Creativity in Mechanical Design: Exploring Suitable Methodologies for Better Practice

Paul Briozzo, Rod Fiford, Peter Lok.
School of Aerospace, Mechanical and Mechatronic Engineering, University of Sydney

Email: paul.briozzo@sydney.edu.au

*C*5: Systems perspectives on engineering education

CONTEXT

The Unit of Study, Mechanical Design 1 is a traditional mechanical engineering design subject that depends on the use of lectures and texts focusing on applied solid mechanics content in key design areas but historically less so on creativity, creative methods and the design process. The methods used to generate innovative ideas with a mechanical focus are seldom described in the standard mechanical design literature. When students are given set tasks, they are able to readily complete mechanical design problems to varying degrees of completion when presented with an initial creative design framework. However, when the creative design framework is removed from the problem, an impediment that is most likely caused by a lack of developed creative design skills has been observed.

PURPOSE

The use of idea generation methods that have not traditionally been used in mechanical engineering design based literature are explored with a future aim to improve student's skills in developing innovative creative solutions that are suitable for subsequent survey analysis.

APPROACH

The initial approach decided upon before a comprehensive study takes place, emphasised creativity and creativity methods within a milestone lecture and reinforced its importance in subsequent mechanical design focused lectures and tutorials. Informal discussion and observations made during tutorial sessions reinforced the viability of future work.

RESULTS

Positive feedback in discussions held indicated that when more emphasis was placed (by way of lectures, tutorials and discussions) on the use of a creativity method, a more productive outcome in ideation (idea generation) was noted. It is expected that the use of broader and more socially open idea generation methods such as Design Thinking will yield more and better mechanical design ideas than the sole use of the traditional linear design process.

CONCLUSIONS

This discussion paper has found that placing greater emphasis on creativity in a mechanical design framework is more successful than those used in the traditional mechanical design process. A more formal study will commence and be undertaken across the next twelve months by way of a formal survey and qualitative data analysis. The use of richer content more focused on creativity will be included into mechanical design units of study with an outcome giving graduates greater idea generation skills that are readily transferable into industry or potential postgraduate study needs.

Introduction

Creativity in the context of engineering courses is typically defined by authors such as Daly et al (2014) as, 'The ability to engage in a creative process'. Whilst Howard et al (2007) refer to a creative process rather than creativity and define it as, 'A cognitive process culminating in the generation of an idea'. Widely used mechanical design based teaching texts such as Shigley et al (2004) and Norton (2006) do not directly refer to creativity, but the 'Design Process. Shigley et al defines the 'design process' as an 'innovative and highly iterative process' and emphasises that it is a 'decision-making process'. Similarly, Norton (2006) states that the design process is, 'essentially an exercise in applied creativity'.

In summary, the definition of creativity varies if and when it is noted in the literature. The absence, apparent lack of emphasis and unity in the definition of creativity is a major concern as the important role that creativity plays in engineering solutions cannot be underestimated. The need for creativity in a design based curriculum is critical. Christiaans and Venselaar (2005) (cited in Charyton 2015) state, '65 percent of engineers in the workforce (from mechanical, application and manufacturing engineering companies) agreed that today's engineers need to be more creative and innovative to be globally competitive'. Creative solutions are clearly valued and needed by society.

There should thus be pressure on Universities to put greater emphasis on ensuring that creativity is a part of design courses offered in their engineering programs. Stoufer et al (2004) cited in Charyton (2015) further emphasises this point, 'Without training in the fundamentals of creativity, only 3 % of the population associate creativity with engineering'.

Background

The key goals of this paper are to present the current state of creativity in the mechanical design Unit of Study (UoS), Mechanical Design 1, MECH2400/9400 offered at the School of Aerospace, Mechanical and Mechatronic Engineering, University of Sydney and the future potential for development within the mechanical stream. The MECH2400 cohort is made up of undergraduate students undertaking a core UoS that is a part of the Mechanical, Aeronautical, Biomedical and Mechatronic second year streams; whilst the MECH9400 cohort is made up out of postgraduate students who mostly originate from overseas universities.

In 2017, the total number of students enrolled in the UoS equalled 330. The current large number of students has created challenges in terms of repour between the lecturer and students. This is a particularly salient point in a design based UoS as students are less likely to engage in discussion or raise questions within a large cohort. Coupled to this point, very few of the students have any previous practical mechanical design experience.

This UoS also serves as a platform for further study in more stream specific UoS offered by the School. Within the mechanical stream, Figure 1.0 illustrates the UoS as a key foundation stone within the framework of a proposed Engineering Design Major and subsequent core UoS that focus on Manufacturing Engineering.

Within the mechanical stream the UoS delivers introductory content that is broadly divided into three core components;

1. Graphics - Freehand sketching, engineering drawings using AS1100 as a framework and CAD using SolidWorks™ as a medium.
2. Design - Creativity, the design process and stress/strain analysis of machine elements and bearings using derived equations.
3. Power Transmission - Analysis of common machine elements involved in power transmission throughout a mechanical system.

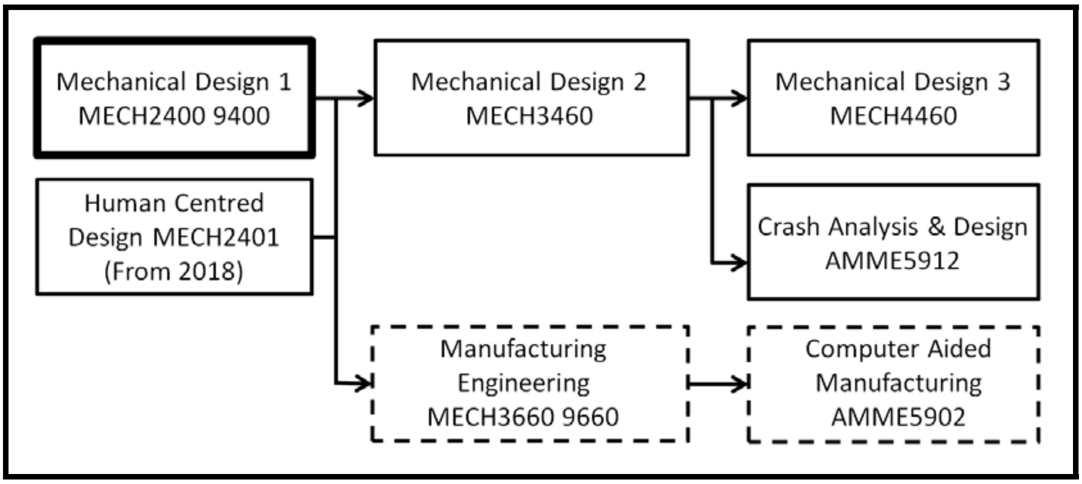


Figure 1.0 Proposed Engineering Design Major UoS Map (Source: Briozzo, P. 2017)

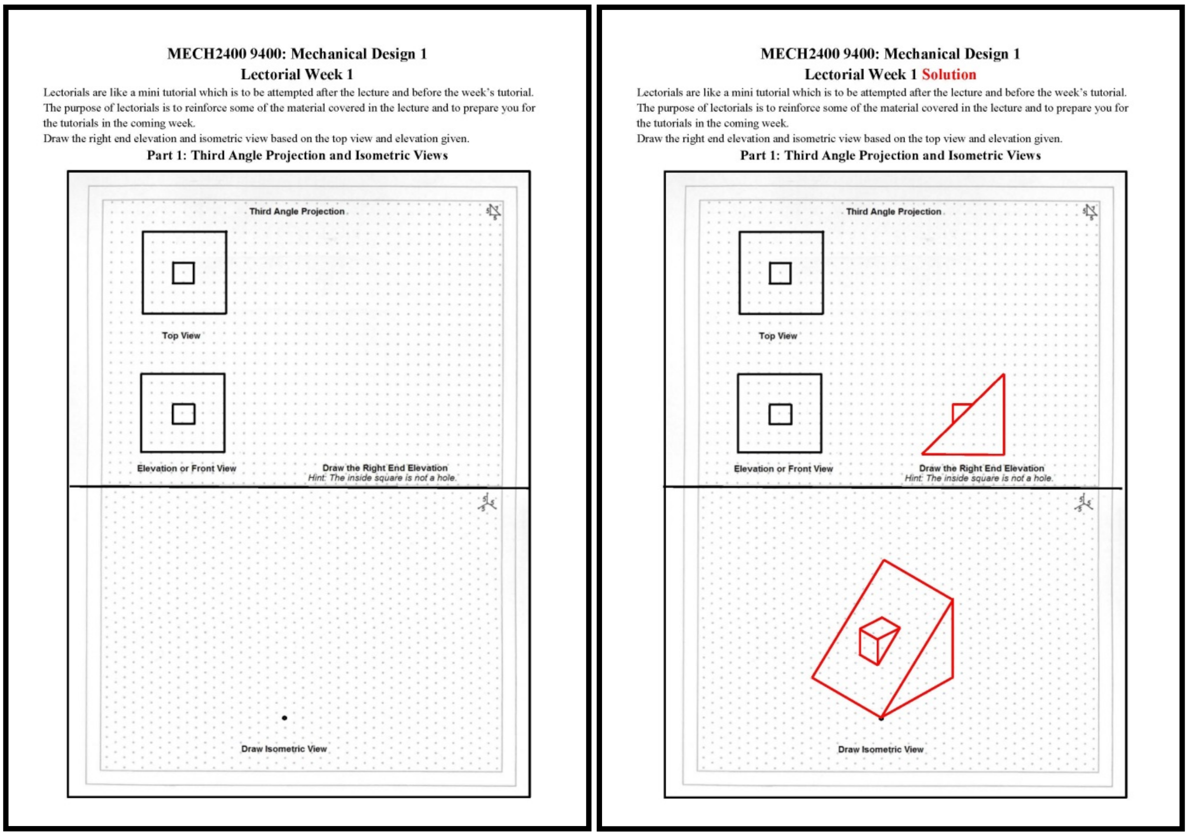


Figure 2.0 and 2.1 Lectorial and Solution (Source: Briozzo, P. 2017)

Lectures

Lectures are given in a traditional format twice weekly for a period of one hour each in duration. As at 2017, the number of students easily exceeds 300. However, a recent trend noted by the author is that the number of students attending the lectures has dropped. The typical flow of the lecture is for the author to pause midway and introduce a "lectorial". A lectorial is a mini tutorial to be undertaken during five to ten minutes of the lecture. Informal discussions with students have indicated that lectorials promote a positive and active learning environment rather than a passive listening space. It has been informally observed by the author that students that take part in the regular lectorials often demonstrate engagement with the topic at hand and are better placed to undertake the week's tutorials. Figures 2.0 and 2.1 demonstrate a week 1 lectorial and its accompanying solution that reinforce recent delivered lecture material, focusing on special concepts, third-angle and isometric projections.

Tutorials

Tutorial enrolments are large and range from 60 to 100 students per room. Students are generally given printed tutorial material related to the lecture content of the week. Tutorial content is also available online but it has been observed by the author that printing a separate sheet focuses the task at hand. Once tutorials have been undertaken, the students attempt is inserted into a Portfolio that is self-assessed and reviewed by tutors on a monthly basis. The tutorials also provide a meeting place for group assignments and informal meetings with the author.

Course syllabus and weekly content

A breakdown of the weekly content and the assessment schedule is provided in Table 1.0.

Table 1.0 Simplified Unit of Study and Assessment Outline (Source: Briozzo, P. 2017)

Week	Weekly Content	Assessment
1	Freehand Sketching; Orthogonal Projections + CAD	
2	Detail & Assembly Drawings to AS1100 + CAD Design for Reliability; (Guest Lecturer)	
3	Tolerancing - Dimensional & Geometric + CAD	Free Hand Sketch (5%)
4	Specifications & Drawing Analysis + CAD	
5	Design & Creativity; Applied Stress (Beams) + CAD	Design Portfolio 1 (5%)
6	Design of Structural Bolted Connections to AS4100 + CAD	Group Assignment: Design, Analysis & Eng. Drawings (10%)
7	Bearings Plain & Rolling Element + CAD	Quiz 1 (20%)
8	Springs + CAD	
9	Geometry of Gears +CAD	Design Portfolio 2 (5%)
10	Design of Shafts to AS1403 + CAD	Group Assignment: Design & Build (20%)
11	Keys and Shrink Fits & Couplings + CAD	
12	Flat & V Belt Drives + CAD	Design Portfolio 3 (5%)
13	Toothed Belt Drives & Engineering Analysis + CAD	Quiz 2 (20%); Group Assignment: Gearbox Design (10%)

Initial graphics content

The UoS begins by introducing students to basic freehand drawing skills, in order to generate pictorial projections incorporating straight lines and ellipses. The pedagogy used is a combination of; traditional lectures using a lectern based visualiser, lectorials and a conventional tutorial based task associated with each lecture topic. Orthogonal projections and the remaining content related to student learning in graphics are covered in the same format.

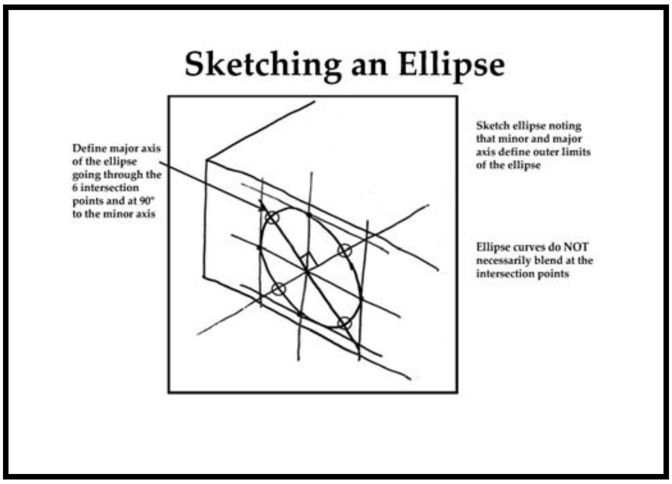


Figure 3.0 Sketching an Ellipse (Source: McHugh, P. 1993)

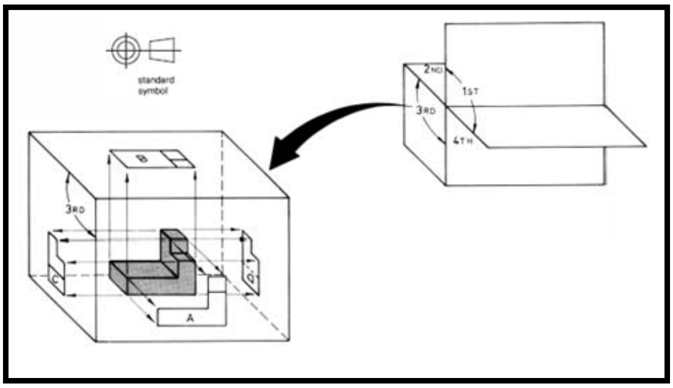


Figure 3.1 Third Angle Projection (Source: Boundy, A. 2002)

The importance of freehand sketching skills in creativity and the design process is paramount. Goldschmidt and Smolkov (2006) (cited in Charyton 2015) state, ‘Sketching is instrumental in design problem solving and results in creative solutions.’ Blackler (1995) goes further to reinforce engineering drawings as a necessary topic in design, ‘Engineering drawings are an essential element in the design process itself, in communicating the design outcome and in preserving the design details for future reference’. Effective sketching skills and the ability to generate and read engineering drawings are highly valuable life-long skills required by all engineering graduates within their respective discipline. These are skills that are technology independent. It is the author’s experience that skills gained in the use of specific CAD packages quickly become obsolete as software and hardware revisions are introduced across a relatively short period of time.

Creativity in mechanical design

In this UoS, creativity in mechanical design is delivered following the content on graphics. The topic of creativity in mechanical design is broken down into six main methods that students may wish to consider using to generate ideas:

1. Trial and Error: Trial and error is presented with Edison as its leading proponent. However, this creativity method is not encouraged in the UoS as it lacks a hypothesis and does not require valuable research to be undertaken, which may have averted time consuming false leads. Whilst the method may produce a random solution (without a benchmark) it may be applied in cases that lack any background knowledge. Trial and error as a creativity method is observed to be very common amongst students initially faced with their first “design and build” or “competition” based tasks.

2. Brainstorming (in a Group Setting): Group brainstorming is promoted as a divergent creativity method in the UoS as most of the assignments require group work, regular meetings and ongoing positive repour between students. This creativity method is also directly supported in the tutorials by encouraging “round table” discussions with direct support from tutors and the UoS coordinator. Assignment assessment in the UoS is indirectly linked to successful group work which depends on the generation of a number of creative solutions. The use of trade-off tables as demonstrated in Table 2.0 are encouraged as an effective divergent method that allows for the comparison and evaluation of a number of brainstormed solutions. It should be noted that Trade-off tables are not a creativity method but a tool used to categorise brainstormed ideas.

Table 2.0 Example of Trade off Table (Source: McHugh, P. 1993)

Concepts		**Beam & Rod**			**Swing Link**			**Rack & Pinion**	
Functions	**Value**	**Score**	**V*S**		**Score**	**V*S**		**Score**	**V*S**
	(/10)	**(/10)**	**(/10)**		**(/10)**	**(/10)**		**(/10)**	**(/10)**
Smooth Finish	2	6	12		4	8		9	18
Corrosion Resistance	6	4	24		3	18		2	12
Speed	4	5	20		3	12		6	24
Stability	8	4	32		9	72		7	56
Range	4	7	28		4	16		5	20
Total			**116**			**126**			**130**

3. Analogy: The use of analogy as a creativity method is highly encouraged as it draws on previously well-known and successful designs and encourages their application in an alternate environment. Analogy inspired designs may also be drawn from nature. Figures 4.0 and 4.1 illustrate a successful implementation of analogy as a creativity tool. Students readily accept and use analogy in their group assignments as it is easy use and completed by readily available internet search engines.

Figure 4.0

Weddell Seal showing off her flippers!

(Source: Costa, D. 2017)

Figure 4.1

Flippers

(Source: Unknown. 2017)

4. Inversion: Inversion is defined by Clear (2017) as, ‘This way of thinking, in which you consider the opposite of what you want, is known as inversion’. The creativity method

inversion is presented but not readily implemented by students as it requires a more structured definition of examples than the tutorial time allows. A simple case is provided, ‘How to do you clean windows so more light can get in? Reconsider the situation as one of letting more light in, not necessarily cleaning the windows.’

5. Design Thinking: Design Thinking (DT) or human-centred design focuses on the client needs rather than technical problems. Figure 5.0 breaks down the various steps in the DT process. One of the leading proponents of Design Thinking, Brown (2008) defines DT, “a discipline that uses the designer’s sensibility and methods to match people’s need with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.” DT as a creativity method, is particularly strong in multi diciplinary projects such as Project Everest, Figure 5.1. During the UoS given in 2017, students were able to directly relate to DT as a creativity method as one of the student’s from the cohort, J. Bergman (personal communication, August 24, 2017) presented their work using DT on Project Everest in Cambodia.

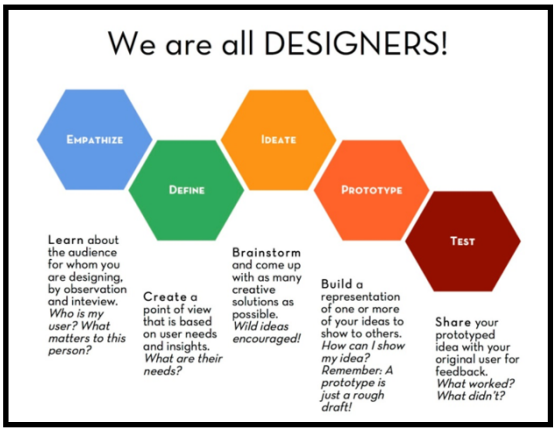


Figure 5.0

Design Thinking Process

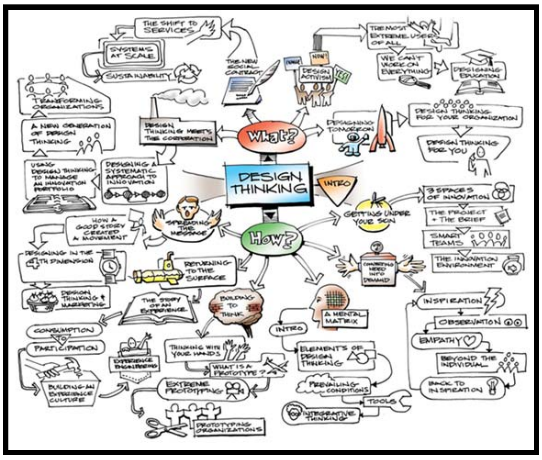
(Source: IDEO 2017)

Figure 5.1

Project Everest

(Source: Bergman, J. 2017)

6. Mind maps: The use of mind maps as a creativity tool in the UoS is highly encouraged with informal student feedback indicating that their use is a positive move towards idea generation. Mind maps allow a broader picture of a design to be formed Figure 6.0 highlights the combined use of DT and Mind maps. Elmansy (2017) states that, ‘Mind mapping is one of the efficient methods that organise all of these (design thinking methods) in a formation and in a visually brain-friendly method.’ In contrast, Figure 6.1 illustrates a flow chart from typical mechanical design text. Note that it does not directly emphasise the creativity component of the design process.



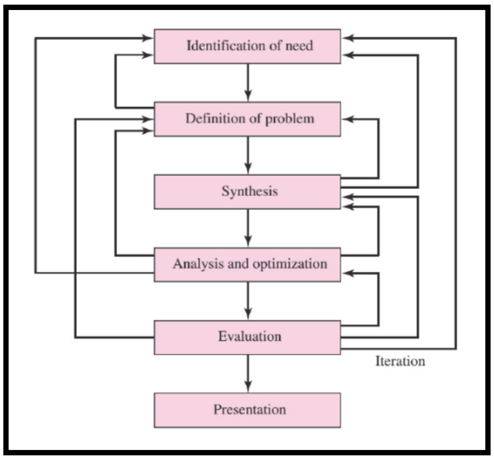


Figure 6.0

DT Mind Map

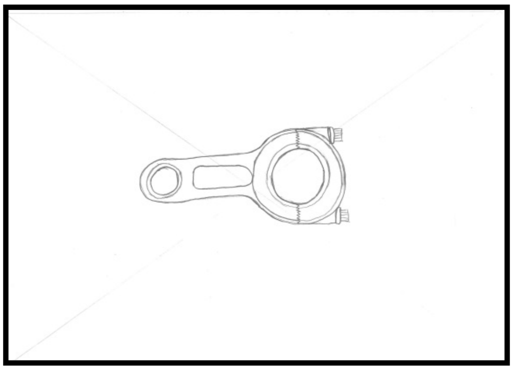
(Source: Brown, T. 2008)

Figure 6.1

Phases in Design

(Source: Shigley et. al. 2004)

Figures 7.0 to 7.2 graphically illustrate the key steps in developing a relevant mind map within the UOS. Using a central theme of the redesign of a connecting rod that was originally designed for an agricultural purpose into a connecting rod that is needed for a racing engine, students are asked to explore the features of the connecting rod that need to be researched and redesigned. Students are initially asked to draw two faint lines diagonally opposed to accurately locate the centre of the page. Figure 7.1 illustrates a basic freehand line sketch that graphically identifies some of the key features of the connecting rod is drawn to define a central starting point. The line drawing is then converted into a coloured shaded image (in this case, grey) as shown in Figure 7.1 in order to give the image a level of realism. It is important to actually sketch the image by hand rather than to use an already prepared image in order for the participant to gain a level of geometric familiarisation.



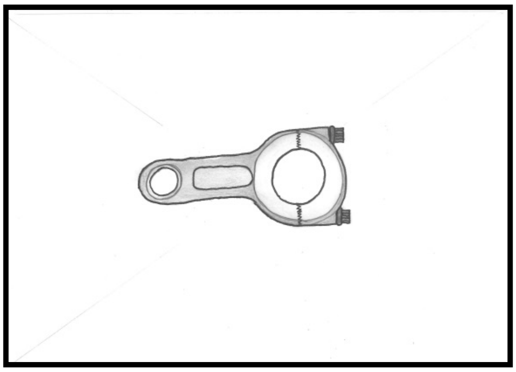


Figure 7.0

Connecting Rod Initial Line Sketch

(Source: Briozzo, P. 2017)

Figure 7.1

Connecting Rod Shaded Image

(Source: Briozzo, P. 2017)

In order to give the image a level of realism, it is important to actually sketch the image by hand rather than to use an already prepared image in order to gain a level of geometric familiarisation with the design at hand.

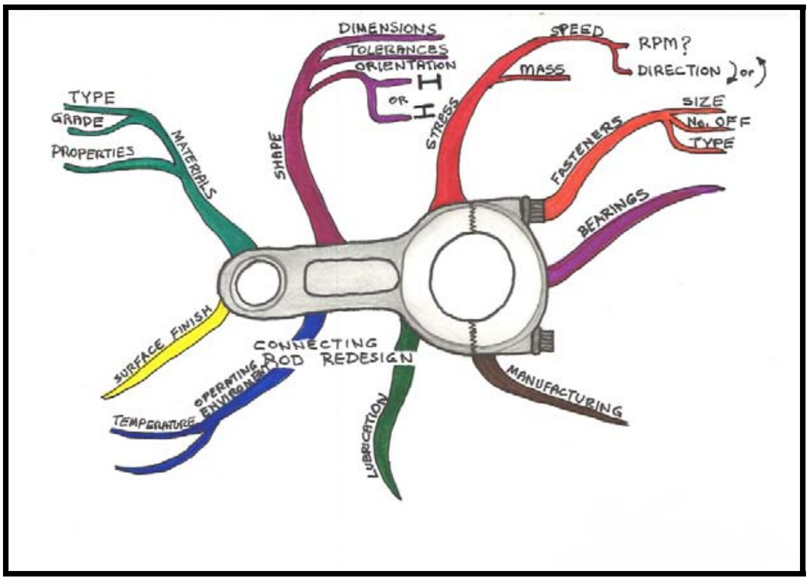


Figure 7.2 Connecting Rod Mind Map (Source: Briozzo, P. 2017)

Once a level of guidance through some of the features that need redesigning has taken place, students are guided by tutors to research key points such as; boundary conditions, materials, manufacturing, shape & dimension. These are core points that are represented by coloured thick branches that radiate outward from the central theme, gradually thinning and diverging outward to represent the various sub themes associated with the redesign. Figure 7.2 defines most of the features of a basic Mind map as applied to a mechanical design based problem.

Pahl et al (2007) refer to semantic networks as a graphical method of representing a mechanical design based problem. However, semantic networks differ from mind maps in that they emphasise the connections that exist between the separate features rather than the progressive idea development that radiates from a central point. Figure 8.0 illustrates semantic network for a bearing.

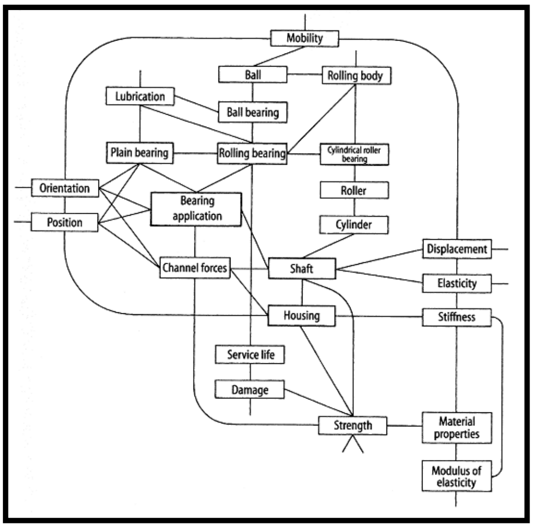


Figure 8.0 Extract of a Semantic Network Related to Bearings (Source: Pahl, et al. 2007)

Results

Tutors observed some students' attempts at applying the mind map method resembled closely to a semantic network, similar to Figure 8.0, consisting mostly of words or phrases within interconnected nodes, with no incorporation of sketches. Students who followed the steps introduced for constructing the mind map, included many common features as shown in Figure 7.2. Some mind map attempts included a basic outline sketch without further attempts at adding realism. Most students needed further clarification before attempting to construct the mind map, perhaps indicating their unfamiliarity with this type of activity in the UoS. Informal discussions with students indicated that using mind maps as a creativity tool assisted in the visualisation of the problem given but to a lesser degree in generating ideas.

Discussion

The informal discussions and the authors' observations of student's preferred ideation methods in mechanical design based assignments over a number of semesters warrants further research. A formal study that incorporates;

- Qualitative data gathered using ethnographic research methods to directly interview students with an aim to gather their opinions on the effectiveness of different relevant creativity methods, and;
- Graphic data gathered from mind maps and compared using criteria such as; shape, colour, depth of text content, variety, quantity etc.;

Image analysis methods incorporating coding techniques such as those suggested by Cohen et al. (as cited in Rose 2007) that carefully dissect each facet of an image by asking a systematic series of questions e.g. "What are the features of the image", may be readily applied to any samples of drafted creativity samples collected.

It is proposed that creativity methods could be introduced to other components within the course syllabus, with the aim to foster students' confidence in implementing more creativity tools in mechanical design problem solving.

Conclusion

This paper has presented the current status and need for the development of creativity skills in students in a UoS that focuses on the area of mechanical design. However, creativity and innovation skills should be life-long skills that are instilled in graduates in each UoS that they undertake in their degree. The authors feel that a necessary start must be made in order to establish; what are the initial skills in creativity that students possess, which creative methods are relevant to a particular UoS and which are the most effective for a given problem as a matter of priority.

Acknowledgements

The authors would like to kindly acknowledge; Dr. Anne Gardner CREITE UTS, Dr. Lesley Jolly and A/Prof. Keith Willey for their continued support (and patience) of the authors in the area of education research.

References

Blackler, J. (1994). *CONSIDERATIONS in DESIGN*. Sydney, Australia: John Blackler.

Brown, T. (2009). *CHANGE BY DESIGN*. New York, United States of America: Harper Collins.

Charyton, C. (2015). Creative Engineering Design: The Meaning of Creativity and Innovation in Engineering In *Creativity and Innovation Among Science and Art* (pp.135-152). London, United Kingdom, Springer-Verlag.

Clear, J. (2017). Inversion: The Crucial Thinking Skill Nobody Ever Taught You, Retrieved from http://jamesclear.com/inversion

Cohen, L., Manion, L., Morrison K., (2011). *Research Methods in Education.* New York, United States of America: Routledge.

Cross, N. (2011). *DESIGN THINKING*. London, United Kingdom: Bloomsbury Academic.

Elmansy, R. (2017). How to Use Mind Mapping for Better Thinking, Retrieved from

http://www.designorate.com/how-to-use-mind-mapping/

Howard, T., Culley, S., Dekoninck, E., (2007). *CREATIVITY IN THE ENGINEERING DESIGN PROCESS.* Paper presented at the International Conference on Engineering Design, Paris, France. Retrieved from

https://www.designsociety.org/.../creativity_in_the_engineering_design_process

Norton, R. (2006). *MACHINE DESIGN*. New Jersey, United States of America: PEARSON Prentice Hall.

Pahl, G., Beitz, W., Feldhusen, J., Grote, K., (2007). *Engineering Design*. (K Wallace, L Blessing Trans.) London, United Kingdom: Springer. (Original work published 1997).

Shigley, J., Mischke, C., Budynas, R., (2004). *Mechanical Engineering Design*. New York, United States of America: McGraw Hill.