

The development of creativity in engineering students

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BACKGROUND

Engineering teaching practices typically tends to be dominated by the application of scientific principles. This often encourages standard measures and procedures for engineering activities. This can inadvertently reduce engineering students' creative capabilities, which are particularly critical in their transitions to their early professional careers.

PURPOSE

The purpose of this paper is to highlight challenges faced by engineering students when developing their practical creative capabilities. From this a better understanding of the type of formal teaching required can be had.

DESIGN/METHOD

Engineering students in two different subjects, machine design and engineering management, were given large projects that required a report to be produced. In the report the students were to document a creativity tool that they found and then used to solve an identified problem that needed creativity. While students were given a list of tools to help their searching, that is all that they were given. After assessment a focus group about the experience and challenges faced by the students while taking on these challenges was held for each group.

RESULTS

Preliminary results indicate that students enjoy taking on challenges that require creativity. However, for the development of creativity, students' background and understanding of creativity within engineering, as along with the context required to support creativity, should be addressed. This is particularly the case when students seem to be struggling to recognise the situations that require creativity.

CONCLUSIONS

Engineering students need to be taught more than creativity. They need to be taught how to combine this with their knowledge of engineering theory to develop ingenious solution, which is the work of the engineer.

KEYWORDS

Creativity, creativity tools, student retention

Introduction

Creativity is one of those critical skills that should be embedded in engineering students' learning process to prepare them to face challenges of dynamic and complex environment. The authors' intention initially was to identify a short list of popular creativity tools and techniques that could be beneficial across units with dissimilar contents (management and design). The authors are of the opinion that creativity cannot be taught, but learned. Thus the intention was to have a collection of creativity tools that engineering students could use and practice with to develop their practical ability to be creative. This is the context in which creativity will be discussed in this paper. The authors are aware of other definitions; we are focusing on what we think would help an engineering graduate.

From the two focus groups we observed creativity was unlike an extra topic to be covered or an activity to be practiced in a unit. Instead it was noted to have somewhat subtle requirements and complexities, already known in the literature, along with some that were unique (possibly) to engineering. Further, it was observed that students have difficulty with these requirements, and need a different type of assistance from what was initially assumed. This paper reports on our initial observations.

Background

Creativity has been cited as an important characteristic in engineers that should be developed in engineering students (West, Tateishi, Wright, & Fonoimoana, 2012) and in the past decades there has been an increased focus on creativity (Bjørner, Kofoed, & Bruun-Pedersen, 2012). This was after it was noticed that it was lacking in engineering degrees (Kazerounian & Foley, 2007). However, there has been little argument to remove the science subjects as well. There are even challenges where students need to take units that are not in line with core standard engineering. Kazerounian and Foley (2007) reported that there is a tension between the engineering sciences subjects and creative subjects as course coordinators have had to find the best balance between both types of subjects. Thus more efficient methods of developing creativity have also been researched so that both can be taught (Genco, Hölttä-Otto, & Seepersaad, 2012).

However, creativity itself is a very broad topic and there are numerous definitions of creativity. Sternberg (1998) has listed sixty one ways that it can be defined. Apart from complexity in defining creativity, creativity is also context dependent and it can be only defined through learning process in which a particular topic has been taught (Ergin & Rouyendegh, 2012). As Brown says 'When intelligent and informed people of good will disagree widely about something, chances are that nobody really knows what's going on.' (Brown, 1989).

In this paper, to allow for a more general bias, the definition we will take is an etymological one. The origin of the word 'creativity' comes from the middle English 'create' meaning to bring out of nothing and from the Latin 'creare' to bring forth ("The Oxford dictionary of English," 2005-). From this the authors take creativity to be the act and ability to generate a solution when no established method is present. Further, instead of teaching creativity to students, the authors take the position that it is possible to enrich learning to develop creativity indirectly. From this perspective, what is needed is an understanding of how engineering students choose to confront problems that require creativity. This will make it easier to determine the skills that typical engineering students need to improve for practical engineering creativity.

Purpose

The aim of this paper is to determine the type of creativity education that engineering students actually need so that future efforts developing creativity in engineering can be more efficiently directed.

Methodology

Method

Two subjects that are different in nature (engineering management and machine design) ran projects that had similar expectations in the use of creativity tools at the same time – semester 1 of 2012.

Students were asked to have an element of their report allocated to explaining the selection and application of a creativity tool that they used in the process of completing the project. This was simply to ensure that students would put effort into being creative. A list of potential tools (such as brain storming, six hats, morphological analysis, synectics and others covered by Silverstein, et.al (2008)) was provided, but that was the only guidance given. A tool is defined by the authors as anything that is intended to help find a solution to a problem that, to the knowledge of the person confronting that problem, has no established solution.

During the 10th week of the semester 5 students from each group participated in a one hour informal focus group to discuss their experiences in the subject with an emphasis upon creativity in the related assignments, which required the use of a creativity tool. Questions about their experience taking on the problem, working within a group and assessment to encourage creativity were put, but the conversation was only semi structured. The students were of mixed gender and engineering disciplines, but were all around 22 years of age. The students who participated were all volunteers after an email was sent to them via the subject online learning system.

The transcripts of the focus groups were then analysed by the authors for themes that affected how students confronted the problems that required creativity and what is needed to help better develop this ability.

Justification

Two subjects of a different nature were compared to evaluate how students responded differently to the same requirement, but in a different context. This was to help better understand the underlying attitudes and abilities related to creativity.

The academic guidance was limited to, once again, ensure that it was the students being compared, and not the academics involved.

By the time of week 10 students would have completed most of their work. Especially the work that required creativity. Therefore, it was a suitable time for the students to reflect upon their experiences. Later would have been desirable so that students had more to reflect upon. However, it was thought unlikely to have sufficient participation closer to the exam period.

The use of a focus group was chosen to allow for the efficient gathering of various perspectives in an open manner that would be more exploratory than a survey would allow for. This was deemed important because this was an early stage project, and the nature of the findings was unknown (Burns, 1994). Further, it was then possible for the authors, along with another experienced colleague (see acknowledgements), to go over the transcripts together. This helped to ensure that the identified themes related to developing creativity were genuinely present.

Subjects used

Machine design

Machine design is a subject that introduces students (around 240) to the basics of machine element principles and design. For some students this will be the first time that they have ever been exposed to such mechanisms before: mechanisms like gears, journal bearings and clutches. Prior to this subject the majority of students have only done engineering science subject, which are to provide the theoretical foundation for this subject.

As part of the subject students are to build a gearbox in groups. The groups are self-selected, but they must have a mix of local and non-local students and a mix of disciplines (the subject has mechanical, robotics and mechatronics, and product design engineering students). The gearboxes are designed in a CAD package to produce dxf files, which are then used to cut the parts from 3mm acrylic. Students were also supplied with 6mm diameter acrylic rod – the gearbox had to be made from acrylic only. The assignment assessment included the relative performance of the team's box against other teams' boxes with regards to power to volume and efficiency. The boxes were tested with a standard motor and a load of the team's choosing above a minimum. The rest of the assessment mark came from the report on the gearbox that was to include a literature review, a design strategy, the documentation of a creativity tool, documentation of the design and a reflective piece about the project. To encourage an even distribution of effort, the mark allocated for the report was the lowest gained in the various sections.

The benchmark design process was the following:

1. Identify the most efficient motor speed from the motor performance curves
2. Decide to lift only 0.5kg because it placed the least load on the box, and produced less friction
3. Note that the shaft diameter of 6mm could be used with the weight from above to determine the output torque
4. Use the output torque and the input torque to determine the required gear ratio
5. Generate a number of possible gear train configurations that would meet that ratio
6. Evaluate each configuration for size
7. Design the box to ensure easy of assembly

This is only a benchmark. Students might have found better processes or different yet equally good ones. Or even processes that were not quite as efficient, but still identified points that required divergent creative thinking (such as steps 5 and 7) and convergent rational thinking (such as the other steps and the preliminary research into gearbox design that was expected of the students).

Engineering management

Engineering management consists of two units: engineering management I and engineering management II. In engineering management I, around 300 students study the basic management concepts such as managerial decision making, planning, leadership etc in addition to some preliminary concepts in project management like scoping and work breakdown structure. In engineering management II, however, the emphasis is more on business side of organisation. For example, concepts such as layout, process design, marketing and accounting are explored. This subject had 40 students in the semester investigated.

One main project has been defined for each unit. In engineering management 1, students are required to analyse a company and form an opinion on the effectiveness and efficiency of the company's management. There were no particular constraints on the type/size of the chosen company. In engineering management II, however, students were required to develop a business plan with their own creative product and analyse its viability. There was no constraint to force them to choose an engineering product. Both projects were run in somewhat very similar formats. Each group developed its own topic and was to provide an

initial presentation, a final presentation, a final report and a group task (documenting their planning and monitoring activities).

Results

After reading over the transcripts the following 4 themes were identified:

- The need for guidance in approaching problems given background
- The ability to understand the role of creativity within problems
- The influence of assessment
- The influence of team dynamics

Each of these themes will be explained below. Selected quotes will be used to highlight the nature of the discussion had, but showing the whole transcript is clearly impractical. Further, it is worth noting that the transcripts would have been reviewed within the context of the subject the authors ran. Therefore, the interested reader is encouraged to contact the authors to discuss this transcript and analysis further.

Student background and the need for guidance

In the machine design group some students indicated that they felt less equipped to take on engineering challenges that lent themselves to creativity than did other students due to prior experience, and that some guidance was required.

As one student in the machine design focus group said about understanding the problem of the gearbox “..a lot of people are in the course because they have grown up with their head under the hood of a car[,] and they... [‘]see[‘] the problem..” and another in the same group said about the help they would like “..just a little bit of help from the tutor going ‘Right, you might want to start looking at this’ and just kind of give us ideas of how we should look at it.”

In the management group students struggled with solving ill-defined problems that would benefit from creativity: “Yeah, I just think we struggled with it, going from – you know, how everything is normally set for us.” These students also felt a need for desire with comments such as “We spent the first few weeks going ‘But what does he want?’”, which suggest more desire for guidance from the lecturer, and “you need to do things in groups or in a tute”, which indicated a desire to try working on the problem while under supervision.

Without this guidance students appeared to have difficulty formulating the engineering problem given in machine design. A comment from one student seemed to sum up the feeling that came from this ‘Yeah, just imagine you’ve got an input and you need to know the output and there’s something in the middle that’s giving you that. And that’s how simple it was to think about it. But we’re standing there going, ‘Oh’... we’re just looking at gears and the teeth and how much they could lift and if we had to change it to make it better, and we just – there was so much in there.” This seems to suggest that systemic thinking might also need developing (Cross & Clayburn Cross, 1998). It also seemed to result in an inability to determine when creativity should be applied and then apply it, as indicated by another student “...by the time we got into our projects, all – a lot of that creative process, or where the creative process would be, was kind of completed..”

Students did seem to feel that with more practice they would get better if that practice had an element of reality. One student in the machine design group said “ I wouldn’t mind either having – if we can do one new project, it’s the first time most people have had to try and make something.” This desire for practice with reality was not unique to the machine design group. One student in the management group noted a greater understanding of business planning once the project became real to them. The first comment made was “after we finished our project.. we sat down and we’re like, you know, we could actually do something like this..” and another comment “..when we watched the other presentations, immediately, we’re like ‘They missed this, they’ve missed that.’ How do you know where the holes are? It’s because we did it ourselves.”

In summary, unless students had a past that involved working on problems with an element of reality they had difficulty formulating such problems and determining an approach that was suitable for solving them without some kind of guidance. This seemed to be stronger for the technical subject than for the management subject.

Understanding of creativity

The attitude of the students toward the problems encountered in the two different subjects suggests that they have set ideas about creativity and how it relates to engineering. When talking about the gearbox design one student said “we’re designing a gearbox, how creative can you be about that?” However, when talking about the business plan project, one student said “..I don’t think you can get more creative than that. It’s like, ‘You guys come up with an idea and you develop it.’”

Despite indications that the engineering task was thought to not require creativity, there were signs of realisation that it could “..there were other groups that did get very creative...Another group, to hold their gearbox together.. had like puzzle pieces..”

One of the reasons for this tendency not to be creative seems to come from a fear caused by a lack of engineering knowledge. As one student said “..for the prototype at least we don’t want to mess around and try and make anything too fancy. We have no idea what we’re really doing, so we’ll just do a gear chain and we’ll just make it as big as possible and we, yeah, we can work out any errors from looking at that.” The better teams appeared to have this knowledge and be able to use it, as another student said “..I think the teams that did the best were the teams that had a similar attitude where you had the best design at the start and then made it work.” A third student was more explicit in the connection between creativity and engineering knowledge by saying “...when you look at what we do when we have creative thoughts, it is – it comes back to knowing your basics and knowing everything that have learnt in our other subjects. So if you can understand that to a higher level, you can see the entire picture and then go, ‘Well, why can’t we go this?’”

Whereas the students in the machine design group would benefit from using engineering knowledge to guide their creativity, but had had difficulty doing this, the students from the management group seemed to naturally look for ways of constraining the problem to make it easier to solve. One student in this group made the comment “we can be creative, but you have to give us limits...” Another student then added “We found ourselves trying to make-define it as something smaller than it was from the beginning because we couldn’t find those constraints.” and a third stated “My whole team, we spent the first couple of weeks looking for the piece (of the subject outline) that says, ‘This is exactly what I want.’ And then when we couldn’t find it, trying to make up our own version of that.”

The influence of assessment

The willingness of students to put effort into creativity was clearly influenced by the nature of the assessment in both groups. This was shown by comments such as “So you’ve got like seven criteria or six criteria that you’re worrying about for the subject. So to actually sit down and then go, ‘I’m going to be creative about this,’ and just get on and do the work is extremely difficult.” But contrary comments such as “It (the marking criteria) didn’t tell you exactly what they wanted, but I thought that was, in a way, helping us be creative...” in the management group.

Comments in the machine design group about assessment focused more on the unique marking (the minimum mark in the report and the mark based on relative performance), and did not explicitly link assessment to creativity. However, one comment suggests that the marking scheme used discouraged all students from learning all skills “(We’ve) become worried about everything we do being perfect because of this rubric and how we’re assessed rather than everyone trying to get everyone to do everything and everyone learn everything.”

Nevertheless, this comment does indicate that the marking scheme made the students take creativity seriously.

Team dynamics

The majority of comments made about team dynamics focused mostly on the issues with differences in desired outcome and the resultant differences in contributions made by the team members.

Disappointingly, there was some evidence that the team dynamics actually prevented learning and the development of engineering skill, which could have included creativity. Comments such as “..one of the people in our group is comfortable to do all the report writing and didn’t want to do much of the design part, she wasn’t very strong at that, so like, she did all the report...”, “..we had one guy who got SolidWorks, he was quick and efficient, so we said, ‘All right, you model the teeth.’” and “..we’ve really been sort of trying to play on each other’s strengths here.’ are indicative of a division of labour that does not encourage collaboration or sharing of ideas.

However, there were some comments made by members of the management group about how the nature of the team can affect not just creativity, but the development of engineering knowledge in general. Two students in management group had the following conversation:

Male1: Yeah, if you know them, yeah, you’re more inclined to share your thoughts and be comfortable with that.

Male2: Yeah, and the fact that you always – like because you will talk more about your actual engineering knowledge with your engineering friends.

Male1: Because no-one want to be a loser.

Male2: You’re always thinking of engineering things and so you just come up with ideas and you just get better.

Male1: Like this is a good example here. Like if I saw you outside now I’d think of [you] slightly differently..

By having a chance to talk openly in a group where there is a common base of interest in engineering and sufficient trust students feel that they will be able to further develop their engineering ability by freely exchanging ideas and testing their understanding.

Discussion

Issues of assessment directing learning and student behaviour in general and with regards to creativity are not new (Oliver, Shah, McGoldrick, & Edwards, 2006), and the evidence from the results that assessment will affect creative effort is not remarkable. Further, the need for comfort and security within a group before creative ideas can be shared is also well founded (Silverstein, Samuel, & DeCarlo, 2008). Additionally, there is also evidence that the division of labour can prevent students from forming shared mental models and engaging in proper group work (Il-Hyun, 2011). Therefore, the results of this research fit with established findings on the basic issues of assessment, encouraging creativity and the nature of learning within group work.

What’s most interesting is the combined effect of background and the use of theory to allow for creativity within the engineering context. The results showed that the students took more naturally to the creativity task in the engineering management subjects than they did in the engineering design subject. Further, this seemed to be related to the students’ ability (or lack of) to understand the engineering problem well enough to know how to combine engineering theory with creativity. This notion of needing to understand theory before being capable of creativity within and engineering context has been noted by others. A quote from an

experienced civil engineer Samuel Florman in Walter Vincenti's *What Engineers Know and How They Know it* demonstrates this well.

'Human error, lack of imagination and blind ignorance. The practice of engineering is in large measure a continuing struggle to avoid making mistakes for these reasons.' P132 (Vincenti, 1993). This quote was used by Vincenti while discussing the use of the control volume specifically, but it highlights the need to use theory to avoid ignorance and imagination to allow for creativity.

This suggests that engineering problems require a continued shifting between theory and creativity along with the ability to know how to shift. The authors were struck by the idea that within the context of de Bono's six hat thinking, which has become an established problem solving tool (Silverstein et al., 2008), this would be the use of the blue hat (the metacognitive type hat used to manage the others) to choose between the white hat (the collection and use of factual information) and the green hat (the use of unrestrained ideas and creativity) (de Bono, 1985). In this context engineers do not so much need creativity, but the ability to determine the best time to use it and the best time to use theory. It is also similar to the modal shift discussed in design by others (Cross, 2006), but more specific to engineering.

The concept that engineering is a managed application of theory and creativity to solve a problem has etymological support too. 'Engineering' in the professional sense derives from the Latin 'Ingenium', which is the also the origin of the word 'ingenious', which is an adjective meaning '(of a machine or idea) cleverly and originally devised and well suited to its purpose' ("The Oxford dictionary of English," 2005-). This act of balancing the practical, or the use of theory to ensure purpose, and the creative is likely the key skill that students felt that they could develop through further attempts at projects and that they needed guidance with.

The reader at this time might feel that the discussion seems to focus more on the nature of the creativity required for engineering tasks like those covered in the machine design subject. Indeed engineering management did seem to allow for a broader view on creativity, and does not as explicitly need the ingenuity as described above. However, as noted by others, engineering management is very much an essential part of engineering education and practice (Palmer, 2002). Further, management does have theoretical foundations, and the use of this theory combined intelligently with creativity would be valuable to the subject. In fact, combining the intelligent combination of respective theory with creativity would likely benefit any engineering subject; it would help to further develop the ingenuity of the engineering students.

Conclusion

Engineering students will be more creative when the environment is supportive of creativity and the assessment demands it. However, they will have difficulty combining it with engineering theory, which is a definite and important aspect of being an engineer. Therefore, along with the established methods of encouraging creativity, ingenuity and how to be ingenious should be an explicit component of engineering education. Without it, it is unlikely that creativity will actually be of use.

How this is done is another question. This paper has highlighted the need to develop this ability in engineering students so that they can develop the type of creativity that they actually need. The requirement was linked to modal shifting and six hats, which provide some idea on how such skills might be developed. However, this was not tested in this research project, and it an ideal avenue for further research.

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Acknowledgements

The authors would like to acknowledge the assistance from ESER (especially Llewellyn Mann) during the research and writing up of this paper. We would also like to thank Llewellyn Mann for conducting the focus groups for us.

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