBartolo, E. Robinson, R. (2007) *A Freshman Engineering Curriculum Integrating Design and Experimentation*. International Journal of mechanical Engineering Education 35/2.

De Hei, M. Sjoer, E. Admiraal, W. Strijbos, J. (2016) *Teacher Educators' Design and Implementation of Group Learning Activities.* Journal of Educational Studies, 42:4, 394-409. doi:10.1080/03055698.2016.1206461.

Delaney, D. Fletcher, M. Cameron, C. Bodle, K. (2013) *Online Self and Peer Assessment of Teamwork in Accounting Education.* Accounting Research Journal, Vol 26 Issue: 3 pp.222-238 https://doi.org/10.1108/ARJ-04-2012-0029.

Department for Education and Employment. (2000) *An Assessment of Skill Needs in Engineering.* [online] Available at:
http://dera.ioe.ac.uk/4449/3/UKEnginSkillsNeeds.pdf [Accessed 23 May 2017].

Design Awards. (2022) *A Design Engineering Award.* [Online] Available from: http://www.designengineeringaward.com/ [Accessed 29 December 2022].

Design Council. (2018) *Eleven Lessons: Managing Design in Eleven Global Brands – A Study of the Design Process.* [online] Available at: https://www.designcouncil.org .uk/sites/default/files/asset/document/ElevenLessons_Design_Council%20(2).pdf [Accessed 4 May 2018].

Designing Demand. (2007) *Designing Demand: The Importance of Design.* Journal of Strategic Directions, Vol. 23. Iss 7, pp.30-32. doi: 10.1108/02580540710753454.

Dickison, M. Ghaleeh, M. Milady, S. Subbakrishna. Wen, L. Al Qubeissi, M. (2020) *Investigation into the Aerodynamic Performance of a Concept Sports Car.* Journal of Applied Fluid Mechanics, Vol. x, No. x, pp, x-x, 200x.

Dieter, G. Schmidt, L. (2013) *Engineering Design.* McGraw-Hill. 5th Ed. ISBN 978-07-339814-3.

Dieter, G.E. Schmidt, L, C. (2020) *Engineering Design.* 5th Edition. McGraw-Hill. ISBN 978-0-07-339814-3.

Dissertation Writers. (2019) *Saunders Research Onion – A Step-By-Step Guide to Structuring Research Methodology Chapter for PhD and Master-Level Researchers.* [Online] Available from: https://ukdissertationwriters.com/saunders-research-onion-guide-to-structuring-research-methodology/ [Accessed 2 July 2022].

Dixson, D. Worrell, F. (2016) *Formative and Summative Assessment in the Classroom.* Journal of Theory into Practice. 55:2, 153-159. doi:10.1080/00405841.

Donato, D. Abita, M. (2019) *Low-Cost 4D BIM Modelling – A Comparison Between Freecad and Commercial Software.* Journal of Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XLll-2/W17, 2019.

Donley, A. & Grauerholz, L. (2012) *Student Handbook to Sociology: Research Methods.* Volume 2. Library of Congress Cataloguing-in-Publication Data. ISBN 978-0-8160-8314-5.

Dormido, S. (2002) *Control Learning: Present and Future.* 15th IFAC World Congress on Automatic Control, Barcelona, Spain pp. 314 – 319.

Downy, M. (1998) *The Classroom Gets Re-engineered when Reforming Engineering Education.* Journal of Campus-Wide Information Systems, Vol.15 Iss 2 pp. 63-65. doi: 10.1108/10650749810216758.

Easton, W. (1963) *Mechanical Engineering Laboratories – Their Design, Equipment and Use.* Journal of Education & Training, Vol. 5 Iss 7 pp. 319 – 321 doi: 10.1108/eb0115307.

Eder, E. Hosnedl, S. (2010) *Introduction to Design Engineering: Systematic Creativity and Management.* Taylor & Francis Group. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/derby/detail.action?docID=1446961.

Ehrlenspiel, K. Kiewert, A. Lindmann, U. (2007) *Cost-Efficient Design.* Springer Berlin, Heidelburg. doi: https://doi.org./10.1007/978-3-540-34648-7.

Elverum, C. Welo, T. (2014) *The Role of Early Prototypes in Concept Development: Insights from the Automotive Industry.* 24th CIRP Design Conference. doi: 10.1016/j.procir.2014.03.127.

Emami, M. Bazzocchi, M. Hakima, H. (2019) *Engineering Design Pedagogy: A Performance Analysis.* International Journal of Technology and Design Education (2020) 30:553-585 https://doi.org/10.1007/s10798-019-09515-7.

EmmonsFrances, M. Wilkinson, C. (2001) *Designing the Electronic Classroom: Applying Learning Theory and Ergonomic Design Principles.* Library Hi Tech. Vol 19 Iss 1 pp. 77-87 doi: 1-.1108/14725960710775054.

Engineering Council. (2021) *AHEP Fourth Edition.* [online] Available from: https://www.engc.org.uk/standards-guidance/standards/accreditation-of-higher-education-programmes-ahep/fourth-edition-implemented-by-31-december-2021/ [Accessed 16 January 2023].

Engineering Council. (2023) *UK-SPEC Fourth Edition.* [online] Available from: https://www.engc.org.uk/ukspec4th [Accessed 24 September 2023].

Engineering Drawing. (2018) *Drawing Office Management and Organisation.* [online] Available at: https://www.joshuanava.biz/engineering-3/drawing-office-management-and- organization.html [Accessed 15 March 2018].

Engineering UK. (2019). *Key Facts and Figures. Highlights from the 2019 Update to the Engineering UK Report.* [online] Available from: https://www.engineeringuk .com/media/156198/key-facts-figures-2019-final-20190627.pdf [Accessed 10 July 2022].

Engineering UK. (2020) *Educational Pathways into Engineering.* Engineering UK.

Engineers Europe (2023) *What is the EUR ING Certificate?* [online] Available from: What is the EUR ING Certificate | ENGINEERS EUROPE [Accessed 24 September 2023].

English Oxford Living Dictionaries. (2017) *Definition of Engineer in English.* [online] Available at https://en.oxforddictionaries.com/definition/engineer [Accessed 24 May 2017].

Excel. (2022) *Looking for a New Manual Lathe.* [online] Available from: https://excelmachinetools.co.uk/catalogue-2021/manual-lathes/?utm_source=bing&utm_medium=cpc&utm_term=best%20mini%20lathe [Accessed 10 September 2023].

Feng, D. Lu, C. Jiang, S. (2022) *An Iterative Design Method from Products to Product Service Systems – Combining Acceptability and Sustainability for Manufacturing SMEs.* Sustainability 2022, 14. 722 https://doi.org/10.3390/su14020722.

Fermentini, G. Rodriguez, N. Favi, C. (2022) *Design for Manufacture and Assembly Methods in the Product Development Process of Mechanical Products: A Systematic Literature Review.* The international Journal of Advanced Manufacturing Technology (2022) 120:4307-4334 https://www.doi.org/10-1007/s00170-022-08837-6.

Fernando, L. (2018) *Dissemination of Design Knowledge: Evidence from the 1950's Brazil.* The Journal of Architecture. Volume 23, 2018. Issue 4.

Fisher, D. (2005) *Bloom's Taxonomy.* [online] Available from: http://oregonstate.edu/instruct/coursedev/models/id/taxonomy/#table_Designer/Developer - Dianna Fisher [Accessed 8 August 2021].

Flatworld Solutions. (2017) *Top 9 Benefits of 3D CAD Modelling in Mechanical Engineering Design.* [online] Available from: https://www.flatworldsolutions.com/engineering/articles/3d-cad-modeling benefits.php [Accessed 21 June 2017].

Flores, R. Belaud, J. Negny, S. Lann, J. (2015) *Open Computer Aided Innovation to Promote Innovation in Process Engineering.* The Institute of Chemical Engineers. doi: 10.1016/j.cherd.2015.08.015.

Foley, C. (2018) *Revised Automotive Quality Standard Drives Lean Processes, Systems Linkage and Teamwork: EMS Companies are Moving Beyond QS9000and ISO /TS16949.*Journal of Printed Circuit Design & Fab Circuits Assembly. (Vol. 35, Issue 8).

Forehand, M. (2005) *Bloom's Taxonomy: From Emerging Perspectives on Learning, Teaching and Technology.* [online] Available from: http://projects.coe.uga.edu/epltt /indesx.php?title=Bloom%27s_Taxonomy [Accessed 8 August 2021].

Foteinopoulos, P. Starvropoulos, P. Papacharalampopoulos, A. Chryssolouris, G. (2016) *Unified Approach in Design and Manufacturing Optimisation of Hybrid Metal-Composites Parts.* doi: 10.1016/j.procir.2016.09.035.

Fraser, J. Simkins, B. Narvaez, K. (2014) *Implementing Enterprise Risk Management.* John Wiley & Sons ISBN 1118691962, 9781118691960.

Freepic (2023) *Metal Lathe Parts with Steel Mechanism.* [online] Available from: https://www.freepik.com/premium-photo/these-are-metal-lathe-parts-it-is-steel-mechanism-with-gears_28558856.htm [Accessed 10 September 2023].

Frykedal, K. Chiriac, E. (2011) *Assessment of Students' Learning When Working in Groups.* doi: 10.1080/00131881.2011.598661.

Gbededo, M. Liyanage, K. Oraifige, I. (2016) *Simulation Aided Life Cycle Sustainability Assessment Framework for Manufacturing Design and Management.* International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering. http://hdl.handle.net./10545/620536.

GCE ICT. (2017) *Advantages and Disadvantages of Simulation Modelling.* [online] Available from:http://cpanel.stpaulsscience.org/gceict/specifications/wjec/unit1/model /simulation/adv.htm [Accessed 22 June 2017].

Gerdsri, N. Manotungvorapun, N. (2022) *Systemising the Management of University-Industry Collaboration: Assessment and Roadmapping.* Journal of IEEE Transactions on Engineering Management, Vol. 69. No 1, February 2022.

Gero, J. Kannengiesser, U. (2004) *The Situated Function-Behaviour-Structure Framework.* Journal of Design studies, Vol 25, pp.373-391.

Ghaleeh, M. Kaczmarczyk, S. Rasool, S. Adams, J. Al-Esawi, N. (2020) *Computer-Aided Structural Analysis of the Lift Car-Frame System Under Emergency Arrest Operational Conditions.* Elevator World Journal, January 1, 2022.

Ghobadian, H. David, A. David, G. (2021) *Inter-Firm Knowledge Transfer Between Strategic Alliance Partners: A Way Forward.* Journal of European Management Review. https://doi.org/10.1111/emre.12447.

Gibney, E. (2012) *Engineering Graduate Numbers Need to Double by 2020.* [online] Available from: https://www.timeshighereducation.com/news/engineering-graduate-numbers-need-to-double-by-2020/422014.article [Accessed 10 July 2022].

Gopsill, J. McAlpine, H. Hicks, B. (2014) *Supporting Engineering Design Communication using a Custom-Built Social-Media-Tool – PartBook.* Advanced Engineering Informatics. doi: 10.1016/j.aei.2015.04.008.

Gov.UK. (2022) *Guidance CE Marking.* [online] Available from: https://www.gov.uk/guidance/ce-marking [Accessed 28 December 2022].

Grabcad. (2023) *GrabCad Community.* [online] Available from: https://grabcad.com/library/lathe-gear-box-2 [Accessed 9 January 2023].

Groenendyk, M. (2016) *Cataloguing the 3D web: The Availability of Educational 3D Models on the Internet.* Library Hi Teck. Vol.34 Iss 2 pp. 239 – 258 doi: 10.1108/LHT=-9-2015-0088.

Grote, Karl-Heinrich. Hefasi Hamid (2021) *Springer Handbook of Mechanical Engineering.* Springer Nature 2021. ISBN 3030470350.

Growth. (2017) *Mechanical Engineering.* [online] Available at: htttps://ec.europa.eu /growth/sectors/mechanical-engineering_en [Accessed 23 May 2017].

Hall, J. Lingefjard, T. (2017) *Mathematical Modelling Applications with GeoGebra.* John Wiley & Sons, Inc. Hoboken, New Jersey.

Hafner, P. Hafner, V. Ovtcharovs, J. (2013) *Teaching Methodology for Virtual Reality Practical Course in Engineering Education.* Journal of Computer Science. doi: 10.1016/j.procs.2013.11.031.

Hartwell, J. (2022) *DFMEA – Complete Guide to the Design FMEA.* [online] Available from https://www.iqasystem.com/news/dfmea-complete-guide/ [Accessed 10 December 2022].

Hassouny, E. Kaddari, F. Elachqar, A. Alami, A. (2013) *Teaching/Learning Mechanics in High School with the Help of Dynamic Software.* 5th World Conference on Educational Sciences. doi: 10.1016/j.sbspro.2014.01.995.

Hatchuel, A. Masson, P. Weil, B. (2017) *C-K Theory: Modelling Creative Thinking and Its Impact on Research.* Journal of Design Thinking and Interdisciplinarity. https://doi.org/10.1007/978-981-10-7524-7-11.

Hawkes, B. Abinett, R. (1984) *The Engineering Design Process.* Addison Wesley Longman Limited.

Heathfield, M. (1999) *Group-based Assessment: An Evaluation of the Use of Assessed Tasks as a Method of Fostering Higher Quality Learning.* Buckingham: SRHE and Open University Press.

HESA. (2021) *Table 58 – HE Student Enrolments by Age and Domicile 2015/15 to 2020/21.* [online] Available from: https://www.hesa.ac.uk/data-and-analysis/students/table-58 [Accessed 4 September 2022].

HESA. (2022) *Higher Education Student Statistics: UK 2020/21.* [online] Available from: https://www.hesa.ac.uk/news/25-01-2022/sb262-higher-education-student-statistics [Accessed 15 August 2022].

HM Government. (2022) *Apprenticeships.* [online] Available from: Apprenticeships (education.gov.uk) [Accessed 2nd December 2022].

Hoidn, S. Klemencic, M. (2021) *The Routledge International Handbook of Student-Centered Learning and Teaching in Higher Education.* Routledge ISBN 978-0-367-20052-7.

Hollis, E. Finch, A. (2019) *Essential Guides for Early Career Teachers: Assessment.* Ed. 1. Critical Publishing. ISBN 9781912508938.

Hooper, T. (2017) *Top Design Engineering Software.* [online] Available at: https://www. pannam.com/blog/top-design-engineering-software-tools/ [Accessed 20 June 2017].

Hosseinpour, A. Peng, Q. (2014) *A Benchmark-Based Method for Sustainable Product Design.* Benchmarking: An International Journal. Vol. 22 No 4, 2015 pp. 643-664 doi: 10.1108/BIJ-09-2014-0092.

Hou, Y. Ji, L. (2008) *Six-Stage Design Framework.* Kybernetes, Vol 37 Iss 9/10 pp. 1349-1358 doi: 10.1108/03684920810907643.

Huang, T, Lin, C. (2016) *From 3D Modelling to 3D Printing: Development of a Differentiated Spatial Ability Teaching Model.* Journal of Telematics and Informatics doi: 10.1016/j.tele.2016.10.005.

Hurst, K. (1999) *Engineering Design Principles.* Arnold, Hodder Headline Group.

IMechE. (2023) *How do I Get My University Academic Programme Accredited?* [online] Available from: *https://www.imeche.org/membership-registration/support-for-universities/how-do-i-get-my-university-accredited* [Accessed 16 January 2023].

Institute of Making. (2020) *Institute of Making – Materials.* [online] Available from: https://www.instituteofmaking.org.uk/materials-library [Accessed 15 September, 2022].

Irvine, J. (2017) *A Comparison of Revised Bloom and Marzano's New Taxonomy of Learning.* Journal of Research in Higher Education, Volume 33 [online] Available from: https://www.researchgate.net/publication/331635743_A_comparison_of_revised_Bloom_and_Marzano's_New_Taxonomy_of_Learning [Accessed 23 August, 2021].

Islam, A. (2022) *Industry 4.0: Skill Set for Employability. Journal of Social Sciences & Humanities Open.* Vol. 6. Issue 1, 2022, 100280.

James—Gordon, Y. Bal, J. (2001) *Learning Style Preferences of Engineers in Automotive Design.* Journal of Workplace Learning, Vol. 13 iss. 6 pp. 239-245 doi: 10.1108/02634501011014598.

James-Gordon, Y. Bal, J. (2003) *The Emerging Self-Directed Learning Methods for Design Engineers.* Journal of The Learning Organisation, Vol. 10 Iss 1 pp. 63-69 doi: 10.1108/09696470310457504.

Jha, B. (2016) *Institutional Resource Centres and Design Education.* Library Review, Vol. 65 Iss 8/9 pp. 625-632 doi: 10.1108/LR-03-2016-0026.

Jiang, H. Kwong, C. Liu, Y. Ip, W. (2015) *A Methodology of Integrating Affective Design with Defining Engineering Specifications for Product Design.* International Journal of Production Research, 2015. Vol. 53. No. 8, 2472-2488, https://dx.doi.org/10.1080/00207543.2014.975372.

Johan, K. (2015) *Perception of Students Towards Lecturers Teaching Engineering Courses with Industry Experience: A Case Study in Malaysia Technical University.* doi: 10.1016/j.sbspro.2015.06.372.

Johnson, A. Jacovina, M. Russell, D. Soto, C. (2016) *Challenges and Solutions When Using Technologies in the Classroom.* In S. A. Crossley & D. S. McNamara (Eds) Journal of Adaptive Educational Technologies for Literacy Instruction.

Johnson, H. (2016) *Minds at Work – Constructivism Resource.* [online] Available from: https://mindsatwork.com/forums/topic/constructivism-resource/ [Accessed 2nd April 2020].

Jones, P. Osborne, T. (2022) *Virtual Reality Methods: A Guide for Researchers in the Social Sciences and Humanities.* Bristol University Press. ISBN 978-1-4473-6075-9.

Jou, M. Tennyson, R. Wang, J. Huang, S. (2015) *A Study on the Usability of E-books and App in Engineering Courses: A Case Study on Mechanical Drawing.* Journal of Computers & Education doi: 10.1016/j.compedu.2015.10.004.

Junginger, S. (2007) *Learning to Design: Giving Purpose to Heart, Hand and Mind.* Journal of Business Strategy, Vol. 28 Iss 4 pp. 59-65 doi: 10.1108/02756660910942490.

Kadarova, J. Kovac, J. Durkacova, M. Kadar, G. (2014) *Education in Industrial Engineering in Slovakia.* Journal of Social and Behavioural Sciences 143 (2014) 157-162 doi: 10.1016/j.sbspro.2014.07.379.

Kafle, A. Luis, E. Silwal, R. Pan, H. Shrestha, P. (2021). *3D/4D Printing of Polymers: Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), and*

Stereolithography (SLA). Journal of Polymers 2021, 13, 3101, doi.org/10.3390/polym13183101.

Kapranos, P. (2013) *Teaching and Learning* in Engineering Education – Are we Moving with the Times? 6th International Forum on Engineering Education doi: 10.1016/j.sbspro.2013.10.707.

Karlsson, L. (2022) *Computer in Education: The Association Between Computer Use and Test Scores in Primary School.* Journal of Education Enquiry, 13:1, 56-85, doi:10.1080/20004508.2020.1831288.

Keckstein, T. Hynek, M. Votapek, P. (2015) *Electronic Study Materials for Design of Universal Centre Lathes.* Journal of Procedia - Social and Behavioural Sciences 176 (2015) 1097 – 1104 doi: 10.1016/j.sbspro.2015.02.271.

Keefe, J. (2022) *What is Ontology? – Definitions and Examples.* [online] Available from: https://study.com/academy/lesson/what-is-ontology-definition-examples.html [Accessed 3 July 2022].

Kelley, T. (2009) *Using Engineering Cases in Technology Education.* The Technology Teacher. April 2009.

Kelley, T. (2010) *Optimisation, An Important Stage of Engineering Design.* The Technology Teacher. February 2010.

Kenett, R. Swarz, R. Zonnenshain, A. (2020) *Systems Engineering in the Fourth Industrial Revolution – Big Data, Novel Technologies, and Modern Systems Engineering*. 1st ed. John Wiley and Sons.

Kirava, C. Yanex, K. Tunde, M. Jeffrey, A. Schoenian, D. Renner, A. (2016) *E-Learning Hands-on Blending Interactive E-Learning with Practical Engineering Laboratory.* The International Journal of Information and Learning Technology. Vol. 33 Iss 5 pp. 278 – 299 doi: 10.1108/IJILT-07-2016-0023.

Kosky, P. Balmer, R. Keat, W. Wise, G. (2021) *Exploring Engineering. An Introduction to Engineering and Design.* Academic Press, UK. ISBN 978-0-12-815073-3.

Kraslawski, A. Srinivasan, R. Chechurin, L. Lelann, J. (2015) *Special Issue – Inventive Design and Systematic Engineering Creativity.* Journal of Chemical Engineering Research and Design. Vol. 103. Pp. 1-2.

Kuprikov, M. Orekhov, A. Shulga, Y. Min, Yan. (2020) *Influence of Passenger Comfort Requirements on the Interior Layout of Long-Haul Aircraft.* Journal of Civil Engineering and Architecture, Vol.9, No. 3, pp. 820-827. 2021 doi:10.13189/cea.2021.090323.

Kyratsis, P. Kakoulis, K. Markopoulos, A. (2020) *Advances in CAD/CAM/CAE Technologies.* Journal of Machines 2020, 8, 13 doi:10.3390/machines8010013.

Kyratsis, P. Markopoulos, A. Kakoulis, K. (2020) *Advances in CAD/CAM/CAE Technologies.* MDPI – Multidisciplinary Digital Publishing Institute. doi 10.3390/books/978-3-03928-3.

Lam, T. (2008) *A Group-based Multiple Assessment Strategy for Construction-related Subjects.* Journal for Education in the Built Environment, 3:2, 46-62. doi: 10.11120/jebe.2008.03020046.

Lasfeto, D. (2020) *The Relationship Between Self-directed Learning and Students' Social Interaction in Online Learning Environment.* Journal of E-Learning and Knowledge Society. Vol16, No 2. https://doi.org/10.20368/1971-8829/1135078.

Lasher, N. (2008) *"A List" Instructional Design.* Industrial and Commercial Training. Vol. 40 iss 7 pp. 381-386 doi: 10.1108/00197850810912252.

La Velle, L. (2022) *The Contested Nature of Teacher's Knowledge: Toward Professional Understanding.* Journal of Education and Teaching, 48:2,143-145. doi 10.1080/02607476.2022.2047338.

Lectura Specs (2023) *Caterpillar RM300 Specifications and Technical Data.* [online] Available from: https://www.lectura-specs.com/en/model/recycling-waste-management/road-recycling-machines-cold-recyclers-caterpillar/rm300-1136484 [Accessed 10 September 2023]

Lee, C. (2013) *Alligators and Academia: The Importance of Primary and Secondary Sources.* [online] Available from: https://blog.apastyle.org/apastyle/2013/01/alligators-and-academia.html [Accessed 24 September 2019].

Leggett, T. (2021) *UK Mechanical and Electrical Engineering Market Report 2021.*

Lewis, P. Cooke, G. Moron-Garcia, S. (2011) *A 'Passport' to Learning: An International Student's Perspective.* PBL Across the Disciplines: Research into Best Practice, p 713.

Library. (2019) *Library: Literature Review: Purpose of a Literature Review* [online] Available from: https://uscupstate.libguides.com/c.php?g=627058&p=4389968 [Accessed 23 September 2019].

Li, S. Xu, L. Zhao, S. (2015) *The Internet of Things: A Survey.* Inf Sys Front 17, 243-259 (2015). https://doi.org/10.1007/s10796-014-9492-7.

Li, L. (2017) *The Role of Anonymity in Peer Assessment.* Journal of Assessment & Evaluation in Higher Education, 42:4, 645-656. doi: 10.1080/02602938.2016.1174766.

Lilley, A. (1998) *Engineering Through Education.* Journal of Education + Training, Vol. 40 Iss 2 pp. 63-67 doi: 10.1108/00400919810206947.

Lottero-Perdue, P. Lovelidge, S. Bowling, E. (2010) *Engineering for All, Strategies for Helping all Students Succeed in the Design Process.* National Science Education Standards.

Lourdes, L. (2013) *World Wide Web, Web Accessibility and Services.* World Technologies. EAN 9788132316848.

MacLean, P. Scott, B. (2007) *Learning Design: Requirements, Practice and Prospects.* Journal of Campus Wide Information Systems, Vol. 24 Iss 3 pp. 187-198 doi: 10.1108/10650740710762220.

Magnoni, D. Offenbacher, C. Kejriwal, A. (2012) *Creating a Materials Samples Collection to Support the Engineering Curriculum.* Journal of Library Management, Vol. 33 Iss 8/9 pp. 511-524 doi: 10.1108/01435121211279858.

Maitra, U. (2013) *The importance of Asking Questions – In Different Ways!* Journal of Resonance, January 2015.

Marlow, W. (1985) *Building Mechanical Models for Real-time Simulation.* Aircraft Journal of Engineering and Aerospace Technology. Vol. 57 Iss 10 pp.2 -4 doi: 10.1108/eb036170.

Marzano, R, J. Kendall, J, S. (2007) *The New Taxonomy.* [online] Available from: http://earth.callutheran.edu/archived-sites/institutionalresearch/documents/ MarzanoandKendall2007Taxonomy.pdf [Accessed 23 August 2021].

McDonald, R. German, B. Takahashi, T. Bil, C. Anemaat, W. Chaput, A. (2021) *Future Aircraft Concepts and Design Methods.* The Aeronautical Journal (2022), 126, pp.92-124 doi:10.1017/aer.2021.110.

McNiff, J. (2013) *Action Research: Principles and Practice.* Taylor and Francis Group. Third Edition. ISBN 9781136283758.

Medland, T. (1995) *An Engineering Designer's View of Virtual Engineering and Rapid Prototyping.* Journal of World Class Design to Manufacture, Vol. 2 Iss 3 pp. 41 – 44 doi: 10.1108/09642369310087093.

Mertins, K. Ivanova, V. Natalinova, N. Alexandrova, M. (2016) *Aerospace Engineering Training: Universities Experience.* MATEC Web Conferences 48, 06002, (2016). doi: 10:1051/matecconf/20164806002.

Meyerhoff, M. Schleef, E. MacKenzie, L. (2015) *Doing Sociolinguistics: A Practical Guide to Data Collection and Analysis.* Taylor and Francis Group. ISBN 9780415698214.

McAlpine, H. Cash, P. Hicks, B. (2017) *The Role of Logbooks as Mediators of Engineering Design Work.* doi: 10.1016/j.destud.2016.10.003.

McDonnnell, L. O'Neill, D. (2009) *Developing Tomorrow's Engineers: A Case Study in Instrument Engineering.* Journal of Education +Training, Vol. 51 Iss 3 pp. 210 – 214 doi: 10.1108/00400919810206947.

Michalak, H. Przybysz, P. (2021) *The Use of 3D Numerical Modelling in Conceptual Design: A Case Study.* Energies 2021, 14, 5003. doi.org/10.3390/en14165003.

Miller, A. Bures, M. (2015) *New Approach to Industrial Engineering Education with the Help of Interactive Tools.* Science Direct. doi: 10.1016/j.sbspro.2015.01.1012.

Miller, R. (2017) *Building on Math and Science: The New Essential Skills for the 21st Century Engineer.* Journal of Research-Technology Management, 60:1, 53-56 doi: 10.1080/08956308.2017.1255058.

Millward, S. (2006) *Do You Know Your STUFF? Training Collaborative Modelers.* Team Performance Management: An International Journal, Vol. 12 Iss 7/8 pp. 225 – 236 doi: 10.1108/00251749310023166.

Modler, N. Winkler, A. Filippatos, A. Weck, D. Dannemann, M. (2020) *Function-Integrated Lightweight Engineering – Design Methods and Applications.* Journal of Chem. Ing. Tech. 2020. 92, No 7, 949-959 doi: 10.1002/cite.202000010.

Moodley, M. (2019) *WhatsApp: Creating a Virtual Teaching Community for Supporting and Monitoring after a Professional Development Programme.* South African Journal of Education, Vol. 39. No. 2. May 2019 doi.org/10.15700/saje.v.39n2a1323.

Morris, C. (2021) *301 Top Tips for Design Engineers.* Austin Macauley Publishers Limited. ISBN 9781528994477.

Morton, W. Uhomoibhi, J. (2011) *E-Laboratory Design and Implementation for Enhanced Science, Technology and Engineering Education.* Journal of Campus Wide Information Systems. Vol.28 Iss 5 pp. 367-377 doi: 10.1108/10650741111181634.

Mourtos, N. (2012) *Defining, Teaching, and Assessing Engineering Design Skills.* International Journal for Quality Assurance in Engineering and Technology Education (2012): 14-30.

Muller, J. Narasimhan, P. Gopalswamy, S. (2016) *Design Requirements Iterative Process (DRIP) Tool Demonstration.* ACM SIGAda Ada Letters, 2017, Vol. 36 (2), pp.60-68.

NASA. (2022) *Engineering Design Process.* [online] Available from: https://www.nasa.gov/audience/foreducators/best/edp.html [Accessed 11 December 2022].

Nedaei, M. Radmehr, F. Drake, M. (2022) *Exploring Undergraduate Engineering Students' Mathematical Problem-Posing: The Case of Integral-Area Relationships in Integral Calculus.* Journal of Mathematical Thinking and Learning, 24:2, 149-175, doi:10.1080/10986065.2020.1858516.

Newman, S. Whattley, D. Anderson, I. (2003) *Engineering Design Education – The Integration of Disciplines.* Journal of Aircraft Engineering and Aerospace Technology, Vol.75 Iss 1 pp. 18 – 26 doi: 10.1108/00022660310457257.

Ng, D. (2022) *Online Lab Design for Aviation Engineering Students in Higher Education: A Pilot Study.* Interactive Learning Environment. doi:10.1080/10494820.2022.2034888.

Nickchen, D. Mertsching, B. (2016) *Combining Mathematical Revision Courses with Hands-on Approaches for Engineering Education Using Web-based Interactive Multimedia Applications.* 2nd International Conference on Higher Education Advances doi: 10.1016/j.sbspro.2016.07.074.

Nikulin, C. Lopez, G. Pinonez, E. Gonzalez, L. Zapata, P. (2019) *NASA-TLX for Predictability and Measurability of Instructional Design Models: Case Study in Design Methods.* Education Tech Research Dev (2019) 67:467-493 https://doi.org/10.1007/s11423-019-09657-4.

Novak, P. Serral, E. Mordinyi, R. Sindelar, R. (2015) *Integrating Heterogeneous Engineering Knowledge and Tools for Efficient Industrial Simulation Model Support.* doi: 10.1016/j.aet.2015.05.001.

O’Gorman, D. E. and MacIntosh, R. (2015) *Research Methods for Business and Management.* Oxford. Goodfellow Publishers Ltd.

Oktay, J. (2012) *Grounded Theory. Pocket Guides to Social Work Research Methods.* Oxford University Press Inc. ISBN 978-0-19-975369-7.

Okutsu, M. DeLaurentis, D. Brophy, S. Lambert, J. (2012) *Teaching an Aerospace Engineering Design Course via Virtual Worlds: A Comparative Assessment of Learning Outcomes.* Journal of Computers & Education. doi: 10.1016/j.compedu.2012.07.012.

Orloff, M. (2003) *Inventive Thinking Through TRIZ: A Practical Guide.* Springer, New York. NY.

Pahl, G. Beitz, W. (1986) *Konstruktionalehre.* Springer, Berlin.

Pan, Z. Wang, X. Teng, R. Cao X. (2014) *Computer Aided Design While Engineering Technology in Top-Down Modelling of Mechanical Product.* Journal of Computers in Industry 75 (2016) 151 – 161. doi: 10.1016/j.compind.2015.05.004.

Paola, I. Simpson, A. (2017) *University Student's Perceptions of Summative Assessment: The Role of Context.* Journal of Further and Higher Education. Vol. 41, No 6, 785-801.

Parker, S. (1997) *Dictionary of Engineering.* McGraw-Hill.

Parsad, U. Athre, K. (2013) *Experiences with Teaching Introductory Product Design to Engineering Undergraduates.* The West Indian Journal of Engineering Vol. 36 No 1 July/August 2013, pp. 66-78.

Peansupap, V. Walker, D. (2009) *Exploratory Factors Influencing Design Practice Learning within a Thai Context.* Journal of Engineering, Construction and Architectural Management, Vol 16 Iss 3 pp. 238-253.

Petty, G. (2004) *A Practical Guide Teaching Today*. 3rd Ed. Nelson Thornes Ltd.

Petty, G. (2014) *A Practical Guide Teaching Today,* 5th Ed. Oxford Press.

Pinterest. (2023) *Multi-Speed Multi-Stage Gearbox Turret Lathe Head 3D Cad Model.* [online] Available from: https://www.pinterest.co.uk/pin/rohit--636485359807150873/ [Accessed 9 January 2023].

Plantec, P. (2004) *The Future…..Will there be a Place for Human Teachers.* Journal of On the Horizon, Vol. 12 Iss 2 pp. 88 – 93 doi: 10.1108/10748120410544180.

Platts, K. (2004) *Developing Knowledge and Skills in Engineers: A Learning Laboratory.* Journal Education and Training, Vol. 46 Iss 4 pp. 206 – 213 doi: 10.1108/ICT-04-2013-0023.

Powers, L. Summers, J. (2009) *Integrating Graduate Design Coaches in Undergraduate Design Project Teams* International Journal of Mechanical Engineering Education.

Pro Engineer (2023) *Lathe Machine Repair Service.* [online] Available from: https://www.proenggs.com/lathe-machine-repair-service.html [Accessed 10 September 2023].

QAA (2023) *Subject Benchmark Statement Engineering.* [online] Available from: Subject Benchmark Statement: Engineering (qaa.ac.uk) [Accessed 24 September 2023]

Race, P. (2001) *A Briefing on Self, Peer and Group Assessment.* Learning and Teaching Support Network. Assessment series No. 9.

Redner, R. Lang, L. Brandt, K. (2020) Evaluation of an Electronics Intervention on Electronics Use in a College Classroom. American Psychological Association Vol, 20. No, 1. Pp.4-12.

Reeves, K. Hernandez-Gantes, V. Centeno, G. Nurnburg, C. (2021) *Constructivists Exercises to Enhance Teaching of Probability and Statistics for Engineers.* INFORMS Transactions on Education 22(1): 55-64. doi.org/10.1287/ited.2021.0246.

Reimlinger, B. Lohmeyer, Q. Moryson, R. Meboldt, M. (2019) *A Comparison of How Novice and Experienced Design Engineers Benefit from Design Guidelines.* Journal of Design Studies 63 (2019) 204-223.

Relish, M. Nielson, I. Gola, A. (2022) *Reducing the Total Product Cost at the Product Design Stage.* Journal of Applied Science 2022, 12, 1921. doi.org/10.3390/app12041921.

Rentzos, L. Doukas, M. Mavrikios, D. Mourtzis, D. Chryssolouris, G. (2014) *Integrating Manufacturing Education with Industrial Practice using Teaching Factory Paradigm: A*

Construction Equipment Application. 47th CIRP Conference on Manufacturing doi: 10.1016/j.procir.2014.01.126.

Rodriguez-Calero, I. (2022) *Practicing Engineers' Use of Prototyping Strategies to Engage Stakeholders During Front-End Design.* (Doctoral dissertation).

Rogalewicz, Michal. Sika, Robert. (2016). *Methodologies of Knowledge Discovery from Data and Data Mining Methods in Mechanical Engineering.* Management and Production Engineering Review. Vol 7. No 4. pp. 97-108.

Rogers, T. (2019) *8 Ways to Determine Website Reliability.* [Online] Available from: https://www.thoughtco.com/gauging-website-reliability-2073838 [Accessed 13 October 2019].

Roll Tex. (2023) *Roll Tex Engineering.* [online] Available from: http://www.rolltexindustries.com/products.html [Accessed 10 September 2023]

Ron, K. (2013) *How Can I Tell If a Website is Creditable?* [online] Available from: https://uknowit.uwgb.edu/page.php?id=30276 [Accessed 13 October 2019].

Rossignac, J. (2005) *Shape Complexity.* The Visual Computer. doi 10.1007/s00371-005-0362-7.

Russo, D. Spreafico, C. (2020) *TRIZ-Based Guidelines for Eco-Improvement.* Journal of Sustainability 2020, 12, 3412, doi:10.3390/su12083412.

Sabbach, K. (1996) *21st Century Jet. The Making of the Boeing 777.* Pan Books ISBN 0330328905.

Sabin, M. Fellows, C. Kosinka, J. (2021) *CAD Model Details via Curved Knot Lines and Truncated Powers.* Computer-Aided Design 143 (2022) 103137.

Salandin, A. (2014) *Student-centered Teaching: An Experience at the Building Engineering School in Valencia, Spain.* doi: 10.1016/j.sbspro.2014.05.107.

Samadhiya, A. Agrawal, R. Garza-Reyes, J. (2022) *Integrating Industry 4.0 to Total Productive Maintenance for Global Sustainability.* Journal of Total Quality Management pp. 1-27.

Sanchez, F. Liscouet-Hanke, S. Tfaily, A. (2021) *Improving Aircraft Conceptual Design Through Parametric CAD Modellers – A Case Study for Thermal Analysis of Aircraft Systems.* Journal of Computers in Industry 130 (2021) 103467 https://doi.org/10.1016/j.compind.2021.103467.

Satyandra, K. Gupta Christiaan, J.J. Paredis, S. Brown, F. (2001) *Intelligent Assembly Modelling and Simulation.* Journal of Assembly Automation, Vol 21 Iss 3 pp. 215-235.

Saunders, M. Lewis, P. Thornhill, A. (2019) *Research Methods for Business Students*. Eighth Edition. Pearson Education Limited. ISBN: 978-1-292-20878-7.

Schneider, R. Pickett, M. (2006) *Bridging Engineering and Science Teaching: A Collaborative Effort to Design Instruction for College Students.* University of Toledo. School Science and Mathematics. Vol 106 (6).

Science Buddies. (2017) *Design Requirement Examples.* [online] Available from: https://www. sciencebuddies.org/engineering-design-process/design-requirements-examples.shtml [Accessed 2 July 2017].

Science Direct. (2022) *V-Model.* [Online] Available from: https://www.sciencedirect.com/topics/engineering/v-model#:~:text=The%20V-Model%20is%20an%20approach%20model%20that%20was,2004%20is%20based%20on%20V-Model%2097%2C%20its%20predecessor. [Accessed 11 December 2022].

Scripavithra, C. Kirubanand, V. Paulose, J. (2022) *Role of Information Tools in Teaching and Learning.* SHS Web of Conferences 139, 03003 (2022). doi.org/10.1051/shsconf/202213903003.

Seibels, A. Schillar, l. (2018) *Systematic Engineering Design Helps Creating New Soft Machines.* Robotics and Biometrics Open Access. https://doi.org./10.1186/s40638-018-0088-4.

Shakoor, M. (2020) *FEMS – A Mechanics-orientated Finite Element Modelling Software.* Journal of Computer Physics Communications 260 (2021) 107729.

Shenke, Z. Quing, W. Yuxin, J. Wei, X. (2021) *A Novel Multi-Objective Group Teaching Optimisation Algorithm and its Application to Engineering Design.* Journal of Computers and Industrial Engineering. Vol 155.

Sheu, D. Chiu, M. Cayard, D. (2020) *The 7 Pillars of TRIZ Philosophies.* Journal of Computers and Industrial Engineering 146 (2020) 106572.

Shigley, J. Mischke, C. Budynas, R. (2004) *Mechanical Engineering Design.* 7th Ed. McGraw-Hill.

Shimoda, M. Otani, H. Shi, J. (2016) *Design Optimisation of Composite Structures Composed of Dissimilar Materials Based on a Free-Form Optimisation Method.* Journal of Composite structures 146 (2016) 114 – 121 doi: 10.1016 /j.compstruct.2016.03.012.

Shopping (2023) *Ducati Seamless Transmission.* [online] Available from: https://www.disdisbuy.com/?category_id=5016711 [Accessed 10 September 2023].

Shuman, L. (2016) *Advances in Engineering Education.* American Society for Engineering Education.

Sinichko, J. (2015) *An Engineering Design Process.* [online] Available from: https://www.viget .com/articles/engineering-design-process/ [Accessed 10 April 2018].

Snape, D. Spenser, L. (2003) *The Foundations of Qualitative Research.* Qualitative Research Practice (pp. 1-23). Los Angeles. Sage Publishing.

Soh, S. Ong, S. Nee, A. (2016) *Design for Assembly and Disassembly for Remanufacturing.* Journal of Assembly Automation. Vol, 36. Iss, 1. (2016): 12-14. doi: 10.1108/AA-05-2915-040.

Sole, M. (2023) *How to Teach Mechanical Engineering Design using Industry Methods While Still Assessing to University Criteria.* Unpublished PhD Thesis. The University of Derby (UK).

Sole, M. Barber, P. Turner, I. (2021) *Mechanical Engineering Design, Learning from the Past to Design a Better Future.* Journal of Design and Technology Education: An International Journal.

SolidWorks (2023) *Pack and Go Overview*. [online] Available from: https://help.solidworks.com/2021/english/SolidWorks/sldworks/c_pack_go_ovw_wpdm.htm [Accessed 17 September 2023]

Sounding Board. (2015) *How Well did your Undergraduate Education Help You Prepare for your Current job?* Journal of Tribology & Lubrication Technology.

Sriraman, V. DeLeon, J. (2001) *Assembly Modelling for Product Design and Analysis.* Journal of Engineering Technology.

Stacey, M. Eckert, C. (2022) *Objects as Carriers of Engineering Knowledge.* Journal of Engineering Studies. doi:101080/19378629.2022.2121213.

Starkey, E. Toh, C. Miller, S. (2016) *Abandoning Creativity: The Evolution of Creative Ideas in Engineering Design Course Projects.* Journal of Design Studies 47 (2016) 47 – 72.

Stefanovic, M. (2012) *The Objectives, Architectures and Effects of Distance Learning Laboratories for Industrial Engineering Education.* Journal of Computers and Education. doi: 10.1016/j.compedu.2013.07.011.

Stewart, S. Giambalvo, J. Vance, J. Faludi, J. Hoffenson, S. (2020) *A Product Development Approach Advisor for Navigating Common Design Methods, Processes, and Environments.* Journal of Designs 2020, 4, 4: doi:10.3390/designs4010004.

Stridharan, B. Muttakin, M, B. Mihret, D, G. (2018) *Students' Perceptions of Peer Assessment Effectiveness: An Explorative Study.* Accounting education, 27:3, 259-285 doi: 10.1080/09639284.2018.1476894.

Surinova, Y, (2014) *Review of Special Standards in Quality Management Systems Audits in Automotive Production.* Research Papers Faculty of Materials Science and Technology Slovak University of Technology. Vol. 21 (2013). Issue 33. pp. 21-30.

Swift, K. (1983) *A Computer Based Design Consultation System.* Assembly Automation August, Vol. 3 Iss 3 pp. 151-154 doi: 10.1108/eb004192.

Taj, A. Fabregas, E. Abouhilal, A. Taifi, N. Malaouui, A. (2021) *Comparative Study of Traditional, Simulated, and Real Online Remote Laboratory: Student's Perceptions in Technical Training of Electronics.* International Journal of Online and Biomedical Engineering, 2021, Vol. 17 (5), pp. 33-48. https://doi.org/10.3991/ijoe.v17i05.21949.

Takhar, S. Liyanage, K. (2020) *The Impact of Industry 4.0 on Sustainability and the Circular Economy Reporting Requirements.* International Journal of Integrated Supply Management (IJISM). https://doi.org/10.1504/IJISM.2020.107845.

Tapia, J. Huacani, L. Mamni, D. Paredes, D. Mamani, M. (2020) *Importance of Laboratory Work on the Teach and Learn Process Ion Engineering.* 2020 IEEE International Symposium on Accreditation of Engineering and Computing Education (ICACIT). doi.10.1109/ICACIT50253.2020.9277674.

Taulli, T. (2020) *Implementing AI Systems: Transform Your Business in 6 Steps.* Apress L. P. 2020 ProQuest Ebook Central.

Teacherhead. (2013) *Assessment Standards and the Bell Curve.* [online] Available from: https://teacherhead.com/2013/07/17/assessment-standards-and-the-bell-curve/ [Accessed 23 February 2021].

Teachthought. (2022) *What Are Alternatives to Bloom's Taxonomy?* [online] Available from: https://www.teachthought.com/critical-thinking/alternatives-blooms/ [Accessed 17 March 2022].

Techwelkin. (2022) *All About Dark Web and Deep Web Access.* [online] Available from: https://techwelkin.com/dark-web-access-deep-web [Accessed 19 March 2022].

Tenopir, C. King, D. (2004) *Communication Patterns of Engineers.* Wiley-IEEE Computer Society.

The Complete University Guide. (2021) *The University of Derby (UK).* [online] Available from: https://www.thecompleteuniversityguide.co.uk/universities/university-of-derby [Accessed 6th November 2022].

The Leaf Project. (2013) *Project Resources: What is a Reliable Source for Academic Research?* [online] https://www.leaflanguages.org/instructional-resources-what-is-a-reliable-source-for-academic-research/ [Accessed 11 February 2022].

The University of Edinburgh. (2015) *Information Services: Predatory or Bogus Journals.* [online] Available from: https://www.ed.ac.uk/information-services/research-support/publish-research/scholarly-communications/predatory-or-bogus-journals [Accessed 20 March 2022].

Thistlethwaite, J. Dallest, K. Moran, M. Dunston, R. Roberts, C. Eley, D. Bogossian, F. Forman, D. Bainbridge, L. Drynan, D. Fyfe, S. (2016) *Introducing the Individual Teamwork Observation and Feedback Tool (iTOFT).* Journal of Interprofessional Care. 30 (4), pp. 526-528. https://doi.org/10.3109/13561820.2016.1169262.

Toh, C. Miller, S. (2015) *How Engineering Teams Select Design Concepts: A View through the Lens of Creativity.* Journal of Design Studies 38 (2015) 111-138 doi: 10.1016/j.destud.2015.03.001.

Toit-Brits, C. (2019) *A Focus on Self-Directed Leaning: The Role that Educators' Expectations Play in the Enhancement of Students' Self-Directedness.* Journal of South African Education Vol. 39. No. 2. May 2019.

Tompkins, K. Brecht, K. Tucker, B. Neander, L. (2016) *Who Matters Most? The Contribution of Faculty, Student-Peers, and Outside Support in Predicting Graduate Student Satisfaction.* Journal of Training and Education in Professional Psychology. 2016, Vol. 10. No. 2. 102-108.

Tricker, R. (2015) *ISO 9001:2015 For Small Businesses.* London. Routledge, 2016. ISBN: 9781138025837.

Ullah, I. Tang, D. Yin, L. (2016) *Engineering Product and Process Design Changes: A Literature Overview*. doi: 10.1016/j.procir.2016.10.010.

Universities UK, (2022) *International Student Recruitment Data.* [online] Available from: https://www.universitiesuk.ac.uk/universities-uk-international/explore-uuki/international-student-recruitment/international-student-recruitment-data [Accessed 15 August 2022].

University of Auckland. (2018) *Resources for Teaching – Group Work.* [online] Available from: https://www.clear.auckland.ac.nz/en/resources-for-teaching/group-work.html [Accessed 29 July 2018].

Value Analysis (2023) *VA in Depth.* [online] Available from: Function Analysis system Technique (FAST) - Canadian Society of Value Analysis [Accessed 22 September 2023]

Vesma, V. (1980) *Careers in Design Engineering.* Journal of Education + Training, Vol. 22 Iss. 4 pp. 101-108 doi: 10.1108/eb06701.

Volchenkova, K. Zhezhera, E. (2021) *Online Course on Soft Skills for Global Engineers. 2021* International Conference on Quality Management, Transport and Information Security. Information Technologies (IT&QM&IS). 2021, pp. 874-878.

Walker, W. Prod, E. (1959) *Teaching Topics: The Teaching of Jig and Tool design.* Journal of Education + Training, Vol. 1 Iss 6 pp. 28 – 31 doi: 10.1108/eb014751.

Wang, J. Xiong, C. Lu, M. Li, K. (2014) *Longitudinal Driving Behaviour on Different Roadway Categories: An Instrumented-Vehicle Experiment, Data Collection and Case Study in China.* The Institute of Engineering and Technology.

Wang, W. (2016) *Reverse Engineering – Technology of Reinvention.* Taylor and Francis Group, Baton Rouge.

Warren, K. (2022) *What is Generation Z (GenZ)?* [online] Available from: https://www.investopedia.com/generation-z-gen-z-definition-5218554 [Accessed 16 August 2022].

WebPa. (2019) *Peer Marks for Group Work.* [online] Available from: http://webpaproject.lboro.ac.uk/ [Accessed 23 February 2019].

Westerweel, B. Basten, R. Houtum, G. (2018) *Traditional or Additive Engineering? Assessing Component Design Options Through Lifecycle Cost Analysis.* European Journal of Operational Research 270 (2018) 570-585.

Whitney, D. (2006) *The Role of Key Characteristics in the Design of Mechanical Assemblies.* Journal of Assembly Automation, Vol. 26 Iss 4 pp. 315-322 doi: 10.1108/01445150610705236.

Whyte, G. Bytheway, A. (2016) *The V-Model of Service Quality: An African Case Study.* European Journal of Marketing. Vol 51, No 5/6, 2017 pp.923-945.

Wicklein, R. (2006) *Five Good Reasons for Engineering Design as the Focus for Technology Education.* The Technology Teacher.

Wiley, J. (2016) *Case Studies in Mechanical Engineering: Decision Making, Thermodynamics, Fluid Mechanics, and Heat Transfer. John Wiley & Sons, Incorporated. 1st Edition.*

Witte, M. (2022) *Gen Z Are Not 'Coddled'. They are Highly Collaborative, Self-Reliant and Pragmatic, According to New Stanford-Affiliated Research.* [online] Available from: https://news.stanford.edu/2022/01/03/know-gen-z/ [Accessed 16 August 2022].

Women's Engineering Society. (2020) *Useful Statistics.* [online] Available from: https://www.wes.org.uk/content/wesstatistics#:~:text=12.37%25%20of%20all%20engineers%20are%20women%20in%20the,A%20Level%20Physics%20in%202018%20were%20female.%20%2822%29 [Accessed 4 September 2022].

Wrigley, C. Straker, K. (2017) *Design Thinking Pedagogy: The Educational Design Ladder.* Journal of Innovations in Education and Teaching international. 54:4, 374-385, doi: 10.1080/14703297.2015.1108214.

Xie, C. Schimpf, C. Chao, J. Nourian, S. Massicotte, J. (2018) *Learning and Teaching Engineering Design Modelling and Simulation on a CAD Platform.* Journal of Computer Applications Engineering Education. 2018;26:824-840 doi:1002/cae.21920.

Yasar, S. Baker, D. Robinson-Kurpius, S Krause, S. Roberts, C. (2006) *Development of a Survey to Assess K-12 Teachers' Perceptions of Engineers and Familiarity with Teaching Design, Engineering, and Technology.* Journal of Engineering Education.

Yin,Y. Qin, S. Holland, R. (2011) *Development of a Design Performance Measurement Matrix for Improving Collaborative Design During a Design Process.* International Journal of Productivity and Performance Management. Vol. 60 Iss 2 pp. 152 – 184 doi: 10.1108/01443579510083622.

Zhitnikov, V. Sherykhalina, N. Muksimova, R. (2021). *Investigation of Errors in Solving Problems for Simple Equations of Mathematical Physics by Iterative Methods.* Journal of Numerical Analysis and Applications, 2021, Vol 14, No. 2. pp. 115-125.

Zhuming, B. Xiaoquin, W. (2020) *Computer Aided Design and Manufacture.* John Wiley & Sons Ltd and ASME Press ISBN 9781119534335.

Zip Forecasting (2020) *Forecasting Methods for Any Industry – Everything You Need to Know.* [online] Available from: https://zipforecasting.com/forecasting-methods.html [Accessed 16 September 2023]

BIBLIOGRAPHY

Bouquet, J. Hensgen, L. Klink, A. Jacobs, T. Klocke F. Lauwers, B. (2014) *Fast Production of Gear Prototypes – A Comparison of Technologies.* doi: 10.1016/j.procir.2014.03.066.

Budhe, S. Banea, M. Barros, S. da Solva, L. (2016) *An Updated Review of Adhesively Bonded Joints in Composite Materials.* doi: 10.1016/j.ijadhadh.2016.10.010.

Huang, S. Fang, N. (2012) *Predicting Student Academic Performance in an Engineering Dynamics Course: A Comparison of Four Types of Predictive Mathematical Models. doi:* 10.1016/j.compedu.2012.08.015.

Huang, T. Zhang, Y. (2016) *Numerical Modelling of Mechanical Behaviour of Engineered Cementitious Composites under Axial Tension.* doi: 10.1016/jcompstruc.2016.05.025.

Kumar, V. (2009) *A Process for Practicing Design Innovation.* Journal of Business Strategy, Vol. 30 Iss 2/3 pp. 91-100 doi: 10.1108/02756660910942517.

Louks, R. Askes, H, Susmel, L. (2016) *A Generalised Approach to Rapid Finite Element Design of Notched Materials against Static Loading using the Theory of Critical Distance*. doi: 10.1016/j.matdes.2016.07.047.

Male, D. (1963) *Mechanical Engineering Laboratories – Their Design, Equipment and Use.* Journal of Education + Training, Vol. 5 Iss 8 pp. 369-370.

Melo, J. Bi, J. Tsai, S. (2016) *A Novel Invariant-based Design Approach to Carbon Fibre Reinforced Laminates.* doi: 10.1016/jcompstruct.2016.09.055.

Odora, R. (2015) *Integrating Product Design and Entrepreneurship Education: A Stimulant for Enterprising Design and Engineering Students in South Africa.* doi: 10.1016/j.protcy.2015.07.044.

Petrelli, D. Lanfranchi, V. Ciravegna, F. Begdev, R. Chapman, S. (2011) *Highly Focused Document Retrieval in Aerospace Engineering User Interaction Design and Evaluation.* Aslib Proceedings, Vol 63 Iss 2/3 pp. 148-167.

Porton, M. Wynne, B. Bamber, R. Hardie, C. Kalsey, M. (2016) *Structural Integrity for DEMO: An Opportunity to Close the Gap from Materials Science to Engineering Needs.* doi: 10.1016/j.fusengdes.2015.12.050.

Tannco, M. Viles, E. Ilzarbe, L. Alvarez, M. (2009) *Barriers Faced by Engineers when Applying Design of Experiments.* The TQM Journal, Vol. 21 Iss 6 pp. 565-575.

Tchier, F. Rabai, L. Mili, A. (2015) *Putting Engineering into Software Engineering: Upholding Software Engineering Principles in the Classroom.* doi: 10.1016/j.chb.2015.01.054.

The Home Shop Machinist (2023). *Craftex B227L Lathe Gearbox Noise Fix.* [online] Available from: https://bbs.homeshopmachinist.net/forum/general/46606-craftex-b227l-lathe-gearbox-noise-fix [Accessed 10 September 2023]

Tranfield, D. Smith, S. (2002) *Organisations Designs for Teamworking.* International Journal of Operations & Production Management, Vol. 22 Iss 5 pp. 471-491 doi: 10.1108/01443570210425138.

Woodside, A. Biemans, W. (2005) *Modelling Innovation, Manufacturing, Diffusion and Adoption/Rejection Processes.* Journal of Business & Industrial Marketing, Vol 20 Iss 7 pp. 380-393.

Wright, D. Yu, B. (1998) *Strategic Approaches to Engineering Design Process Modelling,* Business Process Management Journal, Vol. 4 Iss 1 pp. 56-71 doi: 10.1108/14637159810200175.

APPENDICES

APPENDIX 1

STUDENT'S KNOWLEDGE SURVEY

UNIVERSITY of DERBY

Project Title: Student's Knowledge Survey

I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask any questions.

☐ Please tick box.

I understand that my participation is voluntary, and I am free to withdraw up to two weeks after participating without giving any reason.

☐ Please tick box.

I confirm that I am over 18.

☐ Please tick box.

I agree to take part in this survey.

☐ Please tick box.

☐ Please tick the box to confirm that you have read and understood this information.

Name_______________________________________ Date_______________

<u>Invitation to Participate</u>

Study Title: Student's Knowledge Survey

You are invited to take part in a research study that is being conducting as part of a PhD in teaching mechanical engineering design at the University of Derby (UK).

The study aims to investigate the basic engineering knowledge of students completing module 6ME500 Advanced Engineering Design Modelling.

This will consist of a confidential questionnaire agreeing or disagreeing with several statements.

Version 1

Participate Information Sheet

Study Title: Student's Knowledge Survey

Do I have to take part?

It is important for participants to understand that participation is completely voluntary and any participant taking part in the study is free to withdraw from the study at any point up to the publication of the PhD thesis.

What happens to me if I take Part?

If you consent to taking part in this study, you will be expected to identify basic mechanical engineering components.

Will my participation in this study be kept confidential?

Yes. All information will be treated as confidential.

Version 1

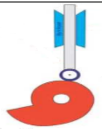
Debriefing Sheet

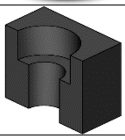
Study Title: Student's Knowledge Survey

Thank you very much for taking the time to participate in this survey, which investigates the basic engineering knowledge of student's completing module 6ME500 Advanced Engineering Design Modelling.

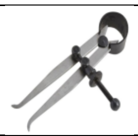
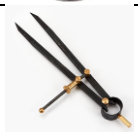
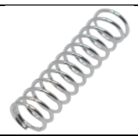
If you decide to withdraw your data from the study, this can be done without giving any reason. Please note, this withdrawal can only take place up to the publication of the PhD thesis.

Version 1

Module 6ME500 Advanced Engineering Design Modelling with Answers		
Instructions – Identify **from memory**, as many of these engineering components as possible		
No	Component	Component name
1		Gasket
2		Actuator
3		Spring Cotter Pin
4		Solid Rivet
5		Wiggler Set
6		Internal Circlip
7		Cam and Follower
8		Helical Gear
9		Tapered Roller Bearing
10		Splined Shaft
11		Lock Nut
12		Shakeproof Washer

13		Thread Insert (Helical)
14		Tension Spring
15		Pop Rivet
16		Slotted Spring Pin
17		Rotary Shaft Seal
18		Rigid Coupling
19		External Circlip
20		Keyway
21		Spur Gear
22		Single Race Plain Roller Bearing
23		Counter Bored Hole
24		Nut
25		Hexagon Head Bolt
26		Plain Bearing

27		Split Pin
28		Grease Nipple
29		Woodruff Key
30		Castle Nut
31		Sprocket
32		Circlip Pliers
33		Outside Callipers
34		Needle Bearing
35		Grub Screw
36		Hose Clip
37		Counter Sunk Screw
38		Clevis Pin
39		Toolmakers Clamps
40		Spring Washer

41		Inside Callipers
42		Allen Keys
43		Micrometer
44		Plain Washer
45		Dividers
46		Thrust Bearing
47		G-Clamp
48		Allen Socker Screw
49		Compression Spring
50		Dial Test Indicator

APPENDIX 2

HEI INTERVIEW DOCUMENTS

Invitation to Participate

Study Title: Research and Compare HEI Methods of Teaching Mechanical Engineering Design.

This is an invite to take part in a research study being conducted as part of a PhD in teaching mechanical engineering design at the University of Derby (UK).

The study aims to investigate the methods used to teach mechanical engineering design in at least 3 HEI. Comparing the methods with each other and with The University of Derby (UK).

This will consist of an interview to discuss the methods used to teach mechanical engineering design in your home HEI, and the research findings in the PhD and methods used by The University of Derby (UK).

Version 1

09/09/2022

Participate Information Sheet

Study Title: Research and Compare Higher Education Institutions (HEI) Methods of Teaching Mechanical Engineering Design.

This is an invite to take part in a research study that is being conducted as part of a PhD in teaching mechanical engineering design at the University of Derby (UK).

The study aims to investigate the methods used to teach mechanical engineering design in at least 3 HEI. Comparing the methods with each other and with The University of Derby (UK).

This will consist of an interview to discuss the methods used to teach mechanical engineering design in your home HEI, and the research findings in the PhD and methods used by The University of Derby (UK).

Do I have to take part?

It is important for participants to understand that participation is completely voluntary and any participant taking part in the study is free to withdraw from it at any point up to the publication of the PhD thesis.

What happens to me if I take Part?

If you consent to taking part in this study, you will be expected to answer questions in an interview on methods used to teach mechanical engineering design in their home HEI. Research findings of the PhD and methods used at the University of Derby (UK) to teach mechanical engineering design will also be discussed.

Will my participation in this study be kept confidential?

No. Your work contact details, and name will be published in the PhD thesis. A brief review of the interview and comments made by the participant will also be published in the PhD thesis.

Version 1

09/09/2022

Interview Questions and Consent

Project Title: Research and Compare Higher Education Institutions (HEI's) Methods of Teaching Mechanical Engineering Design.

1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask any questions.

☐ Please tick box.

2. I understand that my participation is voluntary, and I am free to withdraw up to two weeks after participating without giving any reason.

☐ Please tick box.

3. I confirm that I am over 18.

☐ Please tick box.

4. I agree to take part in this survey.

☐ Please tick box.

☐ Please tick the box to confirm that you have read and understood this information.

Name____ Date________________

Questions	**Subsidiary Questions**	**Reply – Main Points**
Describe the mechanical engineering design module logistics.	Average number of students Full-time/Part-time Male/Female National/ International	
How are classes organised?	Average class size Number of classes Individual work or group Average hours in-house Average hours home working	
What would be a typical assessment design task?	What work would the student's hand-in to go toward their assessment? Details of assessment mark allocations. What is the minimum pass grade? New design or innovation.	
Describe the main teaching methods.	Are any of the following or similar used: presentations, report writing, viva voce, prototypes, reverse engineering etc? The University of Derby (UK) introduced an informal report, presentation in week 4, online group working	
Is each year linked together throughout the programme?	Are modules stand alone or linked? Are students on direct entry at a disadvantage compared to students on a full degree?	
Are there any areas of design that students	Calculations, idea generation, modelling, assembly, production, costing, manufacture, design detail	

find particularly difficult?		
Do you use modelling software?	Software name and version. What advanced features are students expected to demonstrate (FEA, parametric, CFD, optimisation etc.)?	
Do you observe any differences between teaching part-time and full-time students?	If yes, please describe the main differences and how these are mitigated?	
How do students carry out research?	What are the preferred methods students use to research (internet, library, peers, primary, secondary)?	
What standards are students expected to follow?	What standards are used, national, international, university, mixed?	
Is the students basic engineering knowledge at a reasonable level, any gaps found?	The University of Derby (UK) has found a big difference between part-time and full-time students, has this been your experience?	

As part of the design process, is reverse engineering taught?	Research often provides a complete design solution, do students have any difficulties understanding the solution or do they sometime need help understanding it?	

Debriefing Sheet

Study Title: Research and Compare Higher Education Institutions (HEI) Methods of Teaching Mechanical Engineering Design.

Thank you very much for taking the time to participate in this study, which investigates the methods HEI used to teach mechanical engineering design.
Please be reminded that your data will be published in a PhD thesis. If you decide that you would like to withdraw your data from the study, you can do so without giving any reason. Please note, this withdrawal can only take place up to the publication of the PhD thesis.

Version 1
09/09/2022

APPENDIX 3

STUDENT GROUP SURVEYS

Project Title: Working in a Mechanical Engineering Design Group

I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask any questions.

☐ Please tick box.

I understand that my participation is voluntary, and I am free to withdraw up to two weeks after participating without giving any reason.

☐ Please tick box.

I confirm that I am over 18.

☐ Please tick box.

I agree to take part in this survey.

☐ Please tick box.

☐ Please tick the box to confirm that you have read and understood this information.

Name_______________________________________ Date_______________

Invitation to Participate

Study Title: Working in a Mechanical Engineering Design Group

You are invited to take part in a research study that is being conducted as part of a PhD in teaching mechanical engineering design at the University of Derby (UK).
The study aims to investigate the strength and weakness of working in a group to complete module 6ME500 Advanced Engineering Design Modelling.
This will consist of a confidential questionnaire where you are asked if you agree or disagree with several statements.

Version 1

Participate Information Sheet

Study Title: Working in a Mechanical Engineering Design Group

Do I have to take part?

It is important for participants to understand that participation is completely voluntary and any participant taking part in the study is free to withdraw from the study at any point up to the publication of the PhD thesis.

What happens to me if I take Part?

If you consent to taking part in this study, you will be expected to answer questions by stating if you agree or disagree with certain statement. You will also be asked for any relevant comments not included in the survey.

Will my participation in this study be kept confidential?

Yes. All information will be treated as confidential.

Version 1

Debriefing Sheet

Study Title: Working in a Mechanical Engineering Design Group

Thank you very much for taking the time to participate in this survey, which investigates the effect of working within a mechanical engineering design team.

If you decide that you would like to withdraw your data from the study, you can do so without giving any reason. Please note, this withdrawal can only take place up to the publication of the PhD thesis.

Version 1

6ME500 Advanced Engineering Design Modelling

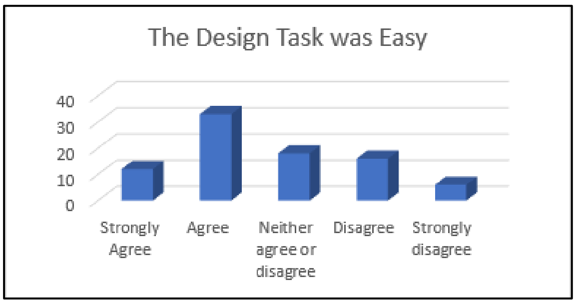
Survey 5 December 2016

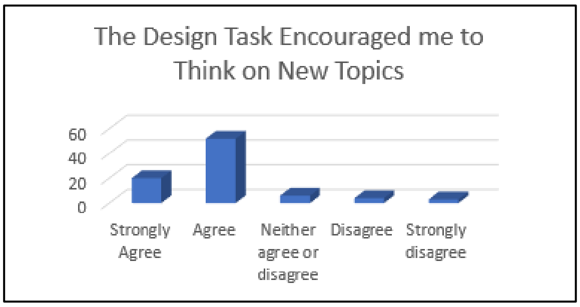
Please respond by ticking, using the following scale:

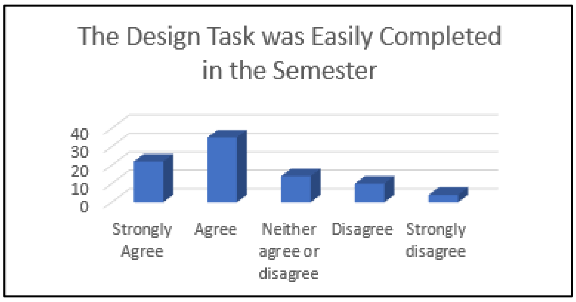
	Strongly Agree	Agree	Neither Agree or Disagree	Disagree	Strongly Disagree
The design task was easy.					
The design task encouraged me to think on new topics.					
The design task was easily completed in the semester.					
The library facilities contributed significantly to my design knowledge.					
Fellow students helped in my understanding of design problems.					
This design task would be better completed as a group activity.					
Social media was used to assist in this design task?					
All of your design was completed in the university.					
Modelling software made the design task easier.					

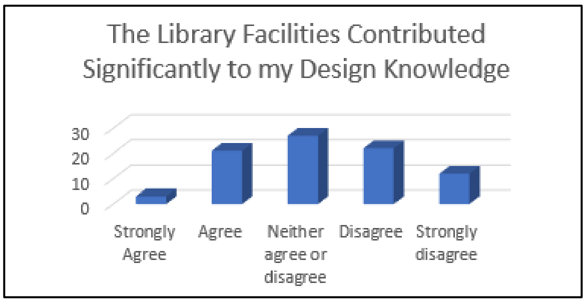
Academic Year 2016/17 Results

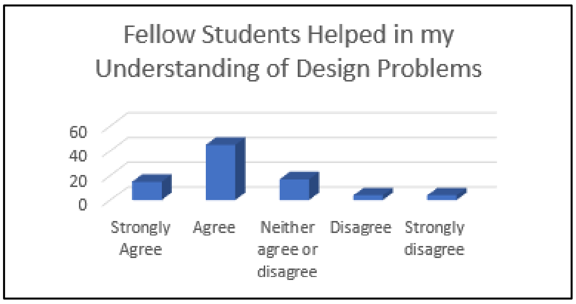
6ME500 Advanced Engineering Design Modelling Survey 05/12/2016									
	1	2	3	4	5	6	7	8	9
Strongly Agree	12	20	22	3	15	15	16	15	30
Agree	33	52	35	21	45	19	15	19	38
Neither agree or disagree	18	6	14	27	17	17	19	8	10
Disagree	16	4	10	22	4	21	19	27	4
Strongly disagree	6	3	4	12	4	13	16	16	3
	85	85	85	85	85	85	85	85	85

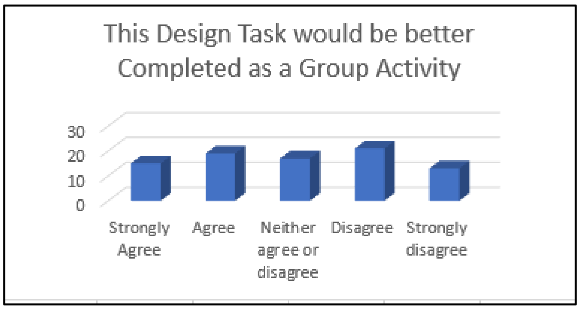


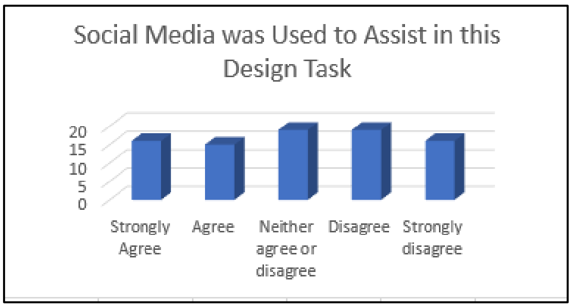


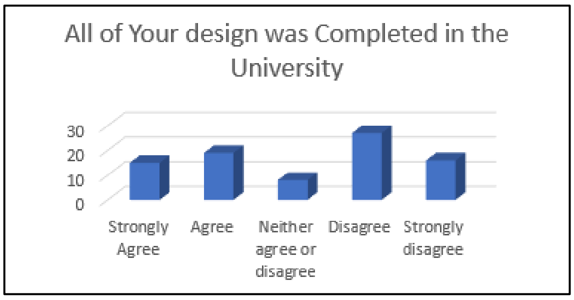


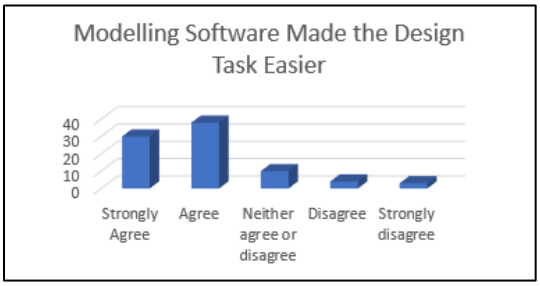











Modelling Software Made the Design Task Easier
40
30
20
10
0
Strongly Agree
Agree
Neither agree or disagree
Disagree
Strongly disagree

(Sole, 2023)

6ME500 Advanced Engineering Design Modelling

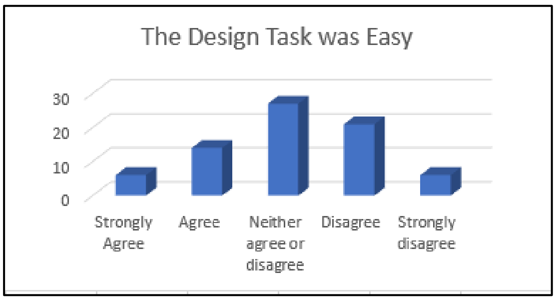
Survey 27 November 2017

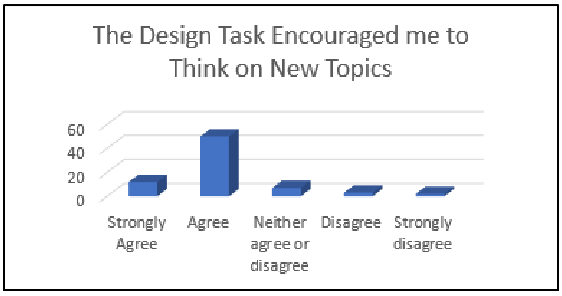
Please respond by ticking, using the following scale:

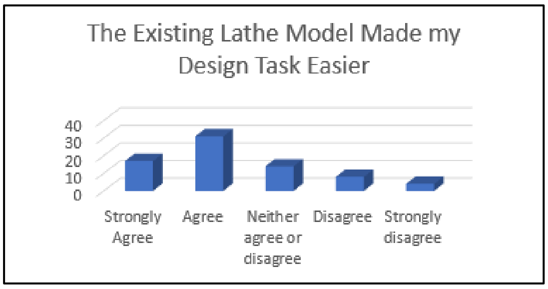
	Strongly Agree	Agree	Neither Agree or Disagree	Disagree	Strongly Disagree
The design task was easy.					
The design task encouraged me to think on new topics.					
The existing lathe model made my design task easier.					
The library facilities contributed significantly to my design knowledge.					
Fellow students helped in my understanding of design problems.					
This design task would be better completed as a group activity.					
Social media was used to assist in this design task?					
All of your design was completed in the university.					
Modelling software made the design task easier.					

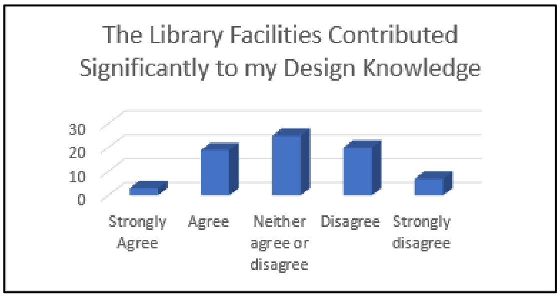
Academic Year 2017/18 Results

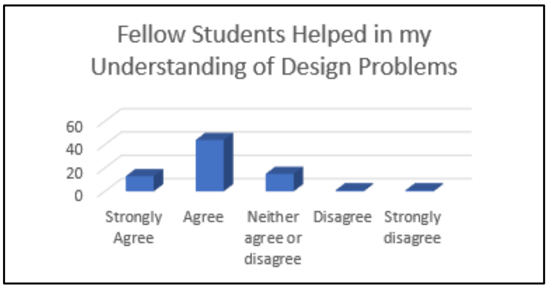
6ME500 Advanced Engineering Design Modelling Survey 27/11/2017									
	1	2	3	4	5	6	7	8	9
Strongly Agree	6	12	17	3	13	12	4	13	25
Agree	14	50	31	19	44	17	8	19	36
Neither agree or disagree	27	7	14	25	15	16	10	6	8
Disagree	21	3	8	20	1	19	25	25	4
Strongly disagree	6	2	4	7	1	10	27	11	1
	74	74	74	74	74	74	74	74	74

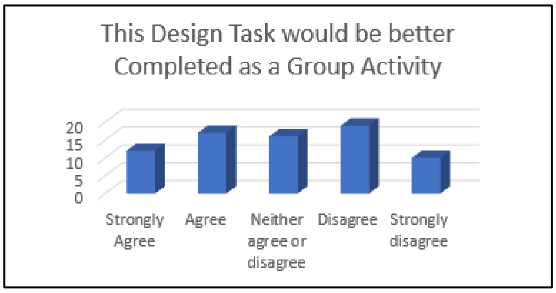


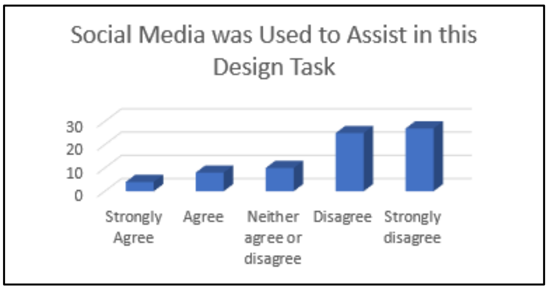


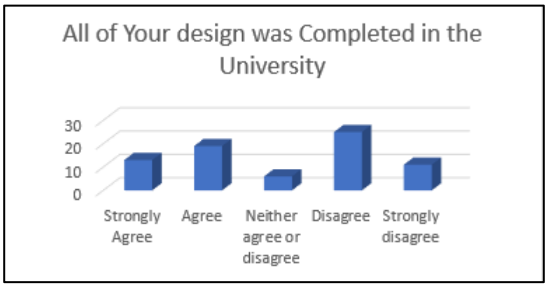


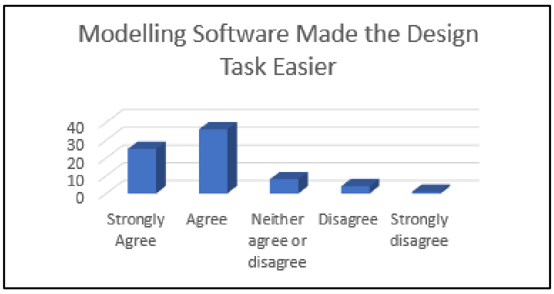











Modelling Software Made the Design Task Easier
40
30
20
10
0
Strongly Agree
Agree
Neither agree or disagree
Disagree
Strongly disagree

(Sole, 2023)

Rubric for Assessing Group Members' Ability to Participate Effectively as Part of a Team

Rater: ____ Date: ______________

Group
Topic: ____

(Circle the appropriate score for each criterion for each member of your group.)

Member Rated (Be sure to rate yourself, too!)	Listening Skills	Openness to others' ideas	Preparation	Contribution	Leadership
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5
	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5	0 1 2 3 4 5

Criterion	Excellent (5)	Good (4)	Fair (3)	Needs to Improve (2)	Unacceptable (1)	Missing (0)
Listening Skills	Routinely restates what others say before responding; rarely interrupts; frequently solicits others' contributions; sustains eye contact	Often restates what others say before responding; usually does not interrupt; often solicits others' contributions; makes eye contact	Sometimes restates what others say before responding; sometimes interrupts; sometimes asks for others contributions; sometimes makes eye contact.	Rarely restates what others say before responding; often interrupts; rarely solicits others' contributions; does not make eye contact; sometimes converses with others when another team member is speaking	Doesn't restate what others say when responding; often interrupts; doesn't ask for contributions from others; is readily distracted; often talks with others when another team member speaks	Never shows up and never contributes.
Openness to others' ideas	Listens to others' ideas without interrupting; responds positively to ideas even if rejecting; asks questions about the ideas	Listens to others' ideas without interrupting; responds positively to the ideas even if rejecting	Sometimes listens to others' ideas without interrupting; generally responds to the ideas	Interrupts others' articulation of their ideas; does not comment on the ideas	Interrupts others' articulation of their ideas; makes deprecatory comments and/or gestures	Never shows up and never contributes.
Preparation	Always completes assignments; always comes to team sessions with necessary documents and materials; does additional research, reading, writing, designing, implementing	Typically completes assignments; typically comes to team sessions with necessary documents and materials	Sometimes completes assignments; sometimes comes to team sessions with necessary documents and materials	Sometimes completes assignments; sometimes comes to team sessions with necessary documents and materials.	Typically does not complete assignments; typically comes to team sessions without necessary documents and materials	Never shows up and never contributes.
Contribution	Always contributes; quality of contributions is exceptional	Usually contributes; quality of contributions is solid	Sometimes contributes; quality of contributions is fair	Sometimes contributes; quality of contribution is inconsistent	Rarely contributes; contributions are often peripheral or irrelevant; frequently misses team sessions	Never shows up and never contributes.
Leadership	Seeks opportunities to lead; in leading is attentive to each member of the team, articulates outcomes for each session and each project, keeps team on schedule, foregrounds collaboration and integration of individual efforts	Is willing to lead; in leading is attentive to each member of the team, articulates general direction for each session and each project, attempts to keep team on schedule	Will take lead if group insists; not good at being attentive to each member of the team, sometimes articulates direction for sessions, has some trouble keeping team on schedule	Resists taking on leadership role; in leading allows uneven contributions from team members, is unclear about outcomes or direction, does not make plans for sessions or projects	May volunteer to lead but does not follow through; misses team sessions, does not address outcomes or direction for sessions or projects, team members become anarchical	Never shows up and never contributes.

Group Process Questions

Describe any communication problems within your group, or describe how well members of your group were able to communicate with each other.

Did you meet outside of class to establish goals and stay in tune with each other?

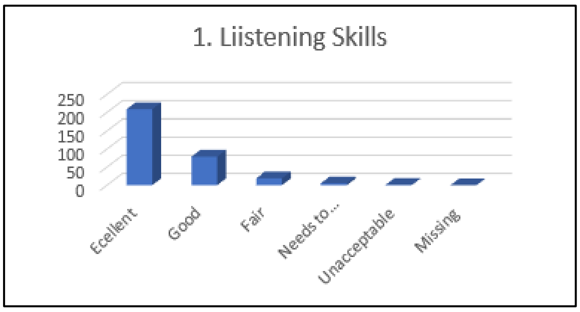
What worries you the most when working in groups?

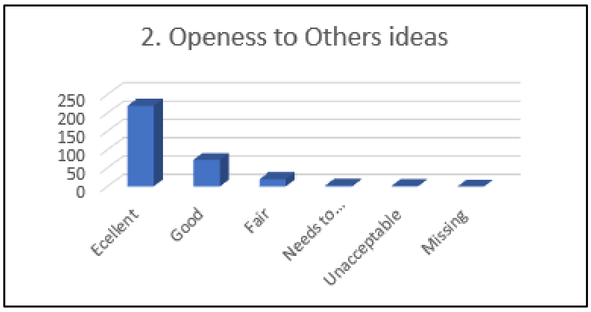
Did you think you did your fair share?

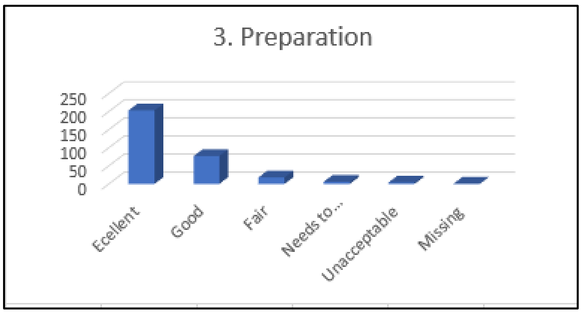
Did others do their fair share?

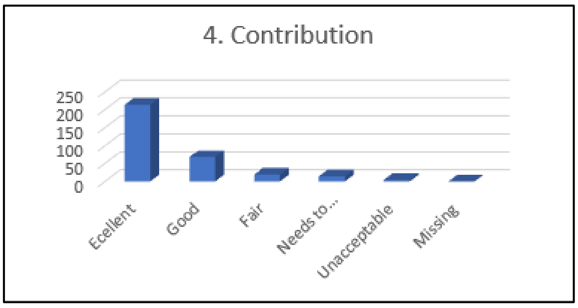
Academic Year 2018/19 Results

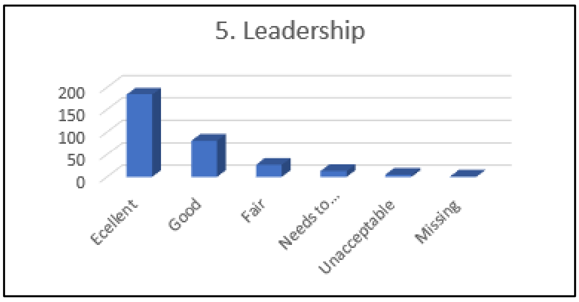
6ME500 Advanced Engineering Design Modelling Survey 27/05/2019					
	1	2	3	4	5
Ecellent	209	220	203	213	184
Good	79	72	77	68	81
Fair	19	20	18	19	27
Needs to Improve	5	3	6	14	13
Unacceptable	1	2	4	4	5
Missing	0	0	1	0	1







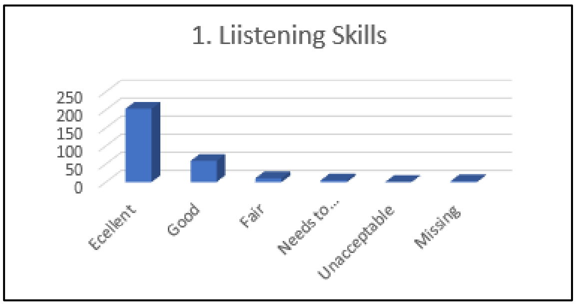


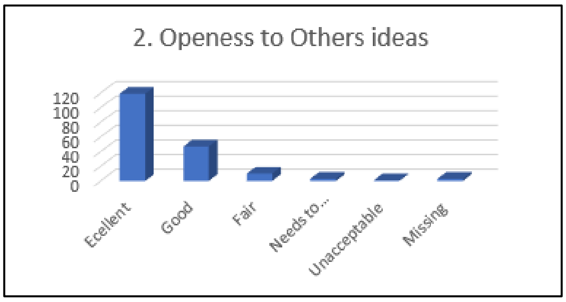


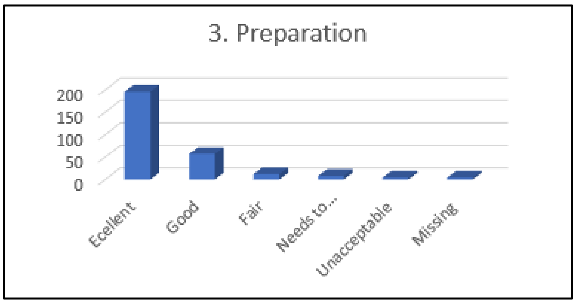
(Sole, 2023)

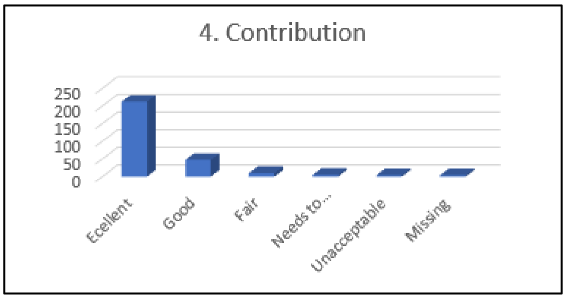
Academic Year 2019-20 Results

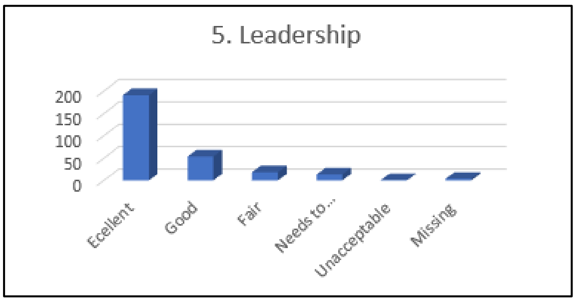
6ME500 Advanced Engineering Design Modelling Survey 24/02/2020					
	1	2	3	4	5
Ecellent	203	119	196	212	191
Good	59	47	57	47	54
Fair	11	10	12	10	19
Needs to Improve	5	3	8	5	14
Unacceptable	1	1	4	4	1
Missing	3	3	4	4	4











(Sole, 2023)

APPENDIX 4

6ME500 MODULE SPECIFICATION & SAMPLE ASSIGNMENT

Module Title	**ADVANCED ENGINEERING DESIGN MODELLING**		**Date of Approval**		**Sep-19**
Module Code	**6ME500**	**Module Level**	**6**	**Credit value**	**20**
Module Delivery Mode	Online/Distance	Blended/Face to Face ✓	Work-Based Learning		
	Apprenticeship ✓		Hours of work experience: N/A		
Module Description	Rapidly advancing technology in the area of 3-Dimensional Parametric Solid Modelling and Profiling has caused a significant shift in the working practices of traditional design engineers. This module aims to impart a significant understanding of parametric principles and will update the student's skills to the application of such techniques in a 3-Dimensional Parametric Solid Modelling/Conceptual Design environment using enhanced modelling techniques. It is essential that such a designer be able to parametrically specify and functionally examine models constructed from initial concept.				
Module Learning Outcomes	On successful completion of the module, students will be able to: 1. Apply and critically evaluate the design intent and full parametric in assembly and the use of complex modelling techniques. 2. Design, model and analyse a component using Finite Element Analysis tools.				
Module Content	**Parts** Advanced sketch techniques, sketch fully defined, dimensioning, advanced features commands and editing part using all features command. **Assembly** Assembling parts, Assembly fully defined, Exploding Assemblies, Creation of movie motion on assembly. **Drawing** Deriving an Engineering Drawing from existing files. Designing the drawing to make it comply with existing engineering standards. **Sheet Metal and Weldments** Fundamental of sheet metal and Weldments commands **Mould Design** Fundamental of mould design **Finite Element Modelling** Apply the principle of Finite Element Modelling, hand calculation on the design and application.				

	If you are a Degree Apprenticeship student, the following knowledge, skills and behaviours are addressed in this module. For **Aerospace Engineering Degree Apprenticeship** students: **Knowledge and Skills** 1. Understand engineering process and practices covering: mechanical/electrical/electronic systems design, design and stress analysis e.g. computer aided engineering techniques, systems design, integration and test, in-service and through product life support, advanced manufacturing, aerospace quality and governance 2. Understand the applicable regulatory and quality requirements as the systems and products mature through their development, qualification and In-Service phases 3. Understand and apply analytical methods (engineering mathematics – algebra, differentiation, function, geometry, trigonometry and statistics) **Behaviours** B. Design and development of processes, systems, services and products Contributing to the continuing development of Engineering within their domain D. Communication and inter-personal skills Be able to demonstrate a range of communication styles and methods. Understanding the importance of networks within and across functions. For **Manufacturing Engineering Degree Apprenticeship** students: **Knowledge** K3 3D Computer Aided Design and Computer Aided Engineering K7 Product improvement and engineering project management Skills S3 Secure and manage appropriate resources Occupational Professional Discussion S4 Manage budgets. **Behaviours** B4 Problem solving orientation: Identifies issues quickly, enjoys solving complex problems and applies appropriate solutions. Has a strong desire to push to ensure the true root cause of any problem is found and a solution identified which prevents further recurrence. B5 Quality focus: Follows rules, procedures and principles in ensuring work completed is fit for purpose and pays attention to detail / error checks throughout activities.

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Indicative Work-Related Tasks (Aerospace Engineering Degree Apprenticeship)

- Construct and evaluate a complex computer aided modelling of a part, focusing on applications in aerospace engineering.
- Assemble a number of complex CAD parts into a stable assembly, as part of a work-based project.
- Carry out an advanced finite element analysis for a part or assembly and produce evidence.

Indicative Work-Related Tasks (Manufacturing Engineering Degree Apprenticeship)

- Construct and evaluate a complex computer aided modelling of a part, focusing on applications in manufacturing engineering.
- Assemble a number of complex CAD parts into a stable assembly, as part of a work-based project.
- Carry out an advanced finite element analysis for a part or assembly and produce evidence.

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<tr><td rowspan="3">Module Learning and Teaching</td><td>Scheduled Learning and Teaching Activities</td><td>24%</td></tr>
<tr><td>Guided Independent Study</td><td>76%</td></tr>
<tr><td>Placement Learning</td><td>0%</td></tr>
<tr><td>Module Assessment</td><td colspan="2">

This assessment applies to Full Time, Part Time and Apprenticeship Students

Summative Assessment (100%):

CW: 100% Weighting: Learning Outcome 1 & 2
Students will be expected to produce a series of individual 3-Dimensional parts using the CAD system and then assemble them together on the CAD system using the appropriate functionality and constraints. Students will also be expected to produce a complex design based on Finite Element Analysis after conducting the hand calculation and drawing of one of the parts. Furthermore, an animation of the assembly will also be expected. The Assignment is handed in on CD. 4500-word equivalent.

The End Point Assessment is independent for degree apprenticeships.

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<tr><td>Reading List</td><td colspan="2">

Link to Aspire

http://liblists.derby.ac.uk/index.html

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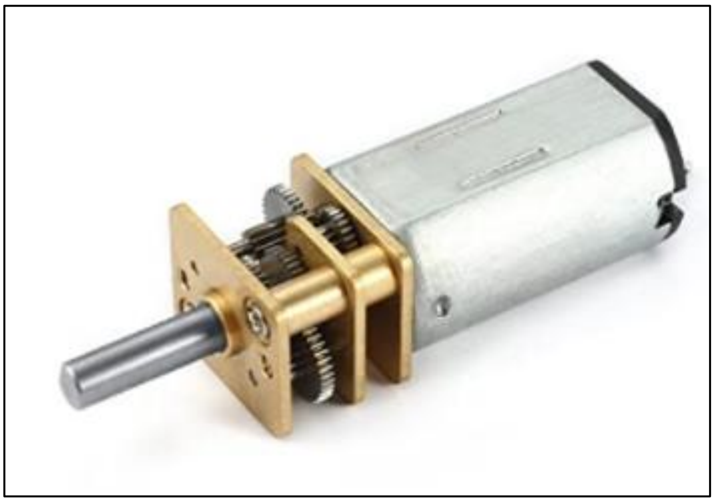
Advanced Engineering Design Modelling

6ME500



6ME500 Assessment Brief

Martin Sole

6ME500 Advanced Engineering Design Modelling

Contents

UNIVERSITY of DERBY

Module Leader

- martin Sole
- m.sole@derby.ac.uk
- 01332 593595

Key dates and details

Assessment Type:

Combination of individual and group work

Presentation, informal report, critique, formal report and 3D model

Assessment weighting:

Group presentation 10% (Group mark)

500-word Informal report 10% (Individual mark)

5 Slide critique 10% (Individual mark)

4000-word formal report 40% (Group mark)

Solidworks model 30% (Group work)

Word count/Length

500-word informal report – 500 words maximum

4000-word formal report – 4000 words maximum

5 Slide critique – 5 Powerpoint slides maximum

Note: Word counts are taken from Turnitin. No other word count will be used.

Learning Outcomes:

3. Apply and critically evaluate the design intent and full parametric in assembly and the use of complex modelling techniques.
4. Design, model and analyse a component using Finite Element Analysis tools.

Submission Method:

All work to be uploaded through Turnitin except the SolidWorks model which will be through Blackboard

Submission Date:

Assessment	**Sub-Assessment**	Weighting (%)	Submission Date	Return Date
	Group Presentation	10	W/c 18/10/21	W/c 08/11/21

Assessment	**Sub-Assessment**	Weighting (%)	Submission Date	Return Date
Assignment 1	500 Word Informal Report	10	18/11/21 23.59	09/12/21
	5 Slide Critique	10	23/12/21 23.59	13/01/22
	4000 Word Formal Report	40	23/12/21 23.59	13/01/22
	SolidWorks Model	30	23/12/21 23.59	13/01/22

Description of the assessment

Rapidly advancing technology in the area of 3-Dimensional Parametric Solid Modelling and Profiling has caused a significant shift in the working practices of traditional design engineers.
This module aims to impart a significant understanding of parametric principles and will update the student's skills to the application of such techniques in a 3-Dimensional Parametric Solid Modelling/Conceptual Design environment using enhanced modelling techniques. It is essential that such a designer be able to parametrically specify and functionally examine models constructed from initial concept.
On successful completion of the module, students will be able to:

5. Apply and critically evaluate the design intent and full parametric in assembly and the use of complex modelling techniques.
6. Design, model and analyse a component using Finite Element Analysis tools.

Assessment Content

An electric motor/gearbox is required to adjust the wing mirror position on a production saloon car.

The electric motor has already been selected and the specification has been provided by the manufacturers. The model is MM28. This specification cannot be changed (see attached specification sheet)

Your design team are to complete the following design task:

1. Design a gearbox to reduce the electric motor 'No load' speed of 9,600 rpm by a ratio of 30:1.
2. The reduction ratio must be within ±10%.
3. No changes can be made to the electric motor.
4. The completed electric motor/gearbox must fit within a space 85 x 35 x 35 mm.
5. The direction of the gearbox output shaft must be the same as the electric motor input shaft.
6. Noise from the electric motor/gearbox must be kept to a minimum.
7. The input and output shafts should be on the same centres.

Assessment Rubric

	Almost	Fair	Good	Very Good	Excellent	Outstanding
	1-39%	40-49%	50-59%	60-69%	70-79%	80-100%
Design specification	Basic detail, no or little research, lacks detail, no benchmarking	Basic detail, but with some research, no benchmarking	Reasonable detail. Some detailed research and benchmarking	Good detail. Research with citations, detailed benchmarking	Very good research with citations, detailed benchmarking with citations. Some sustainability	Very detailed, research, clear benchmarking data with citations from good sources. Sustainability
Initial designs sketches	Basic hand drawn sketches with little detail, no annotations. Poor clarity of idea	Basic hand drawn sketches with some detail, no annotations. Design ideas a little clearer	Hand drawn sketches with some detail, some annotation. Design idea clear and easy to understand	Hand drawn detailed sketches with good detail, some annotation. Clear design ideas well thought out, innovative.	Hand drawn detailed sketches, very good detail, annotation. Clear ideas well thought out. Basic calculations	Detailed sketches with annotations show very good detail. Clear ideas well thought out. Good calculations
Presentation of initial design	Uncoordinated. Poor slide quality. Poor timing.	Coordinated. Reasonable slide quality. Timing OK.	Range of design ideas clearly presented. Good slide quality. Timing good.	Detailed design ideas clearly presented. Some basic calculations. Ideas on materials.	Novel design ideas clearly presented. Gantt chart of design process. Planned calculations.	Range of novel designs. Detailed planned calculations. Materials. Detailed Gantt chart.
Design development	Very little design development, justification, calculations, materials, design not functional	Some design development, justification, calculations, materials. Design may partially function	Reasonable design development, most decisions justified, materials selection. Functional design	Design development is logical, decisions are justified, materials selected are appropriate. Design should function well	Good design development with most decisions justified and logical. Novel functional design	Logical development of designs with all decisions justified. Fully functional novel design with innovation
500-word informal report	Very little information. Greater than 500-words.	Some information. Within 500-word limit.	Information backed up with data. Some images.	Information highlights strengths and weaknesses. Good use of images. References.	Complicated things explained clearly. Excellent use of images.	A complicated design explained simply, backed up with good data and use of images.
Final design justification	Design decisions not justified. No supporting hand calculations, design not functional. Design specification not met	Some design decisions justified. No supporting hand calculations, design partially function	Design decisions justified. Some hand calculations. Design will function. Most of the design specification met.	Design decisions justified. Comprehensive hand calculations. Design will function well. Most design specification met. Those not met, justification provided.	Design decisions fully justified. Comprehensive hand calculations on all components. Design specification met.	A complete, fully functioning novel design with all design features fully justified that meets the design specification
4000-word formal report	No specification. Not a formal report. Over the 4000-word count. Few calculations. Basic material selection.	Reasonable specification. Formal report. Within the 4000-word count. Good material selection FEA analysis. Some parametric.	Detailed specification. Materials selection with Indices. Detailed FEA analysis. Good parametric in assembly Basic conclusion.	Detailed calculations, corroborated with FEA analysis. Very detailed optimisation and parametric. Gantt chart with updates. Conclusion with recommendations.	Calculations checked with re-calculations. FEA of complex part. Parametric of complicated part. Novel design solution.	The novel design could be manufactures with very little additional work required.

		Some calculations.				
SolidWorks model of final design	Does not meet specification. Not operational. Not fully designed.	Meets specification. Nearly operational. Fully defined. Basic FEA.	Exceeds specification. Operational. Detailed. Advanced FEA.	Basic parametric design. Validation of software.	Advanced parametric design. Detailed drawings.	Fully operational design, ready for manufacture.
5 Slide critique on design process	Very little critique. Poor quality slides. More than 5 slides.	Some critique. Slide quality good. 5 Slides.	Each slide has critique. Slides good design.	Critique balanced positive/negative. Slides tell a story	Each slide design is very good and linked to each other. Critique written well.	A well thought out critique with excellent slides and balanced comments.

Anonymous Marking

Include the appropriate statement from this list (delete all others and the title). Not assessments that are not anonymously marked need to logged and approved on this tracker (link)

Submissions in Turnitin and Blackboard

You must submit your work using your **student number** to identify yourself, not your name. You must not use your name in the text of the work at any point. When you submit your work in Turnitin you must submit your student number within the assignment document and in the *Submission title* field in Turnitin. A video showing how to do this can be found here (link)

Submissions that are not electronic

You must submit your work using your **student number** to identify yourself, not your name. You must not use your name in the work at any point. You must clearly indicate your student number both on the work itself where possible (e.g. in a document footer; somewhere on an artefact), as well as on the hand-in sheet you use when submitting your work.

Submissions that require a name

This assignment cannot be marked in line with the Anonymous Marking Policy requirements as you are required to be assessed by your name by (XX PSRB etc.). Please ensure that in this assessment you are identified by your **name**.

Where an assessment is not submitted by a student, e.g. a practical activity, there is no opportunity for the student to submit by student number. Student information is not required on this.

Assessment Regulations

The University's regulations, policies and procedures for students define the framework within which teaching and assessment are conducted. Please make sure you are familiar with these regulations, policies and procedures.

APPENDIX 5

INDUSTRIAL DESIGN SPECIALISTS, REPLIES

John Sulley – Chief Design Engineer 37 Year at Rolls Royce

RE: H300 (Bachelor of Engineering (Honours) in Mechanical Engineering): Contact Details [No Classification]

Sulley, John (NNPPI) <John.Sulley@Rolls-Royce.com>

Tue 23/11/2021 15:00

To: Martin Sole <M.Sole@derby.ac.uk>

Cc: Patrick Barber <P.R.Barber@derby.ac.uk>

1 attachments (420 KB)

Extract.docx;

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

This message has been marked as No Classification by Sulley, John (NNPPI) at 23 November 2021 15:00:10

Hi Martin,

Firstly, I must apologise for how long it has taken me to reply, I am very sorry about that.

I have been very busy these last few weeks, arranging first technical presentations for a US Admiral visit, and then hosting and chairing a manufacturing working group for the MoD which we held yesterday. So, this is the first chance I have had of 'coming up for air' and getting and getting back to you.

1. Generally – looks great!

2. I noted the statement in (2) 'Design Challenge Complexity', that the students were spending 90% of their time modelling and squeezing in the report at the end. I totally agree with your new approach. The key thing is the design thinking behind the modelling. You are probably aware that in Rolls-Royce we have **Designers** and separate **CAD Modellers**. Your different approach should help produce Designers, not CAD modellers.

3. I fully support the 'Group Working' philosophy. The more team work the better. Although they obviously won't be talking to other disciplines at Uni, getting it into their psyche that design work most commonly involves a joint effort, for example with material experts, manufacturing experts, stress experts, etc, is all to the good. I accept that I am talking from a RR perspective where we have the luxury of calling on the expertise of many disciplines, whereas some companies don't have such resources.

4. I think your 'Critique Week' is very important. I think a key thing is the students being able to take constructive feedback and develop. I will openly admit that I wasn't particularly good at taking feedback when I was younger, and I think this probably held me back. I have noticed this with quite a few young engineers recently that I have been mentoring (not graduates of Derby, I hasten to add, but it's probably just an age thing rather than from which Uni they graduate from). I think it stems from them incorrectly thinking they need to show that they know everything or they look inferior technically, but having that perspective holds back their development. We have a general approach, not something we specifically aim at designers, that I think is quite powerful, is: '**Always Assume Positive Intent**!'. So any feedback they are given and help on how to take the feedback I think is very important here. I suppose it's self-reflection, what feedback do they receive, and based upon that, how would they approach something differently next time.

5. 'Report'. I think a key thing here is clearly demonstrating they have met the requirements. When I chair design reviews, although there are many aspects to cover, I ensure I cover two key things: *1. Have they fully* ***captured*** *the requirements. 2. Have they demonstrated they have* ***met*** *the requirements.'* Although it is

important, a lot of designers just focus on the middle bit, i.e. how they went about it. Just having that clarity of thought I think is very important.

Just a general comment:

1. I think the most important thing a designer should have, is grasping the concept of parameter variation and positioning parameters away from '*cliff-edges*' in performance. Accepting that for some companies achieving an '*optimum*' position is extremely important to provide competitive advantage, e.g. RR Aero in respect fuel efficiency, in most cases a '*robust*' position with the parameter range positioned away from 'cliff edges' is the best place to be. If you can get both, then all to the good! I put together some material for a 'Designer Development Framework', I have attached an extract. But, please note this was for developing designers working on nuclear components where we don't necessarily need an '*optimum*' performance position.

Wishing you luck with your new module, I hope it goes well.

Best Regards
John Sulley
Rolls-Royce Associate Fellow – Nuclear Component Design & Performance.

Muhammad Ahmad Majeed Khan Design Engineer

Table 72 Module 6ME500 Advanced Engineering Design Modelling - Pedagogical Application (Reply)

No	Application	Comment
1	General	Student support is maximum.
2	Design challenge complexity	.
3	Work in groups of 4/5 week 1	Idea of working in groups in excellent.
4	Groups to be formed by student's week 1	I will rather have chosen groups myself, because in industry, it won't be necessary that people you are working with will be your friends.
5	Group presentation week 4	
6	Informal individual report week 8	
7	5 Slide critique week 12	That is the very good in my view, student analysing their own work critically.
8	4000-word formal report week 12	
9	SolidWorks model week 12	
10	Grading algorithm	

Reece Matthews Design Engineer Rolls Royce, NVQ Assessor

Hi Martin,

I have reviewed the documents provided and have provided my comments (please see attached).

Overall I think the scope of the module looks good, and I believe there is a good combination of individual and group work to challenge the students in a project representative of industry. I would, however, suggest two key points to consider:

1) DfX (Design for Manufacture/Assembly/Lifecycle) is an essential technique which is not broached in this project. I would consider challenging the students by asking them to initially design for a specific production quantity (i.e. Low volume) and then as part of the formal report ask how they would have to adapt the design and probable MoM if the product was to be mass manufactured.

2) I think there will be a significant shortfall in students softer communication skills if there is not a good amount of verbal communication with Engineering assessors. I firmly believe the interim report should be verbal, and should be audio recorded as evidence. We do this to support NVQ within industry and it is extremely beneficial. This is a key skill students will need to bring into the workplace.

I am more than happy to answer any follow on questions you may have, or to support a short discussion if you wish.

I hope this is helpful.

Best Regards,

Reece Matthews BEng (Hons) AMIMechE
Mechanical Design Engineer, Casings & Structures
NVQ Higher Apprentice Assessor / EPA Mentor
Rolls-Royce CSR

Table 73 Module 6ME500 Advanced Engineering Design Modelling - Pedagogical Application (Reply)

No	Application	Rationale Comment
1	General	Agree with the intent behind this. Need to ensure that **face to face** aspect is maintained as physical meetings if possible as this builds key softer skills which online meeting does not develop. Are pre-recorded sessions a new (COVID) response to e-learning? I worry that this removes any possibility for student engagement/feedback. However, I won't dispute if this is a tried and tested teaching a mechanism with pedigree.
2	Design challenge complexity	Agree this scope is sensible for the given time.
3	Work in groups of 4/5 week 1	

4	Groups to be formed by student's week 1	
5	Group presentation week 4	Who do the group present to in the 'group presentation'? This presentation should be made to peers as well as assessors to allow students to experience and learn from their peers' shortfalls.
6	Informal individual report week 8	Not enough context to comment.
7	5 Slide critique week 12	Agree, ensure that the students critique their approach as well as the outcome.
8	4000-word formal report week 12	Agree
9	SolidWorks model week 12	Agree. Optional exercises should be given along with the pre-recorded videos so students can assess their competence before deciding whether optional classes are necessary.
10	Grading algorithm	Not enough context to comment.

Table 74 Module 6ME500 Advanced Engineering Design Modelling - Practical Application (Reply)

No	Application	Comment
1	Design assignment complexity	Agree this scope is sensible for the given time.
2	Work in groups of 4/5 week 1	Agree. Students should set themselves individual roles within the team, each with their unique accountabilities (Project Mgr, Sub-System leads, etc).
3	Groups to be formed by student's week 1	Agree with the approach, however, cannot comment on difficulties.
4	Group presentation week 4	Agree. Frame this around the standard design structure. This presentation should be focused on 'Understanding Requirements', students should be encouraged to keep things holistic at this stage, focusing on functionality and not jumping to solutions. Presentation should be timed to align with this stage in the programme.
5	Informal individual report week 8	Why would verbal not be possible? Within industrial NVQ, audio recorded 'Professional Discussions' are key required evidence. Students assigning themselves roles would be beneficial here as each student would need to put a different slant on their report (avoid plagiarism).
6	5 Slide critique week 12	Agree, ensure that the students critique their approach as well as the outcome.

7	4000-word formal report week 12	The report should consider DfX (Design for Manufacture, Assembly, Lifecycle) as key considerations for top marks.
8	SolidWorks model week 12	Agree, how about component definition?
9	Grading algorithm	Not enough context to comment.