FUTURE-PROOFING ENGINEERING EDUCATION: PEDAGOGICAL REFORM FOR ENGINEERING RESILIENCE AND MASTERY

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Abstract: Our future dependency on engineering expertise will likely only deepen as a result of the increasing complexity and technological interconnectedness of the modern world. Given that many nations already face engineering skills shortages it is vital to immediately address the employability and preparedness of future generations. This long-term view must, by necessity, broaden the scope of engineering employability beyond graduate/near graduate cohorts to younger learners who will meet the continuing and evolving demand for professional engineers in the Fourth Industrial Revolution. In this paper the immense educational challenge posed by this demand will be acknowledged, highlighting the need for resilience and mastery within the changing engineering profession. This paper will critique how such resilient and masterful learning can occur in education systems that only introduce engineering as a distinct subject for a relatively short time during later stages of Further/Higher Education. It is argued that the most capable and future-proofed engineers may be those who are supported for engineering in earlier learning experiences. To explore this, a model of engineering learning is introduced to consider wider learning, including curricular, non-curricular and societal experiences for engineering participation. This model will consider the prevalence of earlier, broader learning experiences and their potential impact on later masterful and resilient engineering employability. Empirical evidence from 900 secondary school-aged learners will provide insight into this early support and its impact on engagement, identity, and self-efficacy to prepare more employable graduates. Implications for future-proofing engineering employability and pedagogical reform will be discussed.

Keywords; engineering education, mastery, resilience, engineering skills, informal learning, skills and employability

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1. INTRODUCTION

1.1 An evolving need for engineering skills

Rapid technological development continues to reshape the practice and skillset of modern engineering. In the UK, demand for engineering skills continues to change with rapid growth in some sectors (information and communication; construction) and decline in others (manufacturing; automotive) (EngineeringUK, 2019). This demonstrates that the practice of engineering is not static but evolving over time. Engineering curricula and pedagogical practices must be responsive to this challenge to effectively prepare the next generation of engineers. The engineers of tomorrow will not only need to develop a mastery of engineering skills but must also possess a resilience to continuing change in engineering practices as they progress through their careers.

Skill mastery, which can be defined as advanced skill expertise and an intuitive and experienced perspective on its use, is an objective of many educational approaches particularly in fields such as engineering which are reliant on key skill practices (e.g. iterative design, specialised tool usage, or creative problem solving) (Grubbs, Strimel and Huffman, 2018; Dreyfus & Dreyfus, 2008). Mastery is acknowledged to occur as a later stage of skill acquisition and requires time, opportunities to practice, and support from knowledgeable sources (Ericsson, Krampe & Tesch-Romer, 1993; Dreyfus & Dreyfus, 2008; Chepko and Doan, 2015). These same requirements are acknowledged in the development of resilience, defined as a developed adaptive ability to cope and thrive in the face of challenges (Hall, 2015). The need for both well-developed and resilient expertise are acknowledged as vital to the future of UK engineering (Royal Academy of Engineering, 2019).

Given that mastery and resilience are acknowledged as key to the future of engineering skills and employability then we must consider how future engineers can be supported to develop to this level of expertise. As these characteristics are developed over time, we must look across all phases of education to comprehend how skills are developed for engineering. Focusing only on higher education, which occurs at a later stage of education and for a relatively short period of time, may neglect to consider the earlier formative learning experiences with engineering that may support later mastery and resilience in skill development. Understanding the formative experiences that support later study of engineering in higher education may offer key insights in addressing future engineering employability needs.

1.2 The issue with engineering education

A long-term view of engineering learning amongst young people is made difficult, however, by the lack of engineering within the pre-16 UK compulsory curricula. Engineering is not prioritised within the pre-16 compulsory curricula and is not available as a distinct subject area for most learners. Engineering features somewhat more in the Scottish curricula than those of England, Wales or Northern Ireland but this representation is still relatively limited. This contrasts sharply with the subject area of science which is valued and prioritised throughout pre-16 education. The ‘science first, engineering later’ structure of pre-16 education and the necessity to possess science qualifications to enter some tertiary engineering educational pathways implies that science is intended to act as an effective foundation for engineering learning. However, a growing body of literature demonstrates differences in the practices of engineers and scientists questioning how effectively a science education might support engineering learning (Lucas et al., 2016; Grubbs et al., 2018; Calik and Coll, 2012). Literature suggests that the ‘science first, engineering later’ structure to the UK education system favours science leading to a deficit of learner enjoyability, sense of utility, importance, and skill confidence for engineering (Hutchinson & Bentley, 2015).

Whilst the UK education systems feature little engineering within their curricula it is important to acknowledge that learning also takes place outside of classroom settings and that these out-of-school, or ‘informal’, learning experiences may also support skill development for engineering (Halliday-Wynes & Beddie, 2009). Informal learning can take many forms and support learning outside of the curriculum context, for example: the consumption of media, social interactions or maintaining social relationships with knowledgeable others, participating in out-of-school learning contexts such as museums, hobbies and personal interest activities, or engagement with curricular-mapped learning experiences such as school visits are all noted to benefit learning (Penuel et al., 2010; Cheryan et al., 2011; Haden, 2010; Rennie, 2014). Given the lack of engineering in much of the national curricula the relative importance of these informal learning experiences may be great for the development of engineering skills, yet little previous literature has explored the aggregated benefit of such experiences for engineering learning.

Understandably given its limited presence in curricula, little literature has explored the topic of engineering skill development with younger cohorts in the UK. It is difficult to assess skill development in these early stages when limited curricular learning has been offered and it is unrealistic to expect mastery or resilience to have yet developed. Instead, we might consider progress towards mastery and resilience recognising that these are destinations on a long educational journey. Past literature has identified factors related to skill development which support later mastery and resilience. Educational engagement with a topic, defined as affective-emotional, behavioural and cognitive interaction with a subject and commitment to learning is closely linked with skill development and resilience (Fredricks et al., 2004; Hall, 2015). Self-identity for engineering, representing the consideration of oneself as an engineering-type person, and self-efficacy, representing an individual's confidence in their own ability and skills, are also recognised as influential in supporting skill acquisition (Downey & Zeltmann, 2009; Trujillo & Tanner, 2014). Whilst we should not expect a masterful and resilient skill acquisition for engineering to have taken place in younger cohorts it may be that these proxy indicators of learning and later mastery and resilience (engagement, self-identity, self-efficacy) are influenced by informal learning for engineering. Those who have experienced more informal learning experiences may have developed greater engagement, self-identity and self-efficacy demonstrating that formative experiences with engineering can assist in the later education of engineers.

In this paper we empirically investigate how formative, informal learning experiences with engineering, taking place before higher education, may represent an advantageous influence supporting later mastery and resilience for engineering skills. Using recognised factors influential to skill development we will investigate levels of engagement, self-identity and self-efficacy amongst secondary school learners with differing levels of out-of-school experiences with engineering. It is hypothesised that those with wider experience in these learning contexts will have developed greater engagement, self-identity and self-efficacy indicating a greater support for later mastery and resilience in engineering education. Establishing the benefit of early experiences with engineering may inform strategies for foundational engineering skills education.

2. METHOD

2.1 Methodology

A quantitative methodology was adopted to examine the impact of informal engineering learning experiences on indicators of later engineering skills mastery and resilience. A quantitative approach was chosen as to maximise sample size. Secondary school-aged students were sampled as this group were expected to possess a more sophisticated understanding of engineering whilst still receiving little formal engineering education. Learning indicators of later mastery and resilient skill development were used to assess the impact of informal learning; skill proficiencies were not directly tested as these participants had not yet received a tertiary engineering education.

2.2 Participants

A total of 921 secondary school-aged young people (ages 11 to 16) were recruited from 10 secondary schools in England and Scotland. Of this sample, 43% were boys and 57% were girls; 25% were open to some form of future engineering education, but only 8% reported wishing to study engineering at university. Participants were recruited over the course of an academic year through opportunity sampling with schools contacted directly by the research team. Ethical approval was gained from a University of Central Lancashire ethics committee (BAHSS2 0141).

2.3 Instruments

Four quantitative instruments were applied to examine the independent variable (IV) of informal engineering learning experience, and dependent variables (DVs) of engineering engagement, engineering self-identity, and engineering self-efficacy.

IV – Informal Engineering Learning Experience: A 20 item quantitative instrument was developed informed from past research (Archer et al., 2015). Each item asked participants if they had experienced a form of informal learning in the past year, including consumption of engineering media, talking to others about engineering, and taking part in engineering activities such as hobbies (e.g. designing and making things, games) or curricular-mapped learning experiences (e.g. after school clubs, educational school visits). Item responses were tallied resulting in a score from 0-20 representing breadth of informal learning experience for engineering experienced in the last year. The higher the value the more forms of informal engineering learning participated with in the past twelve months.

DV – Engineering Learning Engagement: A novel quantitative measure of affective and cognitive learning engagement was devised informed by past literature (Eccles & Wigfield, 2002; Fredricks et al., 2004). This measure consisted of 12 items accessing engineering interest, understanding, recognition of importance and value of engineering, learning persistence and expectations for engineering learning. Cronbach's Alpha analysis confirmed the reliability of this measure (a=.922). Responses were tallied resulting in a score from -24 to 24 representing the degree to which participants were positively or negatively engaged with learning the subject of engineering.

DV – Engineering Self-Identity: A quantitative measure of self-identity was adopted from the research literature and modified to focus on engineering to examine the degree to which participants saw themselves as the type of person who does engineering (Archer et al., 2015). This measure consisted of four items: "People who are like me work in engineering", "Other people think of me as an engineering type person", "My teachers have specifically encouraged me to consider studying engineering after GCSE/National 5s" and "I don't think I am clever enough to study engineering after GCSEs/National 5s" (reverse coded). Cronbach's Alpha analysis confirmed the reliability of this measure (a=.690). A total score of -8 to 8 was calculated representing the degree to which an individual identified as the type of person to take part in engineering.

DV – Engineering Self-Efficacy: A quantitative measure of self-efficacy was adopted from research literature and modified to examine the degree to which participants believed in their ability to succeed in engineering (Archer et al., 2015). This measure consisted of three items: "I would be confident talking about engineering in lessons", "I know quite a lot about engineering" and "I don't think I am clever enough to study engineering after GCSEs/National 5s". Cronbach's Alpha analysis confirmed the reliability of this measure (a=.680). A total score of -6 to 6 was calculated representing the degree to which an individual believed in their engineering abilities.

2.4 Procedure – Data Collection and Analysis
Once schools had consented to participation print or digital materials were delivered to schools and students were offered the opportunity to participate. Those who agreed were asked to complete a questionnaire containing the IV and three DV measures. Written guidance was provided to participants and teachers overseeing the data collection. Completed questionnaires were returned and analysed using the SPSS statistics software. Cronbach's alpha analyses confirmed the internal consistency of DV measures. A Pearson's correlational analysis and three linear regression analyses were completed on the dataset to investigate the relationship between informal engineering learning and skill development factors.

3. RESULTS

A Pearson's correlational analysis examined the relationship between the breadth of engineering informal learning experiences and the three engineering skill development factors. Statistically significant positive moderate correlations were identified between informal learning and engineering engagement ($r=0.483$, $n=921$, $p<0.001$), engineering self-identity ($r=0.411$, $n=921$, $p<0.001$), and engineering self-efficacy ($r=0.440$, $n=921$, $p<0.001$). Having acknowledged these significant positive correlations next three linear regression analyses were applied to examine the impact of informal engineering learning experiences on the three skill development indicators.

The first linear regression analysis examined the impact of breadth of informal engineering learning on engineering engagement and found a significant relationship ($R^2=0.232$, $F(1,919)= 279.217$, $p<0.001$). Breadth of engineering informal learning explained 23.2% of variance in engineering engagement highlighting its impact. Each additional form of engineering informal learning experienced by a participant increased their engagement score by 1.071 ($p<0.001$) on the scale of -24 to 24.

The second linear regression analysis examined the impact of breadth of informal engineering learning on engineering self-identity and found a significant relationship ($R^2=0.168$, $F(1,919) = 186.329$, $p<0.001$). Engineering informal learning explained 16.8% of variance in engineering self-identity highlighting a reasonable impact on skill acquisition related factors. Each additional form of engineering informal learning experienced by a participant increased their self-identity score by 0.270 ($p<0.001$) on the self-identity scale of -8 to 8.

The third linear regression analysis examined the impact of breadth of informal engineering learning on engineering self-efficacy and found a significant relationship ($R^2=0.192$, $F(1,919)= 220.107$, $p<0.001$). Breadth of engineering informal learning explained 19.2% of variance in engineering self-efficacy highlighting its impact. Each additional form of engineering informal learning experienced by a participant increased their self-efficacy score by 0.264 ($p<0.001$) on the scale of -6 to 6.

4. DISCUSSION

The statistical analyses confirm the hypothesis that those who have experienced greater informal learning for engineering are better supported for later engineering skill development. The correlational analysis highlights that a greater recent experience with engineering learning contexts such as consuming engineering media, talking to others about engineering or taking part in engineering hobbies support greater self-identity, self-efficacy and learning engagement with engineering. As these three dependent variables are acknowledged to support learning and are related to the attainment of mastery and resilience then we can conclude that informal learning is influential in addressing the recognised need for masterful and resilient future engineers in the UK.

The influence of informal engineering learning experience explained 23.2% of variance in learning engagement, 16.8% of variance in self-identity, and 19.2% of variance in self-efficacy demonstrating its moderate but significant role in shaping this support for future engineering skill development. This would suggest that other factors, or forms of informal learning not captured within the IV measure, also influence the displayed development of pre-mastery/resilience learning factors. This is not unexpected as such learning factors are acknowledged to be widely influenced due to their implicit, fundamental nature (Trujillo & Tanner, 2014). However, the positive influence of informal learning experience on skill development factors is established.

These findings demonstrate that a diversity of informal learning experiences is beneficial to engineering learning. This would be supported in other contexts that acknowledge the impact of diverse learning experiences (Marsh & Kleitman, 2002). This may inform pedagogical reform for engineering in the UK context suggesting that in the absence of a curricular presence of engineering greater support for informal learning activities may encourage future engineering skills development. The past deployment of institutionalised informal learning such as the 2018 Year of Engineering in the UK would support that such efforts are possible in the UK context and findings within the current paper would confirm their value. These findings suggest that in the absence of curricular reform informal or curricular-mapped extracurricular engineering experiences may support later engineering skill development.

These findings might also support the adoption of STEM integrative pedagogies that remove curricular boundaries to integrate multiple STEM subjects into the same learning experience. Such strategies are suggested to benefit subject learning and support richer conceptualisations of subjects, but further work is needed to establish their benefit (Honey et al., 2014). The present findings would suggest that a breadth of learning experiences for engineering is beneficial to later engineering learning factors. The addition of engineering practices to existing science, technology or mathematics pedagogies may support later engineering learning amongst younger learners and should be explored.

It is acknowledged that the present study is limited by its lack of direct measurement of engineering skills, as such measurement is difficult in the absence of a dedicated and concerted engineering curriculum. Sophisticated engineering skills expertise are unlikely to develop in the current compulsory curricula, however the present study has informed how early engineering learning may be supported to benefit mastery and resilience in later engineering education.

This examination of UK secondary school learners has established the need for further study of engineering learning in the UK. In particular, a more sophisticated measurement of informal learning experiences amongst UK learners is needed to establish who is supported by such experiences and how this may benefit the development of engineering expertise. A census of these engineering learning experiences may better inform our understanding of engineering aspirations, skill development, and career readiness in the face of evolving engineering practices. Whilst this task may be difficult to accomplish due to the diversity of forms informal learning can take such efforts are crucial in the absence of an engineering national curricula to understand the experiences that may, silently, be shaping the future of UK engineering.

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