DISCIPLINARY PERSPECTIVES ON CREATIVITY IN HIGHER EDUCATION
WORKING PAPER

CREATIVITY IN ENGINEERING EDUCATION

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Purpose

The purpose of the Working Paper is to promote discussion about creativity in engineering education. It is a vehicle for collaborative learning based on the perceptions and insights of higher education engineering teachers. Readers are invited to develop or add to the propositions and ideas contained in the paper, or add alternative views, so that the paper more accurately reflects understandings about creativity in the discipline of engineering. Please send further contributions to the author Norman.Jackson@heacademy.ac.uk.

Introduction

The Higher Education Academy's Imaginative Curriculum project[1] is encouraging higher education teachers and disciplinary communities to consider the role of creativity in students' learning and their experiences of learning. Underlying this attempt to engage higher education are the assumptions that:

- Being creative is present in all disciplinary learning contexts, although we rarely use words like creativity to describe such things.
- We all need to be creative (inventive/adaptive) in a world that is constantly changing: a world that requires us also to change/adapt.
- Apart from those disciplines that explicitly recognise creativity as a central feature of their identity (like the performing arts and design), creativity is largely implicit in discussions about teaching and learning, However, teachers do value creativity, originality, flair and imagination in their students' learning. Indeed some teachers believe that creativity is one of the hallmarks of excellence in learning and performance.

Underlying our project is the desire to show that **creativity is an important part of being :** it is integral to being a biologist, lawyer, historian or, in this case, an **engineer**. But being creative means different things in these different contexts for being.

To test this proposition an email survey was conducted aimed at gaining insights into how higher education engineering teachers understand creativity in the contexts of the subject and practice of engineering and the subject and practice of teaching engineering.

[1] www.imaginativecurriculum.net

Questions used to prompt discussion

Q1. **How are engineers creative?** What is creative about being an engineer? What sorts of things do engineers do that are creative?

Q2. **What is it about the subjects within engineering that stimulate / encourage teachers and students to be creative?**

Q3. **How do engineering teachers help/enable students to be creative?** What forms of teaching encourage/enable students to be creative? What contexts/conditions for learning encourage/enable students to be creative?

Q4. **How do engineering teachers evaluate students' creativity?** How do they assess/reward creativity in engineering education? What criteria are used to evaluate creativity?

Q5 **What factors inhibit students' creativity in engineering education?**

ENGINEERING PERSPECTIVES ON CREATIVITY

Introduction

Engineering is a discipline that seems to recognise and value creativity.

> 'Engineering is the *creative application of scientific principles* (US Engineers Council). While the manifestations of engineering creativity are overwhelming in everything that surrounds us, the nature of ingenuity and creativity remains elusive. Furthermore, it can be argued that today's education system neither promotes ingenuity not provides all the necessary tools to sustain it.' [2]

> 'Engineering requires *innovation, creativity and flair focused in a design process*' … Design is at the heart of engineering and it where professional engineers demonstrate their creativity and innovation.'[3]

> 'The toughest problems facing our society – how to provide all our citizens with adequate and affordable food, housing and medical care, efficient and economical public transportation, clean and safe energy – are not likely to be solved by easy or conventional means. If they could be they would have been solved by now. *To the extent that the problems are technological, creative engineers are needed to solve them*. We – engineering professors – are in the business of producing engineers. It would seem our responsibility, and also in our best interest, to produce some creative ones – or at least not to extinguish the sparks of creativity our students bring with them.' [4]

Some manifestations of creativity in engineering (based on responses of participants)

Engineering is a diverse discipline…'directed towards the skilled application of a distinctive body of knowledge based on mathematics, science and technology integrated with business and management, which is acquired through education and professional formation in a particular engineering discipline.'[5]

Engineering is basically the application of maths, physics, electronics and technology to finding and solving real-world problems. Engineers create our material world. They apply science to produce 'things'. There is hardly a product you can name that has no input from an engineer. Engineers design products, processes and systems. Engineering solutions have been developed for the benefit of

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[2] J Carlos Santamarina. http://www7.nationalacademies.org/besr/geoengineering_creativity.pdf
[3] UK Subject benchmark statement for engineering p3 and p6
[4] Richard M Felder (1987) On creating creative engineers. Engineering Education 77(4) 222-227. http://www.ncsu.edu/felder-public/RMF.html
[5] The Engineering Council, Part 2 of SARTOR 3rd edition (Ref2)

society. The discipline is underlain by the moral purpose of trying to improve the lives of people. Creativity is inspired by society and with so much engineering creativity around us it is difficult not to be inspired.

While the main requirement of engineering is not be creative but to be disciplined, engineers must employ both analytical/deductive (convergent) thinking and more inductive and divergent (imagine lots of possibilities) ways of thinking in their work. The design process requires judgement, creativity and discipline as well as technical skill.[6]

Engineers are routinely called on to *design* or *invent* new processes and *adapt* existing processes and products so that they are better and/or more cost-effective *(and therefore more useful and valuable)* than anything currently available. These inventions and adaptations are subject to a variety of technical and economic constraints i.e. acts of creativity are fundamentally connected to the world of economics and technical specification.

All design challenges are ambiguous. There are always a range of possible answers to any design challenge. The answer is always uncertain or ambiguous. Not all design solutions are equally good and some are definitely wrong.

Inspiration for creativity in the design of new products or processes can come from any source in the physical environment. The products of engineering are all around us. Engineering solutions have been developed for society to use, usually but not always to improve the quality of life. There is an ethical dimension to creativity as it is utilised in the field of engineering.

In the world of creating buildings the possibilities are pretty endless. And the chance to influence an urban landscape can be incredibly inspiring. I call it conception to completion. I always carry a notebook with me to jot down ideas. There's nothing like looking back and seeing the first doodle of a building on the corner of a page and then there it is, in real life.[7]

Engineers *transfer ideas* and things from one context to another. They *adapt* products produced for one market so that they can be used in another market. *Extending the use of something* is another dimension of the engineering creative enterprise.

Engineers *solve* problems – more accurately they diagnose and solve technical problems that don't lend themselves to routine or conventional solutions. They also *find problems that could only be imagined and conceptualised by an engineer* with their knowledge and technical background. Without the questions being asked and then answered the world would not advance technically and technologically in the way it does.

Perhaps there is something unique in the way imagination is utilised when the imagination can access the domain specific knowledge and skills of an engineer. Perhaps there is also something significant about creativity in the way engineers are inspired to imagine by the technical problems they encounter and the economic constraints within which they work.

Engineers have to solve problems, often on the basis of limited and possibly contradictory information. In situations of incomplete data imaginative use of pattern recognition and predictions based on similar situations must play a part in the thinking process.

Engineers have to apply systems thinking to complex problems in order to think of the problem holistically – how the components of the system interact and relate to each other. They must balance costs, benefits, safety, quality, reliability appearance and environmental impact. Balancing so many

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[6] D. L Decker Engineering design processes, problem solving and creativity. http://fie.engrng.pitt.edu/fie95/3a54/3a54.htm

[7] John Roberts Head of structures for Atkins, international structural engineering company. Independent Education and Careers p12 07/04/05

variables in finding solutions may be a distinctive feature of engineering problem working and an important driver for creativity.

Creativity can be manifested in designs – imaginative and novel; in the testing side of the product – how can a tidal wave be simulated without actually having one available? and in the application of the product – how can we extend the use of this?

To be creative, engineers need to develop methodologies for formalising specifications of requirements and then identifying appropriate technology to satisfy them. Grading solutions is particularly important to ensure optimum solutions are found. This must take account of satisfying performance requirements and external market forces such as economics of manufacture and perceived values of end users.

Creativity can also be manifested in the way engineers interact with and motivate or encourage colleagues by examples of good practice or conduct. They can also be creative in the way they communicate within their field or with members of the public.

The selling of ideas and novel solutions to clients must also be part of the creative process of an engineer. In presenting a unique idea or novel solution to a technical problem the creative engineer must convince other people of its value and its technical and economic feasibility.

Creative processes of engineers

The creative processes of engineers can be related to some of the generic models that have been proposed to explain creative thinking processes.

> 'In response to the requirements of the client's brief, a number of possible design solutions emerge from the sub-conscious mind of an engineer – i.e. through the sub-conscious creative process. The various constraints, or criteria, of the brief (together with a range of other criteria and influencing factors – ranging from 'explicitly defined and formal' to 'tacit and informal'), constitute the basis for analysis and evaluation of each of these emerged design solutions (or design schemes).'
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> 'Generically, the creative process is based on a sub-consciously synthesised solution to a posed goal/brief/challenge/problem. The best design solutions are often produced by experienced practitioners, of high ability, who have carefully and reflectively analysed the 'brief' in detail and who then have had an intervening sub-conscious 'incubation' period before the 'Eureka' experience – i.e. the synthesized created solution (idea, or scheme) – comes forth into the conscious mind. Generically, the whole creative process can often be iterative and cyclical in nature, and it does not always follow a set, expected pattern. The various created solutions, which have come forth from this sub-conscious creative process, have still to be subjected to a process of further analysis and evaluation (ranging from formal to informal in nature), so as to check or justify the adequacy and efficacy of these solutions to the design goal/brief.'
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> 'Engineering *problem solving* can be conceptualised as a series of steps for example[6]: 1. recognise a need, 2. accept the challenge, 3. define the problem, 4. collect information, 5. synthesise and ideate, 6. analyse and optimise, 7. evaluate, and 8. implement. There are several creative situations which might be applied within the engineering problem solving process[6] the most applicable are: Design, Invention, Opportunity, Problems, Improvement, Planning, Futures and Projects.'

Forms of teaching that encourage/enable students to be creative

Teachers' conceptions of teaching are critical to any consideration of the promotion of students' creativity. At least one respondent felt that it was not possible to enable students to be creative.

> 'University academics regularly kid themselves that they are enabling students to be creative. If the students are not creative by the age of 18 it is unlikely they will learn the trick. What we can achieve (and is usually mis-labelled creativity) is a holistic approach to problems.'

Negative views of the idea that creativity can be taught are based on transmission models of teaching where teachers attempt to transfer their own knowledge and sense making to students through lecture dominated teaching, where students' engagements in learning are predominantly based on information transfer, and are heavily prescribed and controlled by the teacher. Such conditions are less likely to foster students' creativity than when the teacher acts as a stimulator, facilitator, resource provider, guide or coach: where students are given the space and freedom to make decisions about their own learning process and outcomes, and where their reasoned arguments and solutions are valued. The responses of engineering teachers recognise these conditions.

Teachers of engineering recognise that the engineering curriculum can, and often is taught in ways that require little in the way of creativity from students.

> 'The only subject in engineering that contains an intrinsic demand for creativity from students is the capstone design course, which calls on the students to come up with a new (or at least new to them) device or product. The rest of the engineering curriculum can be (and unfortunately, often is) taught in a manner that requires no creativity on the part of either instructors or students.' And 'some subjects in the engineering curriculum are far from creative. e.g. traditional thermodynamics or mathematics. It is only through challenging applications of such science that creative juices start to flow – problem solving!'

However, it is within the power of individual teachers to create the teaching and learning situations in which students' creativity is more likely to emerge.

> 'All courses can be taught creatively in a manner that calls for a great deal of creativity from the students and some instructors do so routinely. The number who do so is relatively small, but it is growing.'

Forms of teaching that engineers believe are more likely to offer opportunities for engineering students to be creative include:

- Design - the creative process associated with the design and building of an engineering structure or machine.
- Working with problems that do not have single solutions
- 'Enquiring' - surely being creative is to explore the unknown?
- Independent project work.
- Projects or competitions for teams.
- Simulated exercises in which <u>actual</u> practice of the skills and areas of thinking and processing is involved.
- Use of open assignments / discovery learning.

Giving students *responsibility* to make decisions for themselves and encouraging them to do so seems to be a feature of a learning environment that encourages creativity.

> 'The more responsibility the students have for defining problems, identifying what they know and what they need to find out, selecting and implementing solution strategies, evaluating solutions, and monitoring and evaluating their own thinking and problem-solving processes, the more their creativity is stimulated.

Inquiry/enquiry and *discovery* based learning feature prominently in responses because of the opportunities they provide for students to make decisions and choices about how and what they are learning. Also problem working situations where the problems are complex with lots of ambiguity, uncertainty and opportunities for not reaching successful conclusions. Just-in-time teaching is also associated with promoting students' creativity.

Encouraging students to *think holistically about problems* is an important developmental activity in engineering education problem work. The relevance of the task or problem to real life situations is seen as being important so that students can practice and experience the sorts of thinking and actions that real work situations would require. Simulating the business environment through competitions is one tactic used to focus creative attention in problem working.

> 'All forms of inquiry-based learning, including guided inquiry, problem-based learning, project-based learning, discovery learning, and just-in-time teaching, promote creativity. The more responsibility the students have for defining problems, identifying what they know and what they need to find out, selecting and implementing solution strategies, evaluating solutions, and monitoring and evaluating their own thinking and problem-solving processes, the more their creativity is stimulated.'

> 'Giving students practice and feedback in solving open-ended problems. Helping them learn (a) to tolerate ambiguity, (b) that the good may be the enemy of the best, but also that the good is very often good enough; and (c) that failures are inevitable, acceptable, and instructive stepping stones on the path to success.'

> 'Problem based situations, group design briefs, creativity exercises, lateral thinking and analogy are all helpful approaches. I particularly find that they can (normally / generally?) be more creative if under a bit of time pressure, but with little social pressure. Therefore, structured brainstorm sessions with external reflection can be very effective. Open tasks are much more successful than closed.'

> 'By encouraging interest in the particular engineering subject, using analogies to identify how the topic is relevant and introducing the concept of the various applications of that particular topic. Teaching methods such as problem based learning aid in the creativity process, giving students challenging laboratory work, leading them rather than showing. Students can be encouraged to be creative by supporting their ideas, encouraging free thought, and, if need be, offering some guidance and direction towards different ideas and concepts.'

> 'Another approach is 'reverse engineering' where students dismantle existing products and identify mechanisms, materials and manufacturing processes which are used. This can be expanded further to get the student to think of alternative products which could make use of the same technology. This encourages the students to apply solutions to new problems and hence be creative.'

> 'A chosen activity should be considered to be, and viewed by the students also to be, important and relevant to future real practice. The active practice of the creative process itself – and its associated knowledge/understanding/skills – should, ideally, also be an actual and important part of the subject's exercise(s). This is analogous to learning how to make an excellent clay pot. Such a skill may best be developed through the personal experience of the essential practice of personally making a clay pot, under the guidance of an expert tutor/mentor, and <u>matching</u> against demonstrable examples of good and even expert practice (i.e. expertly made clay pots – with the expert tutor being able to point out and explain why it is an excellent clay pot).'

> 'We ask students, working in teams, to come up with or 'create' innovative ideas for assignments which involve some element of competition.'

A focus on creativity has the potential to shift the focus in learning from one that is focused on the extrinsic motivator of assessment to motivations that engage with the interests and values of students.

> ‘Many of the factors [that promote students creativity] change the emphasis from ‘extrinsic’ influences to a student’s own ‘intrinsic’ interest and learning – all of which should encourage and enhance the effectiveness of the outcomes of a student’s learning. An intended aim of such a learning approach is that much of that learning should therefore be more integrated, residual, and also transferable to future applications and situations.

Engineering teachers also recognise the importance of the environment for learning when they are trying to encourage students to be creative.

> ‘Good geographical locations and a pleasant learning environment – good resources easily (but not too easily) to hand.’

Evaluating students’ creativity

At the pessimistic end of a spectrum of opinions there is a view that most engineering teachers don't require creativity from their students and so don't assess, evaluate, or reward it. A more positive view is that ‘Creativity is valued but not rewarded in most assessment schemes.’ Where it is rewarded the following ways are distinguished:

- recognition via achievement marks
- ‘praise / allocation of higher grade for unique/elegant solution’ recognition via prizes
- recognition via additional contact and support (because staff are interested).

These generally positive views have to be tempered with the sobering thought that ‘academics usually punish any thinking which is different from their own!’

Engineers accept that assessing creativity is difficult and some individuals admit that they are poor at doing it. Some go further ‘I have no idea how to evaluate it!’ ‘Difficulty arises from trying to define how to measure potentially intangible creative activity compared to the seemingly more straightforward task of measuring knowledge and its application in engineering contexts.’ Difficulty also arises when a tutor suspects that a student’s creative products may not be entirely their own. ‘The creative bit, in my experience, may often be traced to a member of staff (how many of your ideas should you give your project student?).’

But perhaps in such situations it is how the student uses a teacher’s ideas that is the focus for evaluation. The issue of plagiarism may be different where creativity is concerned. Many creative thinking techniques promote the idea of piggy backing on the ideas of others yet this is positively discouraged in mainstream academic work. However, students should be aware of the ethical dimensions of making claims for creativity that is not their own.

Assessment of creativity is usually focused on products or outcome artefacts rather than the process or creative act through which the product was conceived and produced. ‘To encourage creativity a significant portion of the available marks should be explicitly allocated to that part of the activity’s process.’
Applying an engineers way of thinking to the assessment of creativity –

> ‘Creativity is not ‘absolute’ and the subject has to be taught using a Management System approach the main steps of which involves :
> Step 1: DEFINE the objective and performance criteria
> Step 2: ORGANISE how the objective is to be met
> Step 3: IMPLEMENT the task in practice

Step 4: MEASURE results against performance criteria
Step 5: REVIEW lessons gained and lessons learnt

> The steps are placed on a circuit so that there is some iteration and improvement is continuous. By using this approach, evaluation is done in the 'MEASURE' step.'

While this provides a hard systems approach to the problem of assessing creativity defining what creativity is, is actually a soft systems problem! The social construction of what is creative and why something is creative would seem to be central to evaluation. This would suggest that negotiation between tutor and student would seem to be important part of the process of evaluating a student's creativity or the products of their creativity.

> 'The actual creative activity and processes should be done (i.e. be experienced) by the student herself. She and the tutor should both be aware of what the important features or criteria of the process are, of important features of the artefact, and also of the relative importance of each of these. Marks allocated to such aspects should be both explicit and clear, and be understood as such by both student and tutor.'

> 'The criteria used to evaluate a students' creativity are very difficult to summarise as you may be looking for 'novelty', 'effective approach', 'breadth and depth of suggested alternatives' or an 'optimum solution'.

> 'Creativity is demonstrated when a solution to an engineering problem has a significant advantage over what has been done before - very high performance / very low cost / new approach.'

> 'We use a definition that is well-established in the literature that says the characteristics of a creative product (or process, or system) are: 1. Novelty (is it original and surprising?) 2. Relevance and effectiveness (does it do what it is supposed to?) 3. Elegance (is it a simple, easy to understand solution?) 4. Germinal (does it lead to other ideas, applications?) This has worked well as a basis for explaining various case study examples to students (e.g. the Berlin Airlift as a creative solution to a problem, or, the design of a mousetrap powered vehicle). Most recently we have refined this definition into what we call 'functional creativity'. This is an engineering-specific definition that encompasses the above criteria, but also gives them more order and weighting.'

Moving from the abstract to the concrete evaluation of creativity depends on the nature of the task or situation.

> 'The way I evaluate it depends on the type of assignment. If I give a brainstorming exercise in a homework assignment or on an exam, I give marks for both fluency (counting independent solutions) and originality (e.g., triple credit for a response no one else thinks of). If I give a design assignment, I give marks for both originality and technical feasibility. If I give a problem-formulation exercise (see http://www.ncsu.edu/felder-public/Papers/Creative_Engineers.pdf for examples), I'm careful to specify and illustrate beforehand the kinds of things that will lead to high marks (real-world scenarios, broad integration of course material, high Bloom-level skills required for solution, high-quality writing, originality, humor,...), and then award marks based on the degree to which those things are present.'

The critical self-appraisal of the products of creative thinking and personal reflection on the creative process are important considerations in the assessment of creativity. Indeed they are recognised by those participants who commented on the creative processes of engineers. They must be particularly important when students are engaging in apprenticeship type activities aimed at raising their awareness of their own creativity. This is an area that relatively few respondents commented on.

> 'Reflection', which it may be suggested should go hand in hand with creativity to make it into a controlled activity rather than a happy accident!'

‘..if students were to have an appropriate degree of ownership of the evaluation/assessment process (under an appropriate degree of moderation by the University staff), this could contribute to enhancement of the learning experiences.’

‘The more responsibility the students have for defining problems – identifying what they know and what they need to find out, selecting and implementing solution strategies, evaluating solutions, and monitoring and evaluating their own thinking and problem-solving processes – the more their creativity is stimulated.

Factors that inhibit creativity in engineering education

Related to teaching – what the teacher does

- Too much time is spent on teaching details which are either irrelevant in an educational context or the knowledge would be picked up in practice.
- Reluctance of teachers to try fresh teaching methods as they require more time and offer no real promotional benefits.
- Formal evaluation of teaching performance is good for ensuring standards are maintained or established but kills creativity as those in charge are more concerned with procedures and less about education.
- Having tutors or mentors who are not experts or who have not had sufficient real practical experiences.
- Interfering too intrusively in the student’s practising of the various processes involved
- Failing to give adequate importance/currency to the creative aspects of the activity (e.g. not giving an appropriate portion of the available marks to that part of the overall activity)
- Overloading the student (in the module, or in the wider curriculum).

Relating to assessment and motivation

- The assessment / evaluation of the learning process being purely extrinsic (i.e. externally determined and allowing students no or little personal ownership or say in the process.
- Overloading the student in the module or in the wider curriculum – which often invokes the adoption of intelligent coping strategies e.g. rote memorisation or surface processing of the learning material.

Relating to what the students’ do

- Activities that do not involve at least simulation of the real creative process, but which are too abstracted from it (e.g. mere verbal or algebraic-numerical, ‘linguistic’ representations of the process).
- Overloading the student (in the module, or in the wider curriculum) – which often invokes the adoption of an intelligent coping strategy of (e.g.) rote-memorization or surface- processing of the learning material

Relating to perceptions

- Some engineers believe one has to ‘produce a working model or device’ before he/she is regarded as creative. This, in turn, prevents them from taking an idea further.
- Lack of perception by the student of the relative importance and relevance of the activity.
- Many students create new devices, approaches, etc in a non academic situation. For example, the students in Singapore are very creative in coming up with solutions for non academic activity but see academic work as ‘routine’ and creativity is not welcome.