ENGINEERING STUDENT ATTAINMENT AND ENGAGEMENT THROUGHOUT THE DESIGN PROCESS

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ABSTRACT

The paper reports on a study that aims to gain an understanding of how senior engineering design students engage and attain throughout the various stages of the design process during a major design project. Following a literature review it sets out to answer 3 main research questions
Q1. Do students engage more with certain stages of the design process during major project work?;
Q2. Do students attain better during certain phases of the design process during major project ?
Q3. Is there a difference in this attainment between year groups of the same degree programme ?
The methodology adopted employs an analysis of marks and an online questionnaire to collect data. Patterns and trends in how senior BEng and MEng Product Design Engineering students engage and attain within the design process are presented, identified and discussed and in turn used to inform reflection on the research questions set.

Keywords: Design education, Design process, Design engineering, attainment, engagement

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1 INTRODUCTION

Product design is 'a generic term for the creation of an object that originates from design ideas – in the form of drawings, sketches, prototypes or models (de Vere, et al., 2009) (Baxter, 1995). (Stack, 2006) stated that process design can extend into the object's production, logistics, and marketing. The product design process involves stages of product planning, concept design, product development, product styling and detail design (Baxter, 1995). (de Vere, et al., 2009) all stated that many writers treat industrial design input into product design as a single stage in a multistage process. Writers such as (Ulrich & Eppinger, 2000), who claim that the industrial design process is a sub-process of the product development process, uphold the opinion that product design is often taught as a component of mechanical engineering or in design schools as an element of industrial design. (de Vere, et al., 2009) also discussed that product design had its roots in Glasgow with the advent of the need for industrial and mechanical concepts brought together to enable students to be more accomplished when integrating the two disciplines then leading to critical reflection.

Therefore, design is a key element of engineering. All engineering disciplines perform some type of design activity. This can clearly be found in any area of an engineering business whether improving production processes, developing a product offering, software development, product or process planning. Engineers must have an understanding of the design process and the ability to apply design principles to any problem situation. (de Vere, et al., 2009) (Kiernan & Ledwith, 2014) (Dym, et al., 2005)

Undergraduate engineering education has undergone many changes over the years in response to influences from industry. (Kiernan & Ledwith, 2014) (English, et al., 2012). Product design and engineering organisations expect their graduate recruitment process to attract the best level of student and those who can aspire to have a deeper understanding of the principles of the design process. The aim of this paper is to present an understanding of how students are performing during the main stages of the design process during their final year projects and then to offer some discussion on how the teaching process can deliver both the expectations of the student and the organisations that eventually employ product and sport design graduates (Spezia, 2009).

Engineering and product design organisations are increasingly under pressure to provide innovative products that meet customer demands at lower cost, in shorter timescales and to become increasingly environmentally sustainable. (Costa & Sobek II, 2004). Today's students have to be able to react positively to these challenges by using design methods that help guide their design efforts to meet these conditions. There is evidence of the need for 'designerly thinking' (Cross, 2006) highlighted that design engineers must be flexible, creative, solution-focussed have a strong understanding of human-centred design constraints and an ability to work in multidisciplinary contexts. In a review, (Dym, et al., 2005), suggest that engineering design courses have yet to create an appropriate engineering and design balance. Engineering design educators are aware of the limitations of traditional teaching methods, which can focus excessively on technical knowledge to the exclusion of other dimensions of engineering design problems (Beder, 1999). (de Vere, et al., 2009)

For students to function effectively in all or any of the taught facets of a design process requires working well in all learning style modes. For example, competent engineers and scientists must be observant, methodical, creative, and careful as well as innovative, curious, and inclined to go beyond facts to interpretation and theory. Similarly, they must develop both visual and verbal skills as information routinely comes in both forms, and much of it will be lost to someone who cannot function in both modes. (Felder, 1996) (Spezia, 2009).

Literature highlights the effect of teaching styles on the student's outcomes (Farris, et al., 2015). If the subject taught is exclusively in a manner that favours the students less preferred learning style this can have a detrimental impact of the design methodology used on a student project. If we compare this to the design stages of a design process to assess a project, which has the potential to use all the styles, described above, the students' discomfort level may be great enough to interfere with their learning. However, on the other hand if the tutor teaches in their students preferred modes, the student may not develop the mental dexterity they need to reach their potential for achievement. This could have an effect on their grades and future career path. (Felder, 1996) (Altman, et al., 1999)

Some students tend to focus on facts, data and algorithms; others are more comfortable with theories and models. Some respond to strong visual forms of information, like pictures, diagrams, and schematics; others get more from verbal forms - written and spoken explanations. Some prefer to learn actively and interactively; others function more introspectively and individually (Felder, 1996). Design projects offer students an opportunity to apply skills and knowledge acquired during their course of study and placement periods. (Kiernan & Ledwith, 2014) (Violante & Vezzetti, 2017)

Aim: The aim of this study was to gain an understanding of how senior engineering design students engage and attain throughout the various stages of the design process during a major design project.

Q1. Do students engage more with certain stages of the design process during major project work?

Q2. Do students attain better during certain phases of the design process during major project ?

Q3. Is there a difference in this attainment between year groups of the same degree programme ?

2 BACKGROUND TO THE STUDY

The degree course under evaluation is Product Design Engineering (PDE) at the Department of Design Manufacture and Engineering Management, within The University of Strathclyde, Glasgow.

Product Design Engineering (PDE) is a multidisciplinary engineering course, designed to provide the skills necessary to become a successful design engineer, sought after by industry. This degree is concerned with creating new products that satisfy and anticipate the needs and aspirations of society. The department offers its students a successful combination of tools and techniques in order to compete in a global market. The students design new products with a focus on exceptional functionality, look good, be reliable, easy to use and offer value for money (Product Design Eng., 2017). Programmes such as PDE, extend to universities across the world spreading international recognition of the importance of design. A significant number product design schools are located in the UK, however, the geographic spread is now wider, including Europe, North America, Japan, Australia and South America.

Product Design Engineering at the University of Strathclyde involves studying for 4 years full time to achieve a Bachelor of Engineering Honours degree (BEng. Hons.) or 5 years full time to achieve an integrated Master of Engineering degree (MEng). Students performing at the required level in 4th year can choose to graduate with a BEng Hons degree or continue to 5th year to complete an MEng degree. If they do not achieve the required level of performance in 4th year then they cannot continue to 5th year and must graduate with a BEng Hons. This study focusses on the 4th and 5th year of the PDE degree programme and in particular the 'individual major design project' which is undertaken by all students in these final two years. This is the largest weighted assessment in 4th and 5th year. Accounting for 33% of 4th year and 50% of 5th year.

Final year projects are assessed using the marking schedule shown in figure 1. The marking scheme follows the 4 main stages of the Design Council's Double Diamond design process of ‘Discover’, ‘Define’, ‘Develop’, and ‘Deliver’ (Design Council, 2015). Each of the four design stages can easily be mapped to other generic design processes and methodologies such as Pugh (Pugh, 1991) and Ulrich and Eppinger (Ulrich & Eppinger, 2000). Each project report is reviewed separately by two project assessors each providing an independent score allowing for better level of accuracy when marking the student’s final design report. A full and thorough moderation process also takes place. The application of a weighting to each of the stages helps students understand the emphasis on particular stages within the four design stages. The weightings used in ‘discover’ and ‘deliver’ stages carry a figure of 20% whether for 4th year BEng, or 5th year MEng degrees. However, the ‘define’ and ‘develop’ stages carry a weighting of 30% for 4th year BEng projects emphasising a greater importance attached to these sections, as they require a higher intellectual discipline to complete successfully. For MEng degrees and students in 5th year, in the same subject areas the weightings for ‘define’ and ‘develop’ are 25% and 35% respectively. The MEng degree placed greater emphasis on the ‘develop’ stage because a greater breadth and depth of analytical skills are required from Masters students.

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Stages	Criteria (as appropriate to each course and project) *Each project should demonstrate the knowledge and skills learnt by each student on each specific course*	Checklist	Comments 4th year MEng/BEng/BSc DM402 UG Individual Project 1	Indicative Classification for each section (tick) Fail <40	3 40-50	2.2 50-60	2.1 60-70	1 70-80	1* >80	Mark avail.	Mark awarded
DISCOVER	• Investigation of project area (incl. market & customer needs, viability, compliance, etc.).									20	
	• Identification of key project objectives & design requirements.										
	• Completeness of background to proposed work, context set clearly										
DEFINE	• Quality of research of the subject area (eg. literature review, business context, software, tools, etc.)									30	
	• Quality of investigation into the key issues, stakeholders, etc.										
	• Presentation of methodology to tackle the problem										
	• Degree of challenge.										
DEVELOP	• Quality of analytical work (eg. critical analysis of literature review, logical argument, calculations etc.)									30	
	• Clear description and discussion of the work carried out (eg. interviews, experiments, etc.)										
	• Quality of investigation into consequences of implementation (e.g. risk benefits, costs, etc.)										
	• Evidence of achieving key project objectives (incl. performance, costing, business plan, legal & regulatory compliance, etc.).										
DELIVER	• Overall level of creativity and quality of final outcome in relation to objectives set.									20	
	• Quality of justification, final discussion, conclusions, recommendations and executive summary.										
	• Quality of construction of submissions (incl. abstract, intro, structure, diagrams, references, appendices, etc).										
	• Understanding of business/ethics/confidentiality.										
All projects should have focus relating to student's course – DFx: design for x, e.g. Design for Sustainability, Human Factors, DFMA - Design for Manufacture & Assembly, Business, etc. Some projects may have more than one focus at different project stages. This should be reported clearly.									Total 40 credits	100	%

Figure 1. Marking scheme for final (4th and 5thYear) major projects

3 METHOD

3.1 Overall methodology

This paper investigated the three research question by adopting two main data collection approaches:

- Analysis of marks for each of the project stages of Discover, Define, Develop and Deliver for each of the students in 4th and 5th year.
- A questionnaire was carried out with the 4th and 5th Year students undertaking the major design projects

Each of these is described in the following sections.

3.2 Analysis of Marks

The analysis period covered projects completed in 2019 and therefore is unaffected by any effects or impact of the Coronavirus Pandemic. The review undertaken resulted in analysis of marks for individual major design projects allowing comparison of student results; (1) between the four design stages; (2) between 4th year and 5th year students of the PDE degree

The researchers undertook an analysis of the students' marking schemes used in the evaluation of design stages to determine if there are any variations in the marks attained and to what extent variation occurs. Throughout the completion of their major projects students are also encouraged to review the marking schemes to appraise, reflect and develop their direction, goals and output (Farris, et al., 2015)

The paper attempts to explore the different student performance (the results) throughout the design process, as discussed earlier. The research will note the characteristic strengths and weaknesses of student learning in projects and knowledge via assimilated academic stimulation. (Felder, 1996). The research team's 1st step was to review the marking schema see figure 1, which is a format based on the four design stages of discover, define, develop and deliver. The example shown in figure 1 is a 4th year schema a 5th year version has not included in the paper but is similar in construction. Marks from the thorough and robust marking and moderation process were obtained from the originally completed

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marking schemes and analysed. In this particular year there were 41 BEng Projects and 20 MEng Projects. The number of MEng projects is lower as less students progress from 4th to 5th year.

3.3 Questionnaire

A questionnaire was used to survey both 4th and 5th year level students on completion of their major individual design projects. Three main questions were used to investigate their thoughts and perceptions on engagement throughout the different design stages of their final year projects. Jensen et al, suggested that teaching methods can be evaluated by the use of a student questionnaire, designed to measure the quality and effectiveness of the teaching method. The results of the questionnaire can conclusively show that this method is a very effective way of teaching a products-based course (Jensen, et al., 2012). A questionnaire was developed to solicit feedback from students (39) to determine if any or all of the design stages influenced their efforts and engagement when investigating their project subject areas. The team also wanted to assess whether knowledge of the weightings in the marking schema made any difference to their engagement. The questionnaire focussed on 3 main questions:

- Reflecting on your individual major projects, how would you rate each of the design process stages in terms of interest and stimulation?
- When you completed your project how would you rate each of the design process stages in terms of satisfaction?
- In your opinion rate each of the design process stages in terms of importance?

The questionnaire was created using Qualtrics software, an online data collection analysis and feedback tool used for concept testing and employee evaluations. Facebook was used to upload the questionnaire and invitations sent to 4th and 5th year students each of who had recently completed their major individual design project. 39 responses were returned. From the questionnaire returns, the researchers found that 58% of the respondents were studying at MEng level and 42% were studying for a BEng in Product Design Engineering.

4 FINDINGS

4.1 Analysis of Marks

The results of analysing the marks achieved in each year group are shown in table 1, which shows the average marks achieved in each design process stage by each year group.

Table 1. Average marks scored in each phase of the design process

Year Group	Discover Average Mark	Define Average Mark	Develop Average Mark	Deliver Average Mark	Average mark (all phases)
4th year	63.54%	62.67%	62.64%	62.48%	62.83%
5th year	70.35%	69.06%	69.64%	71.67%	70.18%

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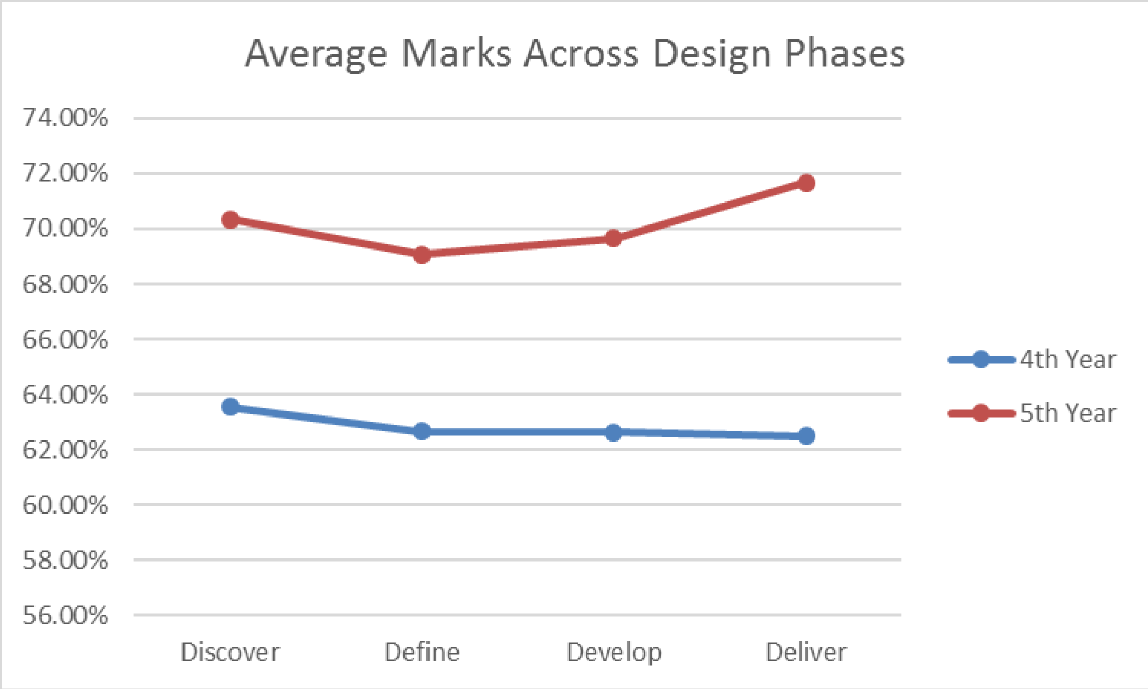

Figure 2. Comparison of 4th and 5th year marks across the design process

Table 1 and figure 2 show that in general 4th years perform at a lower standard than 5th year students. Fourth year students are generally performing approximately 63% average whist fifth years are on average performing at just over 70% average. Figure 2 also shows the general trend of marks across the design process with 4th year marks showing a slight decline as the design process progresses whilst 5th year show a slight dip in performance in the middle phases of define and develop but with an overall upward trend from start to finish.

4.2 Questionnaire Results

- Reflecting on your individual major projects how would you rate each of the design process stages in terms of interest and stimulation?
- When you completed your project how would you rate each of the design process stages in terms of satisfaction?
- In your opinion rate each of the design process stages in terms of importance?

The questionnaire results will focus on three main questions. The first of these questions asked, 'Reflecting on your individual major projects how would you rate each of the design process stages in terms of interest and stimulation?'. The results from this question are shown in Table 2. The results show that the highest rated stages are 'Discover' and 'Develop' with a smaller standard deviation indicating a reasonable consistency in the marks attained. On the other hand, 'Define' and 'Deliver' were slightly down in the student's estimation with a high standard deviation.

Table 2. Interest/stimulation - respondents' results

Field	Min	Max	Mean	Std. Dev	Variance
Discover	5.00	9.00	**7.55**	1.30	1.70
Define	0.00	8.00	**4.00**	2.26	5.09
Develop	4.00	10.00	**7.64**	1.55	2.41
Deliver	0.00	10.00	**6.00**	3.52	12.36

Students felt the "Discovery" stage was of higher interest and a typical response was, "Discovery" was most interesting as it allowed me to learn about new industry developments and standards. "Deliver" scored low as I was not so pleased with the output of my project."
Some of the feedback also highlighted that students enjoyed the "Discover" and "Delivery" stages and these were prominent in their feedback. This feedback came from the satisfaction of being able for develop their own individual project brief that was of interest to the student and of value in gaining

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potential employment. Participants indicated in comments that their satisfaction increased as the project progressed.

The second question focussed on "most satisfaction" (table 3), maintained this focus on the design stages where the participants were asked to respond to "When you completed your project how would you rate each of the design process stages in terms of satisfaction?" Responses to this question are presented in table 3.

Table 3. Most satisfaction - respondents' results

Field	Min	Max	Mean	Std. Dev	Variance
Discover	3.00	10.00	**7.45**	2.02	4.07
Define	0.00	9.0	**4.90**	2.62	6.89
Develop	2.00	10.00	**7.45**	2.23	4.98
Deliver	3.00	10.00	**7.64**	2.06	4.23

In table 3 the "Deliver" stage provided the highest score, with the "Discover" and "Develop" stages scoring equally high with a similar level of consistency. The "Define" stage was found to be more of an issue for the students being assessed as providing a low level of satisfaction.

The last in this series of questions was to determine, if there was a design stage that was more important than the other stages, asking, ' In your opinion rate each of the design process stages in terms of importance? The response from each participant showed that the 'Develop' stage was slightly higher than the other stages and had a lower spread (standard deviation) of marks. Table 4 highlights this analysis.

Table 4. Most Important step in the design process – respondents' results

Field	Min	Max	Mean	Std. Dev	Variance
Discover	4.00	10.00	**8.36**	1.77	3.14
Define	3.00	10.00	**7.80**	1.89	3.56
Develop	6.00	10.00	**8.55**	1.50	2.25
Deliver	4.00	10.00	**8.64**	1.72	2.96

Feedback from participants for this question favoured the "Develop" stage over the other stages

"I would have to say that the development stage is the most important. Ensuring that you have a strong concept and ironing out any recognised problems at this stage can save a lot of headaches during the rest of the design process."

However, contradictory comments were also included as part of this question response;
"Discovery is most important because you need to know and understand the need for your product and your market and if you get this wrong you will get the other phases wrong as a follow on effect".

5 DISCUSSION

This section will discuss the results presented in section 4. It is clear from table 1 and figure 2 that 5th year marks are consistently higher throughout the major project across all stages of the design process. 5th years are achieving an average of just over 70% and 4th years approximately 63%. There are several reasons for this. Students on the MEng stream have to meet a specific academic standard in 4th years to progress to 5th Year MEng study. Therefore, this group of students are a select group of students with proven academic ability. Furthermore, students in 5th year benefit from having undertaken a major project in 4th year and the lessons they have learned from this leads to improvement. In addition, there is the sense of students making "the final push" to achieve the best mark possible in their last year of study. Whilst the standard of 5th year project work is expected they account for 50% of the year and 4th year a third. It could be argued that whilst the expectations are higher for 5th years they have more focussed time to dedicate to their major projects with less distraction than 4th years.

Figure 2 shows quite different trends in the marks achieved by each of the year groups. 4th year shows a slight but steady decline in attainment across the 4 project stages. Starting with an average of just over 63.5% for discover and gradually declining by just over 1% to a little under 62.5% for discover. One explanation for this is that as students are undertaking major individual projects for the first time

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they spend a little longer in the initial phases of discover and define and tend to rush through the latter phases of develop and deliver. This lack of experience of time management and having a grasp on how long each of the phases takes in turn leads to a slighter lower mark for the final two phases. It is also possible that whilst 4th year students are encouraged to review and reflect on the marking schedule that naivety leads to this being an activity that is carried out just before the submission date. Leading to 4th year students not fully understanding the weightings associated with each project stage until the project is all but complete. This can mean that students spend more than 25% of their available time on the discover phase which is worth only 20% of the marks available.

Fifth year demonstrates a different "dip" trend, commencing the discover phase with and average mark of almost 70.5% there is an initial dip to just over 69% for define then gradual increase in attainment through develop to completing the project with an overall increase to almost 72% for the deliver phase. This demonstrates that 5th years have more experience with major projects. After a strong start in the discover phase this their marks improve through the latter phases leaving enough time to finish off with the deliver phase being the strongest. It also demonstrates that the maturity of the masters years and awareness of weightings which are 20:25:35:20. Students typically find the third phase of develop the most difficult and challenging phase. The dip at the define phase suggests that students are spending less time and forfeiting marks on the less weighted define phase in favour of spending longer in the more heavily weighted sections of develop and deliver. This "dip" phenomenon also concurs with the finding of the questionnaire which highlight the Discover and Deliver phases as giving the most satisfaction to students with Define being the least satisfactory, interesting or stimulating phase.

6 CONCLUSIONS & FURTHER WORK

This section will reflect and respond to the research questions identified in at the end of section 1:

Q1. Do students engage more with certain stages of the design process during major project work?

The results of the questionnaire suggest that students engage most with the Discover, Develop and Deliver phases of the design process. These consistently score higher in terms of satisfaction and importance. Define phase scores lowest in all categories of interest, stimulation, satisfaction and importance.

Q2. *Do students attain better during certain phases of the design process during major project ?*

Trends in attainment are more obvious in the more mature 5th year student cohort, with students typically achieving higher marks in design phases they find more rewarding and rate as being more important. Attainment in the various design stages also reflects more awareness of weighting of marks in the more experienced student cohort. 4th year attainment is flatter but shows slight and steady decline from start to finish of the design process. This is reflective of the inexperience of the less mature 4th year cohort.

Q3. Is there a difference in this attainment between year groups of the same degree programme?

5th years attain consistently higher through the design process. This mirrors their pre-selected academic ability and experience of previously undertaking a major design project. Fifth year attainment also demonstrates more awareness of allocation of mark allocation.

In conclusion this study answers the three research questions and meets the overall aim of gaining an understanding of how senior engineering design students engage and attain throughout the various stages of the design process during a major design project. This study focusses on data collected over one academic year. Further work could carry out a longitudinal study over a number of years to investigate if the trends are common over a number of years, and could compare different engineering design disciplines.

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