NURTURING FUTURE ENGINEERING SKILLS THROUGH SELF-DETERMINED INNOVATION AND ENTREPRENEURSHIP PROJECT WORK: A CASE STUDY OF A SCOTTISH UNIVERSITY

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Abstract: Engineers can make a difference to the challenges of the next decade. However, the skills required by engineers to meet these requirements of society and industry require a new approach to engineering education that emphasises competencies of innovation, collaboration and value-based decision making. Complementarily, transversal and meta-skills will be required to support engineers and engineering students adapt to new, emergent technologies and problems. Consequently, within Scotland, meta-skills are increasingly embedded in authentic programmes (such as Graduate Apprenticeships) and incorporated within modules seeking to develop engineers and holistic engineering practice. This paper will present a case study of a Scottish University that, through one module, provides students with an opportunity to develop such future engineering skills.

In this third year module, a team of students are required to identify an opportunity that seeks to help a specific group within society through a Design Futures/Thinking approach, and then iteratively develop a desirable, viable and feasible solution over twelve weeks; students are required to self-align their ideation with UN SDGs. This paper will outline the skills that students develop from innovation, to empathy, to human-centred problem solving, to future/horizon scanning, to collaboration and self-awareness. Also, it will share student experiences about skills developed and the benefits and challenges of such an approach to nurturing skills relevant to employability in the 21st Century.

Keywords; engineering skills; meta-skills; innovation; entrepreneurship; design futures

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1. INTRODUCTION

The role of the engineer to positively address the challenges of society, and particularly the challenges of the next decade, has already been recognised (UNESCO, 2021a). It has also been identified that the challenges that engineers will need to tackle are different – being more complex and "wicked" (Schuelke-Leech, 2020; Lönngren and van Poeck, 2020), and requiring different meta-skills and competences. Kumaruzamen et al (2020, pp21-22) highlights skills such as "complex problem solving; creativity and critical thinking; people management and working with others; service orientation; and negotiation and emotional intelligence," with Maisiri, Darwish and

van Dyk (2019) identifying additionally technical skills, including programming and digital capabilities.

Consequently, engineering educators have been reviewing their approaches to curriculum and pedagogical approaches, recognising the potential of authentic learning approaches, such as Challenge-Based Learning (CBL), Problem-Based Learning (PBL) and Project-Based Learning (PjBL). Within these approaches, the rate of change has differed, with some universities seeing wholescale shifts in Faculty visions (for example, Membrillo-Hernández et al, 2021), or adopting whole-programme changes (for example, NMiTE university in UK), whilst others have focused just at a module or course level.

Within Scotland, the Scottish Government has recognised the value of Meta-Skills, with the development of a framework by Skills Development Scotland (SDS, 2018). SDS (ibid, p8) defines meta-skills as "timeless, higher order thinking skills that create adaptive learners and promote success in whatever context the future brings." The main Meta-Skills categories are Self-Management, Social Intelligence and Innovation, with twelve associated skills groups. Additionally, within the context of engineering programmes greater focus is being placed on addressing complex issues through the fourth edition of the UK Engineering Council's Accreditation of Higher Education Programmes (AHEP4). AHEP4 emphasises "*inclusive design and innovation, and the coverage of areas such as sustainability and ethics …[and] coverage of equality, diversity and inclusion"* as reflected in changes in the naming of two of the main Learning Outcomes areas: Design and Innovation, and The Engineer and Society (Engineering Council, 2021, p2).

This research is focused on one Scottish University with a long-standing third year module that aims to develop the knowledge and skills around sustainability, innovation, inclusiveness and addressing societal challenges. The research question is "*To what extent does this module nurture and develop future-focused meta-skills in engineering students?"* Next, literature will be outlined around the required skills and how project opportunities can provide the necessary context. The methodology and findings from a mixed method case-study are then presented, before key messages and future work are outlined.

2. LITERATURE REVIEW

As outlined in the introduction it is already recognised that contemporary engineering education models are needed to address the role that engineers must play in society to meet the challenges of the coming years. This imperative is recognised in changes to competency standards from Engineering Councils, as well as employers, and in broader national education policies. There is a recognition that these skills need a new approach and an approach that is (in part) futures-focused.

Two main drivers of contemporary and future engineering skills are Industry 4.0, as well as the United Nations Sustainable Development Goals (UNSDGs). With regards to Industry 4.0 then systematic literature reviews and empirical studies have identified a combination of technical skills - around digitalisation, simulation, visualisation, and using Internet of Things, robots and automation; as well as around programming and digital skills, for example around cloud and security (Maisiri, Darwish and van Dyk, 2019; Kumaruzamen et al 2020). Additionally,

(meta)cognitive skills – such as critical thinking, cognitive flexibility, curiosity, and lifelong learning; and meta- and transveral-skills, such as (inter)personal, communication, innovation and problem solving, ethics and professionalism, and social intelligence (Perkins, 2019; Sky Project, 2020) have been identified as key skills. Specifically, within the Scottish context, then the SDS framework document maps the meta-skills against the automation potential and finds that many of these meta-skills do not have high automation potential, thereby representing essential capabilities of 21st Century graduates (SDS, 2018). Education for Sustainable Development requires a further set of competences, focused around "Systems Thinking, Anticipatory competency (Futures Thinking), Critical Thinking, Strategic Competency, Collaboration, integrated problem-solving, self-awareness and normative" (UNESCO, 2021b), with QAA (2021) identifying a range of ways to achieve that. There is a strong degree of overlap in the skills that are driven by these two key trends, particularly around self and self-management, ethical and human/planet-centred innovation, and collaboration.

The opportunity to engage students in group project work, particularly projects that are more complex and (initially) poorly-defined and structured, and that can be aligned to societal needs, offer the potential for students to develop many relevant competencies, both related to Industry 4.0 and UN SDGs – such as Systems Thinking, Futures Thinking, and collaboration. Design Thinking, Design Futures and Human-Centred Design approaches offer the potential for students to explore possible futures and develop sustainable products and services (Angheloiu, Sheldrick and Tennant, 2020; Canina et al, 2021). In particular, the combination of these techniques encourages students to scan the horizons for signals and drivers that are early signs of paradigm shifts. For engineers, this encourages them to look beyond their own current realities and to explore a wider range of options, focusing on the role of engineering in addressing human- and society-focused future needs. To-date, there is limited published research in such approaches in engineering, particularly in developing appropriate future-focused skills, and such an approach is used in this case study research.

3. METHODOLOGY

This research is based on a case study of one Scottish University and particularly on one Scottish Credit and Qualifications Framework (SCQF) level 9 (third year undergraduate) module; this is a 20 credit module (so notional learning hours of 200 hours). This module is a module shared across a number of programmes (in mechanical, electronics, electrical and audio engineering) and typically has around 200 students enrolled every year, including full-time, part-time and Graduate Apprentices; Graduate Apprentices study for an Honours qualification alongside working in an organisation with a strong emphasis on applied and work-based learning. The module has an aim to develop students' innovation and entrepreneurial skills with a particular focus on addressing future societal challenges (particularly within the context of the UN Sustainable Development Goals). A Design Futures/Value Proposition and Testing approach underpins the structure of this module, adapted from models and approaches from Osterwalder and colleagues at Strategyzer. Students work in groups to firstly define a relevant problem, then to develop the feasibility, viability and desirability of that idea through business idea testing as well as technical feasibility analyses. To support students, in the initial weeks, students work through more structured activities that encourage them to consider the future, what they value, groups that they are interested and

empathise with, leading to an identification of multiple possible groups/ideas proposed by each member of the group, that are then narrowed down through evidence sharing and a final target idea chosen by the group. Students then present their value proposition at a mid-point in the module, before refining and testing this idea further in the second-half of the module (summarised in a group report). Additionally, students submit an individual reflection based on their learning in this module.

A mixed method strategy has been used, combining a survey of current students around relevant skills, and an analysis of a current student's module learning reflections. An anonymous questionnaire was distributed to 175 students in the last 2 weeks of the module using Microsoft Forms, with 39 responses (so response rate of 22%). The questionnaire was designed to capture students' previous experiences of group work and to determine their self-assessed level of skill before they started this module and after this module, as well as asking students to highlight the key skills that they gained; the questionnaire was generated by the co-authors based on a synthesis of Scottish Institute of Enterprise Fit-for-Future questionnaire, internal questionnaire around meta-skills, and Systems Thinking skills (Arnold and Wade, 2017). The analysis of a purposive sample of 37 reflections was conducted to gain further insight into what students considered as being important skills developed in the module; data was analysed using a simple, inductive descriptive coding approach with a second cycle looking for patterns. Illustrative extracts around skills from these reflections are quoted in the relevant findings section below.

4. FINDINGS

4.1 Skills development of current students through the module

Of the 39 respondents, 34 students had engaged in group project work before in their studies, either in a previous year of the university course (n=27) or elsewhere (n=7) prior to entering the programme directly in third year. Those with previous experience profiled the nature of their previous group experience (Figure 1). The nature of project work already was encouraging the development of relevant meta-skills (including problem definition, societal alignment, user-centred design) as well as engineering design skills. Interestingly there is a wider distribution of responses as to whether students felt that they were able to define the problem and could select a problem on something that they valued (something that is part of the module being researched).

Students were then asked to self-rate their level of skill against a number of questions using a Likert scale (not at all; a little/not very often; a reasonable amount/ reasonably often; quite a lot/frequently; all the time) for their previous group project work experience and their experiences in the module being investigated. These Likert responses were converted to numeric scores (1 for 'not at all' through to 5 for 'all the time') and mean values calculated (Figure 2). The skills with the most change (post as compared to pre) are shown in Table 1 (those with delta >0.5). Importantly, several of the future-focused skills have seen the most change, reflecting that students did recognise that they had developed these important skills.

In terms of skills additional students felt were important, then 10 responses were received, with a variety of responses. Communication, presenting and team-work were highlighted by several students, as well as adapting, and "*asking the right questions.*"

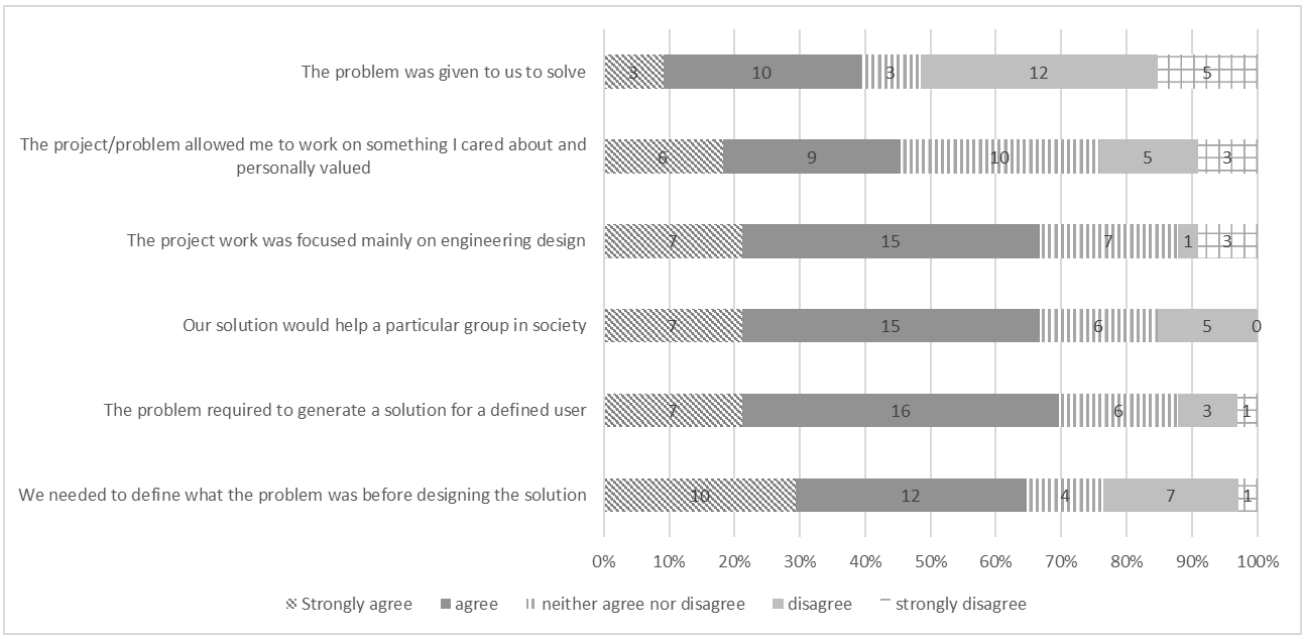

Figure 1: attributes of respondent's previous group work

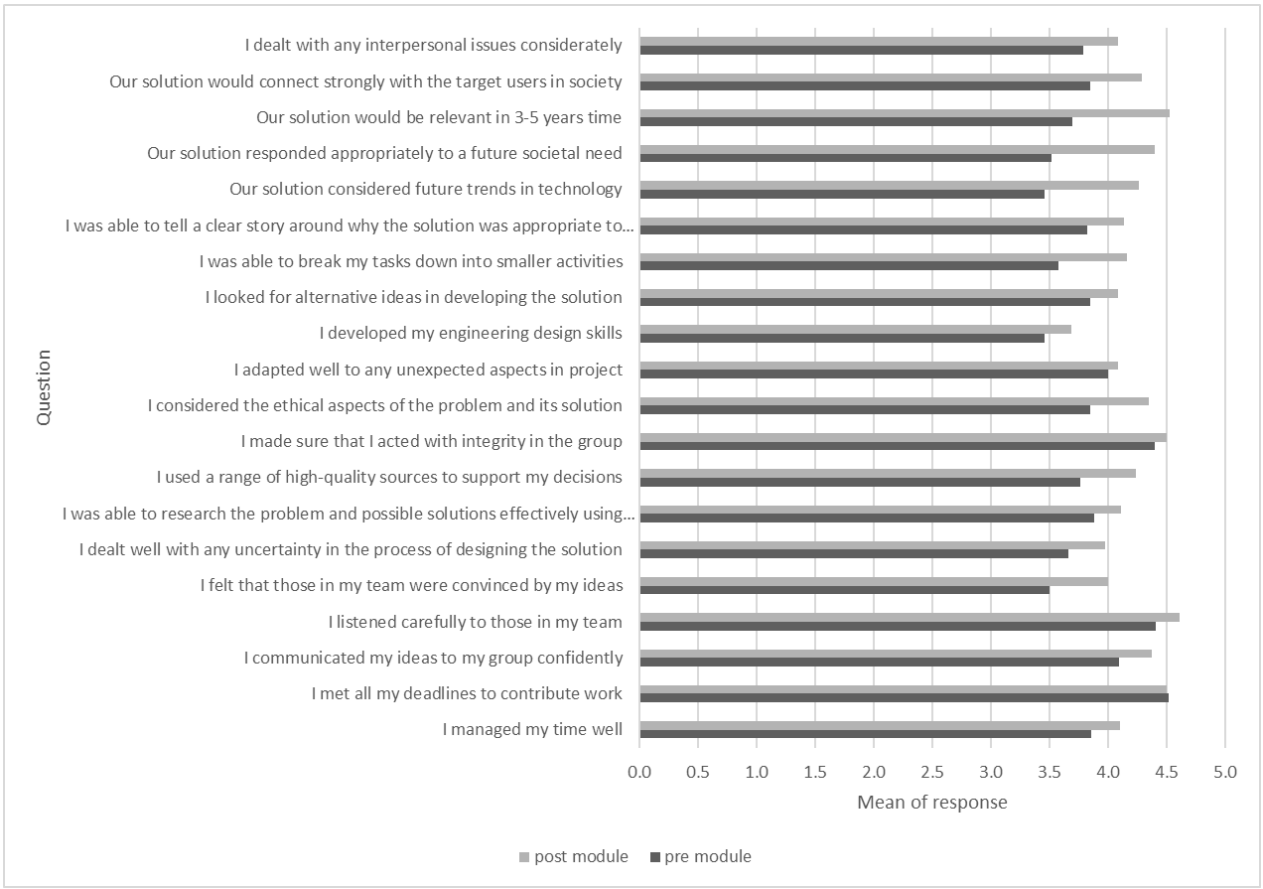

Figure 2: mean values for self-rated skills pre- and post-module

Skill	Delta (post – pre)
Our solution responded appropriately to a future societal need	0.9
Our solution would be relevant in 3-5 years' time	0.8
Our solution considered future trends in technology	0.8
I was able to break my tasks down into smaller activities	0.6
I felt that those in my team were convinced by my ideas	0.5
I considered the ethical aspects of the problem and its solution	0.5
I used a range of high-quality sources to support my decisions	0.5

Table 1: skills with largest changes in mean values post-module (as compared to pre)

4.2 Emerging perspectives from students' reflections

Students submitted a reflective essay at the end of the module. From an analysis of a purposive sample of reflections, a number of repeating subject areas were evident. Many students reflect on the group presentation and their skills in both presenting but also co-ordinating a coherent group presentation. Several students commented that doing a face-to-face presentation after the two years of online learning (due to COVID-19) was more challenging (as students felt out of practice) - "*as the past 2 years show that anyone can lose confidence when not working with a group in campus compared to online*". In terms of co-ordination, online techniques for maintaining collaboration outside of scheduled classes had been enhanced during COVID, and a diversity of platforms were used successfully. In combination with these tools, there was a definite feeling that the face-to-face classes offered better connection between students, as well as with the academic staff, with the importance of trust and effective communication between group members, as well as holding each other accountable being emphasised also. The importance of preparing for meetings and communicating ideas was identified as a point of learning - "*I learned that you need to sell your idea to your team members the same you would try to sell it to potential investors/customers, I will be taking this approach when designing things in future in university or in a work environment.*" Giving and receiving feedback and accepting alternative choices was another area that students highlighted, particularly around the idea that was chosen to be developed – "*On top of this I then learned that I could get onboard with someone else's idea and vision it how they must make it as strong a concept as possible.*" Whilst getting behind another team member's ideas was not always easy for students, there was a clear maturity demonstrated in accepting the process, by which everyone had been able to share their idea and that the group had decided on the best emergent idea. The meta-skills of self-management and social intelligence are evident in the above.

Another key area was around the process of defining the product that the group wanted to develop – skills related to Systems and Futures Thinking, Innovation and service orientation. This was a new approach for some students, "*We went through a bunch of worksheets to find a group of people with a strong emotional desire for us to solve. I was a little dubious to start with*" and "*at first I was confused by the process and felt a little flustered. I realise looking back now that this is was because I was not used to developing a product in this way as we are usually already given a problem to solve for a specific group.*" However, students learned skills in defining the problem as well as learning the importance of understanding the problem the emotional context associated with it. What emerged was that groups often found a connection - "*A shared passion was apparent in our group as we all had grandparents who in some way or another experience a struggle in managing their health. The idea was proposed of finding a way to managing one's health while remaining at home through the adoption of advancing technology*" – and made them see engineering as helping those they cared about, and society more broadly. One student reflecting,

"*it shows a window looking into my own values as a member of society and asked me to display my own empathy towards other groups of which I have little to no shared experiences.*" Progress towards defining the problem was not always linear, and had to adjust their idea after several weeks (recognising that its scope was too big or that it was not responding to (emotional) needs of users, but learned the value of testing and challenging ideas. However, students had reflected that this approach had helped them not be overwhelmed by being creative and demonstrating critical thinking skills, "*this module has encouraged me to take a systematic approach towards a problem which psychologically for me breaks it down into much smaller tasks. This was great as I had never thought creatively this way."*

Throughout the reflections, there was a clear demonstration that students were developing a range of skills, whether around taking personal responsibility, challenging themselves to develop new business and technical skills, understanding communication and team work more effectively, learning how better to give and receive feedback, dealing with challenging situations, adapting to a "post-COVID" learning experience, overcoming previous (negative) experiences as well as developing their creative and innovative capabilities. For some, there was shock "*even now looking back I still can't fathom the amount of people who are really unable to put food on the table each day,*" and the experience was eye-opening "*proved to me how vulnerable people around me are and how much of a lack of understanding I had of what was going on.*" This experience has redefined expectations of what they can be as an engineer, "*this experience has excited me to steer my career towards a field in which I'm passionate. An engineer today can have a huge impact on various fields. The thought of helping unfortunate people is a something I'm excited about and something I want follow."*

5. CONCLUSIONS AND NEXT STEPS

This module is designed to develop innovative and entrepreneurship skills in students, particularly those that are appropriate to tackle complex and future-facing problems. The findings from this research align and indicate that the nature of the open-ended project brief given to students, as well as the methodologies used, do develop those appropriate skills – anticipatory thinking, self-management (such self-awareness, including around values and actions), innovation and Systems and Futures Thinking skills, and improved collaborative skills around negotiation and leadership. Inspiringly, the opportunity has led to some emergent engineers to see their future and the opportunity to contribute to addressing the complex challenges of the coming decade. Future work will be to gain views from a wider range of stakeholders (including staff and employers), as well as students, to better understand how these skills are developed in the module and how they impact on students' growth as engineers, in the remainder of their studies in employment.

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