ENHANCING THE INNOVATION SKILLS IN ENGINEERING STUDENTS

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ABSTRACT
The paper looks at the skills needed for innovation - such as tenacity, independence, imagination, risk-taking, creativity, intuition and leadership – and then identifies typical gaps in those skills within engineering students. The paper presents the case study from the University of Bath focusing on creativity, design and prototyping skills.
The aim of the paper is to present the work that has been done on an engineering design unit to boost creativity, design and prototyping skills for engineers. The paper presents evidence of changes in the students' innovation skills (self-assessed) from the protocol analysis of independently conducted interviews and focus group. The paper then goes on to discuss the overall learning from the teaching approaches focusing particularly on the extent to which the skills needed for innovation have been enhanced.

Keywords: Innovation, skills, engineering design, product design, teaching approaches, tenacity, independence, imagination, creativity, uncertainty, ambiguity

1 INTRODUCTION

This work started at the university in Bath in 2004 and was given more support following the publication of the Cox Review of Creativity in Business: building on the UK's strengths [1]. In which sir George Cox called for: '…broadening the creative understanding and skills of tomorrows business leaders, creative specialists, engineers, and technologists…'. The report also provided clear and useful definitions of: creativity – the generation of new ideas; innovation – the successful exploitation of new ideas; and design – shapes ideas to become practical and attractive for users or customers. These three definitions are particularly useful in this context because they make clear the relationship between creativity, innovation and design.
The motivation for the educational work at Bath was to: improve the experience of the students wanting to specialise in design and innovation: and to enthuse students and develop a passion for design innovation built on solid engineering fundamentals from the first three years of their degree.
This topic is not new and earlier work on skills for innovation has included a focus on: multidisciplinary studio culture and the learning process associated [2]; integrating the work practices of product designers and engineers [3]; identifying the skills missing in design engineers (including innovation-driven design skills) [4] and the effectiveness of open design briefs in developing engineering design skills [5]. Research in to skills needed for innovation also led to some work on the skills needed for entrepreneurship, and although innovation and entrepreneurship are not synonymous (innovation can take place in an entrepreneurial setting or within large companies) the skills framework [6] shown in figure 1 has been used for the educational developments presented here.
The framework describes the generic skills identified in entrepreneurial individuals. These formed the basis for the educational developments on this unit at Bath and the aim of the work became 'to develop students' entrepreneurial skills of tenacity, independence, innovation, imagination, risk-taking, creativity, intuition and leadership'.

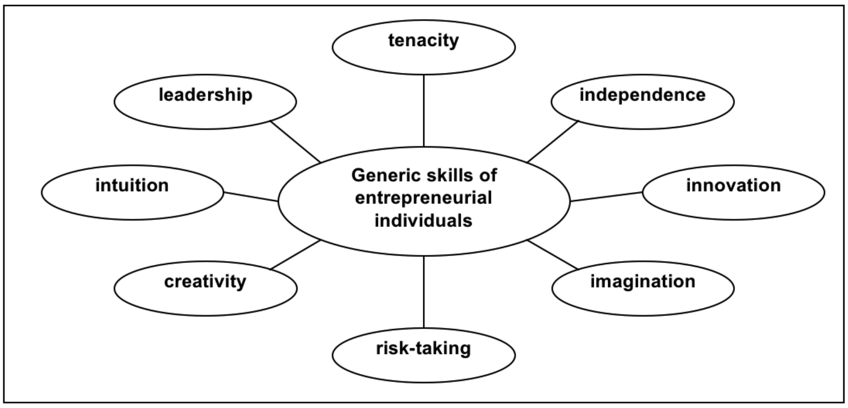

Figure 1. Generic skills needed for entrepreneurship (after [6])

1.1 Description of the Specialist Design unit

For the Unit (titled Specialist Design) the aims are to: illustrate and communicate the totality of the product innovation process, from concept design, through design iteration, to detailed design; and for students to plan their project work and conduct the various stages of a design project independently, which includes learning to deal with uncertainty, ambiguity and risk.

The course gives a rounded view of product innovation that includes differentiating technology-push from market-pull strategies. Through their own major project, many students understand - for the first time - the importance of market needs and understanding end-users, in driving successful product innovation.

In the unit, the students are expected to: question, expand and develop the brief; identify and pursue the research needed for their project with tenacity; define a detailed quantifiable design specification for the product; develop a range of design concepts; design the most promising solutions in detail; and deliver working prototypes that prove the principles of the final solution. Figure 2 shows one student case work example where that broad range of expectations was met.

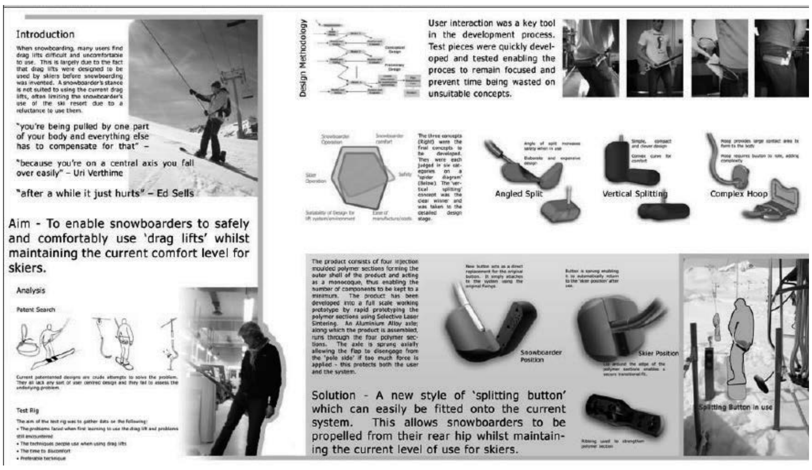

Figure 2. Student case work example.

Earlier work on this unit [7] hypothesised that the main difference observed between designers trained as product designers and those trained as engineering designers, was in the fundamental approach to the design problem or innovation opportunity (shown in figure 3). Engineering designers working on a problem or opportunity will work forward from what is known and understood: they will demand proof and evidence in the earliest stages. Product designers working on a problem or opportunity will make large leaps of the imagination in the early stages and generate the core of a novel idea and then work backwards to 'what is possible' from 'what is imaginable'.

Taking such a product design approach with engineering design students means that the unit will need to enhance the students' skills in imagination/creativity but also need to give them the confidence to deal with the uncertainty, ambiguity and risk-taking required for innovation. Therefore, alongside the student's own design brief, the unit also contains the workshop activities, peergroup sessions, tutorials and guest speakers. These are intended to enhance those particular skills.

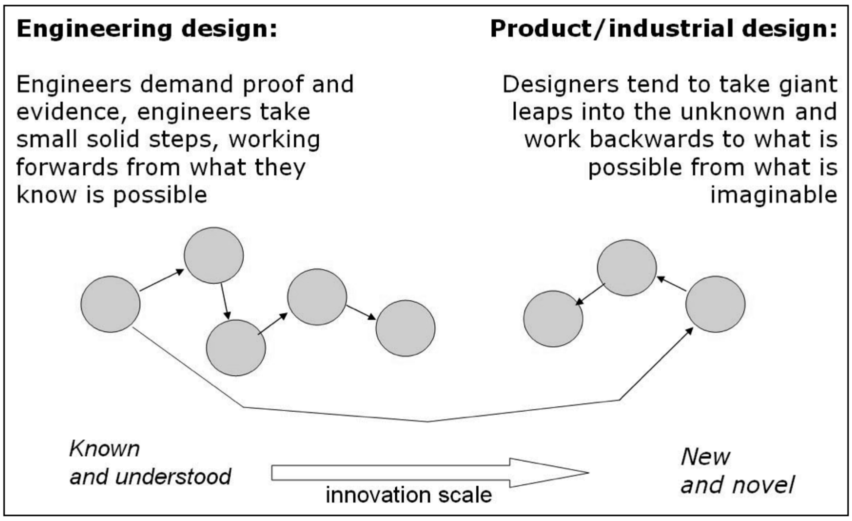

Figure 3. Characterising approaches of product designers and engineering designers [7]

1.2 The skills needed for innovation

From the overall unit aims five specific skills are highlighted as particularly important. The definitions of those specific skills are as follows:

- Tenacity: the ability to persevere with idea development in general and to continue working on a concept until a workable mechanism/embodiment has been achieved.
- Independence: the ability to make strategic design decisions and move the project forward independently.
- imagination/creativity: the ability to imagine solutions, ideas or opportunities that do not exist yet; and the ability to generate multiple solutions, ideas or opportunities (referred to as divergent activities in the design process).
- dealing with uncertainty: the ability to move the project on, despite several unknown variables; and the ability to understand system complexity and prioritising information.
- dealing with ambiguity: the ability to progress the solutions/ideas/opportunities despite contradictions in the information available, the ability to make decisions based on complex qualitative information.

1.3 The activities intended to enhance the innovation skills

The table 1 below gives a description of the unit's workshop activities, peergroup sessions, tutorials and guest talks and relates them to the intended skill development.

Table 1. Activities intended to enhance the innovation skills

Unit Activities in addition to the individual project work	**Intended skill development**
Creative warm-up: students get set a short assignment in which they have to design and build a solution within an hour	imagination/creativity
Visiting talk- MountainTrike: Graduate from the unit, shows how his project has become a commercial product and business	Tenacity, Independence, imagination/creativity, dealing with uncertainty

Brainstorming games: workshop focuses on brainstorming skills through exaggerated exercises: 'no criticism of ideas' and 'building on each others ideas'	imagination/creativity
Lecture research activities: Presents a variety of different research techniques: competitor analysis, technology audit and user research	dealing with uncertainty, dealing with ambiguity
User observation: workshop putting one technique (POINT analysis) from user research into practice	dealing with ambiguity, imagination/creativity
sketching games: workshop focuses on sketch development for design, using exaggerated exercises	imagination/creativity
Visiting talk –Design professional Shows how design ideas can be presented for use in research.	N/A (did not map well onto the skills defined, and was removed from the programme)
Mood boards: Workshop exercise builds skills translating a vision into product styling cues.	imagination/creativity, dealing with ambiguity
Sketch tutorial: Workshop exercise builds skills for representing both problems and solutions in sketches. Sketching as a design thinking tool	Tenacity, imagination/creativity
Peergroup sessions: students elicit responses to progress on their own designs and contribute to each other's work	Independence, Tenacity
Visiting Professor of Innovation design mentoring: mentor to the students as they work on developing their product ideas	Tenacity, imagination/creativity

As part of their project work the students have to deliver working prototypes that prove the principles of the final solution. This prototyping deliverable represents the main educational intervention that enables this new design approach where the students make a leap of the imagination and work back from that idea to what is possible (see figure 3). Following the leap of the imagination, the prototyping quickly forces the students to build something that then eliminates uncertainty and ambiguity (inherent in having to build something practical). This then demonstrates to the students how this imaginative risk-taking combined with early an iterative prototyping can move the project forward effectively.

The practical aspects of prototyping are entirely new to the students and hamper their ability to iterate much within the time. A minority have made any prototypes before. The students are all of a high academic calibre (often with team design experience and 12 months industrial experience), but tend not to be realistic about building practical working models. Some of the problems they encounter are: hold ups waiting for parts, in-appropriate levels of detail for the various stages to prove principles, working with technicians, etc.

2 METHOD AND LIMITATIONS

The data from this study was collected by an independent Learning and Teaching Advisor from the Engineering Subject Centre as part of the HE academy excellence in teaching awards [8]. The data was gathered through observations of the teaching component; interviews with the tutor and recent graduates; and a student focus group.

For this paper, the data has been analysed to show the extent to which the students have improved in the skills needed for innovation as a consequence of participation in the unit. There are two limitations in the data. The first data consists of student feedback on the usefulness of the unit activities shown in table 1. This data (table 2) therefore only links indirectly to the skills enhanced through those exercises (table 1). The second data set are the transcriptions of the graduate interviews and focus group. Where the students made comments on what they felt they had learned, these were coded using the skills defined in section 1.2. above. This is not strictly a correct open coding or axial coding technique, but none-the-less enable some conclusions to be drawn.

3 RESULTS

Table 2. Results from the student survey of the Unit Activities

Unit Activities	Usefulness score 0-10 Average (stdev)	Fun/Interesting score 0-10 Average (stdev)
Creative warm-up:	6.2(2.0)	8.5 (0.9)
Visiting talk- MountainTrike:	8.3 (1.6)	8.4 (1.7)
Brainstorming games:	7.6(1.5)	8.1 (1.8)
Lecture research activities:	8.0 (1.2)	6.2 (1.2)
User observation:	6.9 (1.2)	7.1 (1.4)
sketching games:	6.8 (2.0)	8.9 (1.4)
Visiting talk –Design professional	4.5 (1.9)	4.7 (1.6)
Mood boards:	6.5 (1.4)	7.4 (1.6)
Sketch tutorial:	8.0 (1.5)	7.8 (2.0)
Peergroup sessions:	7.7 (1.5)	7.6 (1.0)
Visiting Professor of Innovation	8.5 (1.3)	8.0 (1.3)

Overall the standard deviation shows good agreement between amongst the students. The highest scoring activities in terms of usefulness (Visiting talk- MountainTrike and Visiting Professor of Innovation) are both sessions run by inspirational mentors and cover a broad range of the skills for innovation (tenacity, independence, imagination/creativity, dealing with uncertainty). Indicating that demonstrating the skills needed for innovation from a personal experience using real innovation examples is perhaps a promising way to deliver the skills needed for innovation.
The second highest scoring activities in terms of usefulness were the lecture on research activities and the sketch tutorial, these apply so broadly across all projects that they scored particularly well, showing that the students are fully engaged in their own project and appreciate tools, techniques and methods that they can immediately apply to their projects. The lecture presents tools, techniques and methods specifically chosen to help them to overcome uncertainty and ambiguity in their projects.
Transcription of the graduate interviews and focus group consists of roughly 3500 words, and provides 29 quotes where students have reflected on what they learned. Each of those quotes could be attributed to one (or sometimes two) of the skills described in section 1.2. Table 3 shows the numbers of times those skills were linked to the quotes and provides an example of each.

Table 3. Data from the graduate interviews and focus group transcriptions

Skills needed for innovation.	No. of the quotes	Example quotes:
tenacity:	6	"the more you put in the more you get out….our (project) is generally the one where you can go so freeform, you can go anywhere, the more effort you put in, you can go so far or completely change direction."
independence:	5	"[we were] given the freedom to be yourself in the project as well. And the freedom to make mistakes… you learn from making the mistakes as well, so it's a very flexible approach to teaching, which I really like about it."

imagination/creativity:	9	"…as I was doing it I could sort of feel myself changing as, what my interests were and developing more creative sort of thinking skills"
dealing with uncertainty:	2	"I've learnt so much more and been encouraged from day one to kind of go out there, get in touch with those people [experts], and I've achieved a lot more because [of that]…"
dealing with ambiguity:	7	…"understanding what the user would want from a product rather than hard numbers, that was something quite good because it was just so different from mechanical engineering… a slightly softer side that is equally valid and so in producing a slightly different thought process..."

Overall, the data shows that the students' perception of their learning does link to the skills needed for innovation. The data shows that the skill of being able to deal with uncertainty is currently least supported through the unit. This unit has been developed year-on-year and as part of a reflective process where notes are made after each session on what worked well and what activities might need further work before repeating the following year. In this case, it seems clear that dealing with uncertainty is a topic that could be further enhanced in the unit content.

4 CONCLUSIONS

The paper shows that the unit is enhancing the innovation skills of the students. More specifically, the data shows that the skill of being able to deal with uncertainty is currently least supported through the unit. Tools, methods and approaches introduced must be very broad in order to be applicable to all the students' projects. Students will want to apply them immediately to their projects, so the timing of introduction is important but not discussed in this paper. The use of inspirational mentors to demonstrate the skills needed for innovation from personal experience, using real innovation examples, is perhaps a promising way to introduce the skills needed for innovation. The prototyping deliverable probably represents the main educational intervention that enables this new design approach where the students make a leap of the imagination and work back from that idea to what is possible. However, this aspect was not studied in this paper and is an area for further research and reflection.

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