CREATIVITY IN THE FIRST YEAR OF AN MENG DEGREE

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ABSTRACT
Creativity is a requirement of the UK Standard for Professional Engineering Competence (UK-SPEC) stipulating within its specific learning outcomes that accredited degree courses deliver creativity. The point at which creativity is introduced in an undergraduate engineering degree may vary depending on the length of focus on developing the fundamentals of design practice. However, to not incorporate some creativity within the first year of design even within a traditional mechanical engineering department would leave a large step-up in the second year as well as omitting an exciting part of the design process.
This paper reviews the design delivery in the first year of an MEng undergraduate degree and appraises the extent to which it uses creativity. The appraisal is assisted by considering how creativity is defined. Although a gradual increase in creativity throughout the second semester of the first year is shown, it is a design and make exercise where the development of creativity is considered to be strongest, and as such is discussed in detail.
The structure of the design and make process is described with references to existing design models, and its creative phase is described by comparing it to the creative process where divergence-convergence exists. According to Rhodes the generation of creativity has four important strands and it is shown that two of these, product and process, are exemplified within the design and make process.

Keywords: Creativity, design, prototype

1 INTRODUCTION

This paper is based on the delivery of creativity in design during the first year of an accredited MEng undergraduate degree at a mechanical engineering department in the UK. The MEng degree must meet the UK Standard for Professional Engineering Competence (UK-SPEC) adopted by the Engineering Council for assessing the output standards of programmes [1]. Under the specific learning outcomes for design, students need the knowledge, understanding and skills to *'use creativity to establish innovative solutions.'* The knowledge and understanding, practical skills, intellectual abilities, and general transferable skills are detailed under the general learning outcomes, which *'describe the overall nature of the programme.'*

The paper appraises creativity within design in the first year of a mechanical engineering degree course. During the first year, much of the time is spent teaching the fundamentals of drawing practice on both drawing boards and CAD. However, whilst understanding how to communicate a design is important, it is appropriate to introduce the design process and, therefore, the need for creativity and concept generation.

The delivery of design in the first year focuses on developing the knowledge, understanding and skills of engineering drawing practice in the first semester, and then their application in the second semester to constrained and open exercises that are individual and group-based, respectively. The opportunity to incorporate creativity is limited in the first semester of the first year, but is possible in the group-based design and make activity in the second semester.

The design and make activity requires students to work in groups of usually six to produce a mechanical product from their own designs. The product is made by the group using conventional machine tools so, whilst students need to be creative in terms of concept generation, they must also be pragmatic due to manufacturing constraints.

Furthermore, most mechanical engineering students do not have the experience to readily assume the role of creative designers, and so it is important to use instruction which breaks the design tasks down into individual phases which can be stepped through week by week.

2 ACCREDITATION

The MEng degree is accredited by the Institution of Mechanical Engineers for its adherence to the criteria of the UK-SPEC adopted by the Engineering Council [1]. The Engineering Council was set up in 1982 to be responsible for the engineering profession on recommendation of the 1980 Finniston Committee Report proposing '*the establishment of an Engineering Authority*' [2]. The UK-SPEC defines the required output standards for academic programmes. The output standards are met when students achieve the four general learning outcomes and the five specific learning outcomes, which are now discussed.

The four general learning outcomes - knowledge and understanding, intellectual abilities, practical skills, and general transferable skills - are said to describe the overall nature of a programme. References to design are made in both the intellectual abilities outcome, which requires a 'creative and innovative ability in the synthesis of solutions and in formulating designs,' and in the skills outcome by 'must possess practical engineering skills acquired through design work, and in the development and use of computer software in design.' Of the five specific learning outcomes, design is listed separately and contains the following: '*use creativity to establish innovative solutions.*'

The delivery of the five specific learning outcomes by the MEng course ostensibly also delivers the general ones, and this can be seen in part from the above two references highlighting the need for creativity. Stepping back and considering how to interweave all of the UK-SPEC's general learning outcomes through a module's learning outcomes can be seen in an Active Learning module, taught at the University of Liverpool [3]. Active Learning experiences like the design and make activity bring students closer to the practical side of engineering but unlike the design and make replace actual experiences from within a traditional workshop or laboratory with learning by software.

3 CREATIVITY

The UK-SPEC stipulates that creativity should be taught, but what is actually meant by creativity? To help understand what creativity is and how it might be delivered in first-year design, this section explores existing research and definitions of it.

A review of creativity principles applied to engineering design by Thompson and Lordan [4] identifies many definitions of creativity which include:

- 'an act of making new relationships from old ideas'
- 'the ability to look at things differently'
- 'newness or uniqueness and value or utility'

A review of sixty common definitions of creativity by Rhodes [in 4] identifies four strands as being important to creativity: the person, the process, the product, and the press. The press refers to the interaction between the environment and a person, and the effect each has on the other in terms of creativity. Thompson and Lordon [4] state therefore that the achievement of creativity is a function of these four strands, and deduce that creativity involves novelty combined with usefulness. Novelty is described as being either a new idea or a combination of existing ideas.

4 DESIGN PROCESS

This section reviews some of the existing models of the design process or more specifically the problem-solving process to compare the design and make stages with theory, and how the design process incorporates creativity.

4.1 The design process

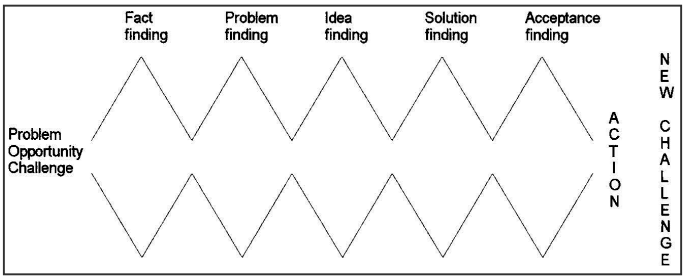
An early suggestion by Dewey [in 4] of the problem-solving process is: defining the problem, identifying the alternatives, and selecting the best alternative. A review by the Design Council [5] identifies the approach of Bruce Archer as playing a key role in developing the discipline of design research: '*Archer wrote Systematic Method for Designers in the 1960s……Archer defined design as employing a combination of the intuitive and cognitive, and therefore attempted to turn the design process into a science by formalising a creative process.*'

A systematic approach is used by Pahl and Beitz [6] to describe the design process. Importantly, problems are solved by a step-by-step analysis and synthesis, progressively moving from the qualitative to the quantitative and from the task to the solution. These descriptions are of a linear format with feedback, and offer a useful breakdown of the design process into clear, discrete phases appropriate to adopt for first-year MEng students.

A wider perspective of the design process that starts with the user and proceeds through to selling a product is given by Pugh [7] as total design. A central spine of familiar phases (concept design, detail design, manufacture) is sandwiched between these two additional phases, and all phases are separated by bi-directional arrows denoting iterations. The Design Council's review [5] highlights the emergence of user participation as one of the key outcomes from models, such as the core-model of Pugh, noting how they formalise the design process.

4.2 The creative process

An interesting aspect of the design process is the way in which it incorporates creativity. The creative process, one of Rhodes's four strands, describes the stages of thinking that creative people use to invent something both new and useful. Thompson and Lordan [4] examine the cognitive or mental thought processes of engineers during the creative phase. An important contribution to the process of creativity is made by the Osborn-Parnes five-stage creative process model, see Figure 1, which promotes imagination (and brainstorming) in the creative acts of fact finding, problem finding, idea finding, solution finding, and acceptance finding.



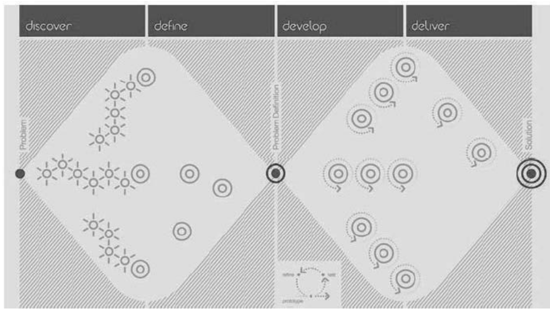


Figure 1.The Osborne-Parnes five-stage creative process *Figure 2. Design Council - double diamond*

The creative process model of Osborn-Parnes, shown in Figure 1, suggests divergence-convergence, noted in work on the structure of intellect by Guilford [in 4]. In an educational context, students may need to have the opportunity to ask questions as part of fact finding divergence. Students in later years are introduced to the Design Council's double diamond phases in design development, shown in Figure 2, where exploration of ideas occurs through a series of iterative loops [5].

Dym *et al* [8] recognise design thinking as divergent-convergent questioning where the first step of a design project is taken by posing questions. In an educational design project, it is pointed out that such questioning has limited effect when known proven principles are applied to a problem to reach a solution. However, this may still be of value to first-year students whose awareness of engineering fundamentals is relatively low, thereby giving experiential validity to their divergent questions within the concept domain prior to convergent questions of the knowledge domain.

5 FIRST-YEAR DESIGN

In order for students to '*use creativity to establish innovative solutions*', they need to apply knowledge of 2D and 3D drawing techniques through practical skills, thereby satisfying the general learning outcomes of '*knowledge and understanding, and practical skills*' prescribed by the UK-SPEC.

There are two design units in the first year of the MEng degree, one for each semester. In the first semester, students are taught how to communicate designs by creating hand-drawn orthographic and isometric drawings of parts and assemblies, and also produce an exploded view of an assembly in either isometric or perspective. A CAD laboratory is also scheduled to give the skills necessary to produce 3D models of parts and assemblies. The first semester therefore improves students' knowledge of the drawing fundamentals and develops practical skills through a series of hand-drawn engineering exercises. In the second semester, three design exercises are set: a five-week constrained exercise, a one-week competition, and a five-week design and make. The opportunity for creativity increases with each exercise, and so it is the design and make activity which is considered in this paper. The five-week allocation is for the design phase only, as the make phase occurs early in the second year.

The design and make activity presents students, working in groups, with the opportunity to generate solution principles and therefore be creative within the concept phase of the design process. The approach to the design and make activity [9], see Figure 3, resembles Pugh's core-based model by starting with the need to identify the market from a brief, but differs from it by replacing the sell phase with a demonstration to staff.

The brief issued to the students contains minimal information, not enough to fully develop a design from, and students must therefore ask divergent-convergent questions [8] to outline and define the market requirements expected by staff which can then be translated into a design specification. The act of asking questions gives students the opportunity to discover the nature of the problem, which is seen as being a critical phase in the double diamond model [5], and then converge at the '*problem definition*'. The brief requires the groups of students to develop a product that is not available on the market, thereby setting an open-ended project which 'raises the potential for creative work through the opportunity to include a significant phase of divergent thinking' provided that the students are not being constrained to develop a preconceived solution [7].

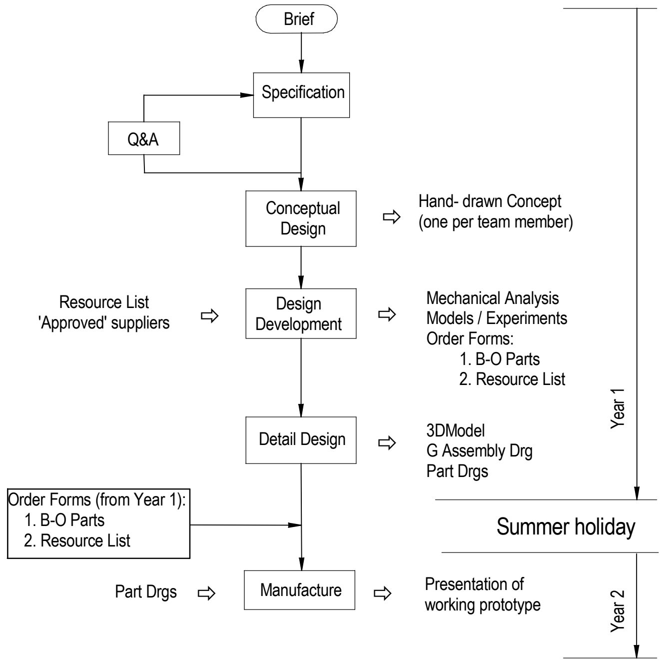


Figure 3. Design and make process [9]

By comparing the design and make process in Figure 3 with the Osborn-Parnes process in Figure 1, it is important for students to be able to find facts and identify inherent problems in order to creatively reach the point from which ideas can then be generated. This point is reached in the *design and make* process when the final design specification is written, although in practice the question and answer sessions spans several weeks and a student group may start to think of or sketch out ideas or concepts from the first week. The concept phase requires students to produce solution principles from which one is chosen to develop. This can be a creative process for students in which divergence-convergence is practised. Thompson and Lordan [4] suggest therefore that '*if creativity is to be improved, more emphasis on the divergent process and the interdependence of divergent and convergent thinking must be desirable.*'

Students enrol onto the MEng degree with A-levels in analytical areas and might not be, therefore, well versed in conceptual thinking. To help the students in the concept design phase create solution principles, morphological analysis is introduced when the design and make activity commences. This technique is normally applied, however, by only a few groups while the others create generic solutions as shown in Figure 4. Whether first-year students feel uncomfortable about breaking the overall function of the product down into sub-functions or simply feel it to be an additional challenge is unclear. Although this should not detract from the creative opportunity the activity offers, perhaps more guidance on its use is necessary.

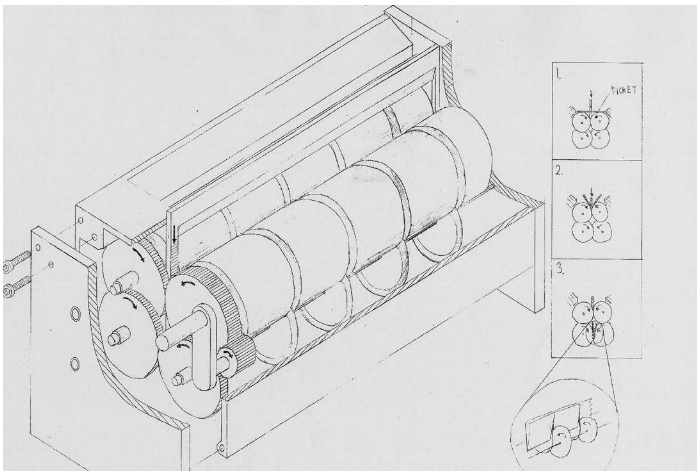


Figure 4. A student's concept drawing

While iteration in the design development phase of the design and make process is not shown in Figure 3, it sometimes happens for some student groups when they build preliminary models (CAD or physical) of their chosen concept principle and discover that it is not going to meet the requirements of the specification. In this scenario, the design development phase compares well with the solution finding phase of the Osborne-Parnes model with students asking further questions about the chosen concept's functionality, and then in the knowledge domain, converge to a decision on whether to proceed with it or not. When student groups choose to reject a concept principle and develop the next in line, they do so with the reassurance that their previous work is not wasted but is in fact a valuable inclusion within their report. It is not certain why more student groups do not iterate in this solution finding phase. Perhaps time proves to be the principal inhibitor.

Rhodes [in 4] includes the product as one of the four strands which are important for producing creativity. The design and make product agrees with this by possessing novelty value and satisfying a need. An example of this is a hand operated raffle ticket machine used as the product recently. This is a machine which separates raffle tickets from a strip, folds them, and dispenses into a receptacle. A solution principle or concept drawing from a student is shown in Figure 4. The sketch shows application of isometric and 2D drawing skills and an understanding from '*the capacity to use concepts creatively, in problem solving, in design*' [1]. In recent years, changes have been made to the isometric exercises to give students practice in drawing a quarter-sectioned assembly. This has proved to be an effective means of clearly representing their concepts in the design and make exercise through graphics and minimal text. A creative product is novel and satisfies a need, and, according to MacKinnon [in 4], should meet a third criterion of having its value communicated to others. The design and make process requires the student groups to manufacture their prototypes in year 2 and communicate to staff its effectiveness and viability by a presentation and demonstration. This final communication shows agreement with the third criterion by the value of their concept principle, the value of the product is predefined in the brief.

6 CONCLUSION

This paper has discussed where creativity, a requirement within the UK Standard for Professional Engineering Competence (UK-SPEC) for accreditation, is delivered in the first year of an MEng course. Whilst the first semester's design exercises develop the UK-SPEC's general learning outcomes of knowledge, understanding, and skills, necessary for producing engineering drawings, a gradual increase in creativity is introduced in the second semester where the specific requirement of creativity was shown to exist in a design and make activity.

The extent to which the design and make activity is creative was initially appraised against a definition by Rhodes which identifies four strands, product, process, person and press, as being significant to creativity. The design and make process was found to be creative in two of these strands, process and product. The process is described more widely by Osborn-Parnes as a creative process, which is achieved by offering opportunities for students to be creative through divergent-convergent questioning. The design and make activity was shown to do this by first presenting the activity in an assignment brief containing information which only outlined the task, and second by holding question and answer sessions in which divergent-convergent student questioning could take place. Care needs to be taken, therefore, to strike a balance between a design brief which had sufficient detail to enable basic understanding of the task, but not so exhaustive as to fully specify it and therefore require no student questions. In addition, the design brief is also mindful of the resource, time and budget limitations within the make phase, and so needs to include data to ensure compliance of the possible solutions to these constraints.

The product, one of Rhodes's four strands of creativity, set for the students to design is described to conform to the definition of a creative product by possessing novelty and satisfying a need. However, offering a creative product year-on-year presents a challenge in not only conjuring a new problem which needs solving, but also one which is suitable for the manufacturing capacity and machine tool capability for use by approximately 250 students. A third criterion of a creative product offered by MacKinnon requires it to be communicated to others. Each prototype made by the groups is formally presented to a panel of staff thereby meeting this requirement of the product also.

In order to encourage all members of a group to share in the creative process, each member is required to produce a hand-drawn pictorial drawing. It has been found that by aligning an isometric exercise to include a sectioned assembly, those students, whose background is generally analytical, are able to produce concept drawings that better represent their individual ideas.

Whilst the design and make activity is said to offer creativity, it does come at a price. Designs may be relatively straightforward for students to draw and assemble in CAD, but are not necessarily easy to machine on traditional machine tools. This has resulted in an underestimation of manufacturing time to produce the in-house parts and, therefore, an increased demand on the workshop. Ultimately, the exercise is student-centred and they decide how the assembly will function. Although a restriction is placed on the suppliers from which they can order bought-out parts, it is difficult to anticipate all relevant components they might need particularly when new designs are being created. Occasionally this has required facilitating by suggesting alternative parts or solutions, or to administrate a supplier to approved status so that orders can be placed with them on the central financial system. A disadvantage of new creative solutions each year is that a corpus of knowledge on how to solve problems throughout the design and make phases does not develop. New solutions may also prevent purchases of higher value items for students to use, such as microcontrollers which are used in a similar exercise at another university, which can be justified on the basis of their reuse over many years.

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