

DESIGN EDUCATION - A REVERSED METHOD TO FILL AN INFORMATION AND KNOWLEDGE GAP BETWEEN FULL-TIME AND PART-TIME STUDENTS

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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 pedagogical 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.

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1 INTRODUCTION

Effective use of design can bring financial benefits to a company. The [Design Council \(2018\)](#) based in the United Kingdom (UK), who are an independent charity and government advisor on design make clear the importance of design and designers. The UK has the largest design sector in Europe and the second largest in the world. Design contributed £71.7 billion to the UK economy during 2018. For every £100 a business spent on design, their turnover increased by £225. The Design Council looked at UK quoted companies which had been identified as effective users of design, these companies out-performed companies listed on the Financial Times Stock Exchange (FTSE) 100 by 200% ([Design Council, 2007](#)).

The ability to design is both a science and an art. The science can be taught, the art is learned by doing. The skill and knowledge base required of a design engineer is extensive ([Shigley et al, 2004](#)) ([Newman et al, 2003](#)). A simple roller bearing involves fluid flow, heat transfer, friction, energy transport, material selection, thermomechanical treatment, statistical descriptions, and so on ([Connor et al, 2000](#)).

Students at a university in the UK, in their final year of a BEng (Hons) in Mechanical Engineering were a mix of full-time and part-time students. The part-time students, as a requirement for admission onto the course were all employed in the engineering sector. A few full-time students had part-time employment but not necessarily in the engineering sector. As part of their final year, they were tasked with a complex design problem. The solutions presented by the students were reasonable and logical. The science behind the designs was sound. A significant difference was identified between part-time and full-time students in the practical application of assembling their designs.

During academic year 2016-17, 73 full-time and 41 part-time students in their final year at the university were surveyed on recognition and application of 50 standard engineering components (keyways, c-clips, bearings, washers, couplings, pins, fits etc). Part-time students gave the correct answer 49% more than full-time students (Table 1) ([University of Derby, 2021](#)).

To address the different between full-Time and part-time students, the curriculum was investigated in year 1 and 2 of the degree programme. Increased emphasis was put on general engineering knowledge, assembly, and application. During the next two academic years (years 2017-18 and 2018-19) a significant improvement was identified in full-Time students.

Table 1. General engineering knowledge survey ([University of Derby, 2021](#))

Academic Year	Students Total	Part-Time		Full-Time	
		Total Students	Average % Correct	Total Students	Average % Correct
2020-21	73	8	96	65	82
2019-20	111	47	89	64	75
2018-19	115	44	93	71	60
2017-18	113	40	92	73	55
2016-17	114	41	86	73	37

Another factor to be considered was the preferred method students use to research a design problem. The main source of information was the internet, which would provide examples of complex systems. These examples rarely provide details on assembly and the components used. These systems required detailed study to fully understand their operation, assembly etc. Two examples given to students were a car differential and a lathe gearbox. Full-time students would have little difficulty understanding the science behind these complex systems but had difficulty understanding the assembly and required components.

The changes made earlier to year 1 and 2 of the curriculum, reduced the knowledge gap between full and part-time students but did not close it fully. The head-start of part-time students was great. They had years of on-the-job training. Some final year students were direct entry and came from widely differing educational backgrounds. Could a traditional teaching theory, as used mainly in the UK, be adapted to assist full-time students to narrow the knowledge gap even further? This paper continues by

explaining a different application of the theory and provides a practical example of how this gap was further reduced to 14%. The results can be seen in Table 1 for academic years 2019-20 and 2020-21.


2 TRADITIONAL PEDAGOGY

Pedagogy is the study of the methods and activities of teaching (Cambridge Dictionary, 2020) and didactics is the theory and practical application of teaching and learning. In the UK as well as most other countries, teachers are trained in the methods and activities of teaching which are often based on accepted theories and follow a traditional interpretation. Review nearly any textbook on teaching and certain theories will be found, Maslow’s Hierarchy of needs, Bloom’s Taxonomy, which was later revised by Anderson and Krathwohl’s Taxonomy (2001), Black and Williams’s, Cognitive Domain, Constructivism, Behaviourist, Experiential Learning, are some of the leading theories (Reece & Walker, 2007) (Curzon, 2013) (Petty, 2014). These theories are continuously updated as modern education develops, changing to the demands of industry and society. Which, if any, of the above theories would be best placed to instruct future design engineers and assist in reducing the knowledge gap between full and part-time students.

Maslow’s Hierarchy, which has been updated and revised many times (James *et al*, 2020), lists the needs of students. Starting with needs that have greatest importance their physiological needs, then safety needs, love and belonging needs, esteem needs, and self-actualisation needs. The needs at the top would only be important to someone if the needs lower down were already largely satisfied (Petty, 2014). Does this apply, greater or less when training engineers when compared to other vocations? These needs are fundamental to all people and would apply equally to an engineer, doctor, pilot, or teacher.

It is important for trainee engineers to have a sound understanding of a topic, as they will be required to apply that topic in many, and varied situations. In the 1950’s Benjamin Bloom, the lead author in a group of educational experts created what became known as Bloom’s Taxonomy. This put learning into a spectrum of tasks or skills. To have a sound understanding of a topic required starting at the bottom and working to the top. At the bottom, skills are relatively undemanding, as you climb, skills get more difficult. Learning for a given topic is only complete once all the steps in the Taxonomy are attained (Curzon, 2013). Blooms has undergone revisions over the years to keep pace with modern educational realities. Anderson and Krathwohl (2001) revised Bloom’s Taxonomy, making cognitive processes, when related to chosen instructional tasks, easily documented, and tracked and changed the original nouns to verbs (Table 2).

Table 2. Anderson and Krathwohl (2001) Taxonomy

	High Cognitive Demand	Create Solve a problem that is not routine, write an essay, report, criticism or argument.	Fully Functioning Knowledge
	Evaluate Make a judgement about a particular activity, policy, plan, or argument.		
	Analyse Analyse a situation, experiment, case study		
	Low Cognitive Demand	Apply Do it after being shown, apply, calculate, use, punctuate	Low Order Skills
	Understand Explain, Classify, Interpret, describe		
	Remember State, Define, Recall, describe		

Lower skills are required before the higher skills can be applied. This is critical for an engineer, but students may not always have the required knowledge, comprehension, and application due to their age, experience, previous education etc. Without the required knowledge, the higher cognitive demand may not be possible and so the topic will be difficult if not impossible to solve. This theory is also

known as Cognitive Domain where a Domain is a level or degree of difficulty (Anderson & Krathwohl, D, 2001).

Black and William's looked at the way assessment is used. The traditional method of teaching is, teach, test, grade, and move on to the next topic. The difficulty with this is that it does not check that the student has listened to the feedback and acted upon it to improve their work. The assumption is made that a student's learning quality and quantity depends upon their ability and that assessment is only a measure of that ability. If the student lacks learning, it is because they lack ability. Black and William's suggest a better way, teach, test, grade, fix, back to test. The assessment is used as a diagnostic tool. The assessment is used by the teacher and student to fix any deficiencies in learning before moving on (Cambridge Assessment, 2019). Engineers will be familiar with this approach because it is using a feedback loop to identify a deficiency, determine an improvement, test the improvement is real. This loop can continue while progress is being achieved.

A misconception teacher's often have of students is that they either know nothing of a topic or they know a good deal. The truth is probably somewhere between the two and will be different for each student. If a student begins a topic with a misconception and then builds on those misconceptions their correct understanding of a topic will be further away from the truth than when they started. Constructivism is the theory of identifying a students' current ideas, and any misconceptions, and then assist the student to modify or abandon those ideas and construct new meaning. The knowledge and understanding a student may have is important. Despite having the same learning experience, everyone will construct on individual meaning which will be unique to them. This is an active and continuous process. Engineering students come from a multitude of backgrounds. Their knowledge and understanding will depend upon their cultural heritage, age, academic education, gender, and industrial background (Reece and Walker, 2007).

Behaviourists are psychologists that study learning in animals and then apply their findings to humans. The basic thinking is that once an animal has learnt, the learning is reinforced by it receiving a reward. The reward, in experiments was usually food. Effective teaching of students involves rewarding with praise, and encouragement. The teacher will set achievable tasks and divide long tasks into several shorter ones. Praise comes as soon after the student has demonstrated learning so that the learning and reward are linked in the students thinking (Dierking, 2015).

Experiential Learning is learning through experience. Experience does not guarantee learning. The starting point is to reflect on your experience to date, critically compare your experience with modern theory, update your plan and then carry it out. The learning process is cyclic and may require several cycles before significant improvement can be measured (Kolb and Kolb, 2017).

2.1 Correlation of Theories

Most theories require, as a starting point, knowledge. The first step in Anderson and Krathwohl Taxonomy is knowledge; the first stage of Black and William's is teach, which requires knowledge; Constructivism requires identifying a student's current ideas and thinking, their knowledge; Behaviourists set achievable tasks based on the knowledge and understanding of their students; Experiential learning starts by looking at your current experience or knowledge.

Knowledge is critical for learning to take place. If knowledge is lacking, then the teacher will have to adjust their teaching to assist a student to gain the required knowledge. What happens if the programme a student is taking is a high-level course, maybe the final year in a degree, and the topic has not been studied by the student, their basic knowledge is lacking. What theory would best be applied to assist in building the required knowledge?

3 STUDENT DIVERSITY OR MIXED ABILITY TEACHING

Take an average class on the final year of a mechanical engineering degree programme in the UK during 2019. The majority of students will be around 20 years old, but some may be much older; 79% will be male and 21% female; 30% will be from a minority ethnic background; 11% will be from a low participating neighbourhood; 8% will be disabled (Engineering UK, 2020).

Previous education will be from a variety of institutions. Most will complete Advanced GCSE's in school. Some will come from a Further Education College studying maybe a Business and Technology Education Council (BTEC) Diploma. A few may have a working-background from a range of

different sectors, not necessarily mechanical engineering, their last formal education completed a few years back.

Students may also have a learning disability or learning disorder. Dyslexia is a learning disability with reading. Dyscalculia, a learning disability with mathematics. Dysgraphia, a learning disability with writing. Dyspraxia, a learning difficulty with motor skills. Aphasia and Dysphasia are learning difficulties with language. Auditory processing disorder is an inability to distinguish subtle differences in sound. Visual processing disorder are problems with visual perception (Kemp *et al*, 2019).

The UK is happy to accept a wide range of international students from many different cultural and educational backgrounds which vary widely from those mentioned above.

Students have preferred learning styles; right-brain learning sees things holistically, is non-verbal and prefers images; left-brain learning sees things in parts, language and logic. Rather than considering learning styles by the way a student processes information, learning styles can be viewed instead by the information input. These inputs can be divided into three paths, visual, auditory, and kinaesthetic (Petty, 2014).

There is a wide variety of strategies that have been developed over many years to assist a teacher to accommodate individual differences of any kind. These strategies are known collectively as differentiation. An area that requires further development is the difference in general engineering knowledge between Part-time and full-time students (Westwood, 2009).

3.1 Full-Time and Part-Time Mechanical Engineering Students

According to the Higher Education Statistics Agency (HESA) during academic year 2013-14, the UK, which is made up of England, Northern Ireland, Scotland, and Wales had 368,503 part-time undergraduate students. In 2017-18 this had dropped to 271,475, a drop of 27%. Full time students in academic year 2013-14 were 1,391,490. In 2017-18 the number had increased to 1,505,065 an increase of 8%. This decrease in part-time students will have a significant affect, in the future on the quality of design engineers (HESA, 2019). An average class on the final year of a mechanical engineering degree programme will consist of students with mixed abilities which is a product of many different influences. A major influence is whether they are full-time or part-time.

3.1.1 Part-Time

Most part-time students choose this path because they are usually in employment. The BEng (Hons) Mechanical Engineering Programme requires part-time student to be employed in the mechanical engineering sector, often in an approved apprenticeship scheme. Usually, one day a week is spent at an educational establishment, the other four days are spent gaining practical experience in their chosen field. This vast amount of knowledge, a library of knowledge, gives them an advantage over the full-time students. To illustrate with a couple examples; a design is required to have two parts pinned together. The choice of pins is large; split, tapered, roll, cotter, grooved, knurled, pull-down, slotted, clinch, hairpin, twist, clevis, hitch, lynch etc. Another design requires a roller bearing. The choice of bearings is ball, tapered, deep grooved, angular, self-aligning, thrust, cylindrical, needle, magnetic, sealed, double race, single race etc. The part-time student may spend a large part of their time using pins and bearings, they learn to recognise the different types, their applications, their names. The library of knowledge built up by part-time students is vast. Alongside this library of knowledge is experience. The experience based on applying and practice, by doing, helps reinforce their memories. Research makes it clear that to remember something we need to move a memory out of the part of the brain used to retain short term memory into that part where long term-memories are stored. This is achieved by various methods; solving related problems; recital, review and practice in retrieval (Curzon, 2013) (Madigan, 2015).

According to the Universities and Colleges Admissions Service (UCAS) for the UK. most part-time programmes are normally taken over a longer time period than full-time programmes which allows the students to learn at a more relaxed pace and also provides more time to build the library of knowledge (UCAS, 2020).

3.1.2 Full-Time

For many full-time student's their path to the final year of a degree programme often involves little industrial experience. After leaving school having completed Advanced GCSE's they then start on the

first year of a degree at university. Some who did not achieve Advanced GCSE's can start on the first year of a degree programme after attending college, maybe studying a BTEC qualification. During the time a student works toward starting on a degree programme they may be fortunate to have a part-time job which helps towards the cost of their studies. An important fact is full-time students do not get the opportunity to build up the library of knowledge that a part-time student has. The library of knowledge is often, extremely limited. They also do not have the experience that a part-time student builds up and that helps reinforce their memory. This lack of an in-depth library of knowledge puts full time students at a disadvantage over part-time students. The significant point is that, even though full-time university students on a degree programme study and learn large amounts of engineering knowledge, subjects such as materials, science, business, thermodynamics, design modelling, Computational Fluid Dynamics (CFD), programming, machining, manufacture etc. they are not building the detailed library of knowledge that part-time students have. This library of knowledge is the building blocks that are required to fully understand how a complex engineering system operates.

4 DESIGN EXAMPLE

Students, in the final year of a degree programme were set the following task: to design a drive system, using a worm and wheel for an automatic garden gate (Figure 1)



Figure 1. Worm and wheel

For students to understand the challenge, analysis and synthesis of existing systems was required (design specification) which would then lead to initial ideas. The initial ideas are reviewed to identify best aspects of each solution. The design considered to be 'best' will then be defined in detail and compared to the design specification. This refining process continues until a final solution, that meets the design specification, is found (Dieter & Schmidt, 2013).

During the design process it was noted that part-time students generally understand the problem deeper than full-time students because of their library of knowledge being to a greater depth. Full-time students may understand the principle behind the involute gear and be able to determine the tooth geometry and model a worm and wheel, but they struggled with the practical aspects. How will the wheel be mounted on its drive shaft; what methods will be used to transmit the torque from gear to shaft or vice versa; what methods can be used to stop the gear sliding along the shaft; what is required to produce a rigid assembly; how will the parts be machined; how will the parts be assembled? (Shigley *et al*, 2004).

5 REVERSE ENGINEERING AND TAXONOMY

Anderson and Krathwohl's Taxonomy relies on student's building their knowledge and understanding of a subject from a low cognitive level to a higher one. Starting at knowledge, moving through six steps, to finally reach Evaluation (see Table 2). This is the normal and accepted method used to teach. Throughout a student's learning process, each lesson, and later, each year, builds on the knowledge and understanding of the previous lesson or year. As previously stated, part-time students will often understand a complex design better than a full-time student as they have a more in-depth library of knowledge. How can a teacher support their full-time students to understand a complex design to at least match that of part-time students?

During the final year of a degree, full and part-time students are required to complete a design module requiring the design of a complex problem. In the early stages of the design process, students will research the problem to determine the main principles of operation. Most student turn to the internet. This will often provide complete solutions to the complex design problem. The students have,

inadvertently, skipped passed the earlier steps that Anderson and Krathwohl suggest are required for complete understanding of a problem, they are starting with create/evaluate instead of remembering. The students have reversed Anderson and Krathwohl's Taxonomy. Full-time students may be able to carry out an evaluation of the complex design, understanding the complex design issues studied in previous years. Their library of knowledge is not wide enough for them to fully understand all the smaller problems such as assembly. This has similarities to design engineers using reverse engineering to understand a complex system. Dieter and Schmidt (2013) provides a four-step process to reverse engineer. Table 3 lists Anderson and Krathwohl's Taxonomy (reversed) and reverse engineering combine and provide an example when applied to the worm and wheel drive.

Table 3. Reverse taxonomy example

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
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?
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?
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.

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?
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?
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.	

Applying a combination of Anderson and Krathwohl's Taxonomy (reversed) and Reverse Engineering it is possible to guide students to fill the gaps they have in their library of knowledge. Begin by Evaluating the complex design by looking at its operational requirements while comparing different designs with each other. Next, the performance of the complex design is broken down into individual parts and how those parts are controlled. How are these parts combined into sub-assemblies? Critically appraise individual parts for their manufacturing and assembly process. Lecturer to provide guidance on appropriate methods of assembly specific to the individual design. During academic years 2019-20 and 2020-21 the gap between full-time and part-time students continued to narrow and was reduced to just 14% (Table 1).

Using Anderson and Krathwohl six steps and combined with the four steps used in reverse engineering, enables students to fully understand the operational requirements of the design and leads them to determine the requirements for fasteners, bearings, and lubrication etc. which will be added to their library of knowledge.

6 CONCLUSION

The financial benefits to industry, by investing in effective design are many. Future designers, to maximise potential benefits, requires an extensive library of knowledge that is continuously changing as the demands of industry change. A comparison between part-time and full-time students exposed a difference in their basic engineering knowledge. The detail, especially in the assembly of a complex system by full-time students, was inferior to part-time students. This was partially addressed by looking at the curriculum taught in earlier years to full-time students, and improvements made to their library of knowledge. A further improvement was made by reviewing how students use the internet to carry out research. An internet search provides partial solutions to a complex design but without the required detail. This required detail was addressed by applying principles of Reverse Engineering. An example was provided using a Worm and Wheel to drive an automatic garden gate.

Improving the library of knowledge of full-time students will reduce the differences between full-time and part-time students and will enable full-time students to become more effective design engineers.

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