**ENTREPRENEURIAL SKILLS FOR ENGINEERS – INSIGHTS FROM THE DEVELOPMENT OF AN ONLINE COURSE**

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**Abstract**

Engineers need to have a solid technical foundation for their education and practice but there is also a requirement to have a wider set of professional and enterprise related knowledge and skills in order to be successful in the workplace. This includes understanding how to develop innovative ideas through to new products and businesses as part of the entrepreneurial journey – including both new venture creation as well as developing a new business area within an existing organization (i.e. intrapreneurial). Traditionally, engineering education has not included the provision of teaching in this area and consequently a new online course has been developed called ‘Entrepreneurial Skills for Engineers’. The course provides a comprehensive and integrated view of the different aspects to support an engineer to become more innovative and entrepreneurial. This paper provides insights from the design and delivery of the online program, including discussion of how the technical material was assembled as well as the learning outcomes for the course and wider pedagogical aspects. A review of the requirements for enterprise education is provided through analysis of literature in the area. The paper also provides guidance to engineering faculty and others who are seeking to develop enterprise related programs for engineers.

**Keywords**

Entrepreneurial and innovation related skills, engineering education, online course.

# Introduction

Engineers should have a solid appreciation and supporting knowledge base in the engineering fundamentals and this includes, for instance, engineering mathematics, design, materials and material failure, thermodynamics and cycles, fluid mechanics and engineering processes. However, many studies have highlighted that there is a further need for engineers to have a wider set of professional related skills (Litchfield et al., 2016; Mitchell et al., 2019), including communication, team working, problem-solving, project management as well as innovation and entrepreneurship. This is because a professional engineer is unlikely to spend 100% of their time on purely technical engineering tasks. In the case where an engineer moves into another functional area, such as commercial management, or sales & marketing, they will of course need to acquire specialist required skills and knowledge to operate successfully in these fields. However, even when they remain in technical engineering roles, they will likely work on projects and in engineering teams; consequently, there is a need for problem solving, team working and other professional skills (Philbin et al., 2019).

Engineers involved in developing new projects, products and engineering areas need to understand how to be innovative (MacLeod, 2010) – how to take an idea forward as part of new product development and how to plan for implementation of a new manufacturing process, or deployment of the new technology within an industrial setting. This set of skills and knowledge required by engineers can be positioned in regard to being enterprising. In this context, enterprise refers to innovation as well as entrepreneurship (and intrapreneurship). This is because being enterprising is not limited to new venture creation but also includes the ability to understand how to develop an idea into a new product or a new business area within an existing company. It also refers to understanding how to commercialize research and technology towards new product development as well as the management of research, technology and engineering projects. Consequently, the question arises how can engineers build on their technical engineering foundation and numerical skills by becoming more enterprising? This question can be partly addressed through specialist education that has been designed and tailored to the needs of engineers and is focused on the provision of innovation and entrepreneurial skills and knowledge for engineers as well as other STEM (science, technology, engineering, and mathematics) specialists.

The structure of this article is as follows. After the introduction is the literature review on the requirements for enterprise education. This is followed by the case study investigation, which includes the following sections: background on the case, design and structure of the online course, illustrative details from one of the course units, and unit summative assessment. The article also includes lessons learnt from the case followed by conclusions and future work.

**Literature review**

Developments in industry (such as the trend towards greater levels of digitalization) along with societal challenges (such as the need to mitigate the impact of climate change) are leading to an environment where engineers need to have access to professional skills and knowledge in order to be effective in the workplace as well as a sound appreciation of innovation and entrepreneurship. Consequently, engineering education has been evolving to increasingly include an element of study associated with innovation and entrepreneurship (Nichols & Armstrong, 2003; Luryi et al., 2007). Indeed, the development of an entrepreneurial mindset along with the corresponding skills and knowledge has been viewed in the context of innovation and creativity as enablers to support students to prepare for a productive professional life (Kriewall & Mekemson, 2010). In this context, it has been found by Täks et al. (2014) that there are four distinct categories related to entrepreneurship education, which are as follows: enterprise education as a first step towards self‐directed learning; preparing for work life and the professional environment; embarking on a path to possible self‐employment; and as a context for developing management and leadership skills. Other studies have highlighted how the use of action-based learning methods can support the personal growth of students and that explicit business associated knowledge should be gradually increased only when professional knowledge linked to the specific discipline has been acquired (Mäkimurto-Koivumaa & Belt, 2016).

Considering the mechanisms for imparting entrepreneurial skills to students, there are cases where entrepreneurship education has been embedded in the university curriculum (Creed et al., 2002). Such an approach involved a two semester program where students were involved in class-based activities as well as direct interaction with local industrial companies, with a view to developing a business plan for a potential spin-off company at the end of the program. This approach has the advantage of providing an almost real world experience of entrepreneurship as part of the education, although clearly running such a program would require a significant commitment by the university and the faculty involved in the program. In another case (Soares et al., 2013), project-based learning was highlighted as being a key component that is developed as part of an integrated project involving entrepreneurship and innovation undertaken by students from different engineering integrated Master’s level programs (e.g. mechanical engineering, industrial electronics and industrial management). This approach involves the students competing against each other in order to develop or improve commercial products that are manufactured by actual companies.

In regard to the provision of entrepreneurial education from a broader perspective, it has been recognized that there has been a proliferation of so called massive open online courses (MOOCs) (Philbin, 2013), which are designed to provide educational opportunities to gain skills and knowledge in the relevant area (Welsh & Dragusin, 2013). Indeed, it has been found that MOOCs can be viewed as a suitable platform to teach entrepreneurship, with this approach providing students with a collaborative learning environment that is enabled by the e-learning platform. This allows development of entrepreneurial skills, including opportunity recognition and resource acquisition (Al-Atabi & DeBoer, 2014). The traditional MOOC model, which is based on text-based materials, video-lectures and forums that support interactions between students, has also been extended further through incorporating games as a key component for learning the fundamentals of entrepreneurship (Romero & Usart, 2013). This highlights how the disruptive nature of MOOCs as an innovative medium for enabling distributed education is continuing to evolve (Flynn, 2013). However, the provision of education through the MOOC model is not without challenges (Yuan & Powell, 2013). There is a continuing need for a viable business model that enables the sustainability of MOOC provision as well as the requirement for robust accreditation of MOOCs and more generally the need to maintain quality standards for this form of education delivery.

**Case study investigation**

**Background on the case**

The course was designed to equip engineers with the skills and knowledge to creatively develop an idea from concept through to a new product or service and become entrepreneurial as well as intrapreneurial through developing and managing a business. The course explores various tools, techniques and approaches that engineers can use as part of the entrepreneurial journey – developing innovative ideas through to new products and businesses. The course was designed as a continuing professional development (CPD) program, which can be taken as a standalone course by professional engineers, although there is also scope to integrate the course into suitable engineering degree programs and delivered to equip engineering students with the necessary enterprise knowledge and skills.

The online course was developed in partnership with a professional engineering society from the United Kingdom, which delivers a range of online programs. This approach allowed the academic team to concentrate on development of the educational material. The educational material was provided to the engineering society, which transferred the material to the e-learning platform. The online course was developed over a period of 9 months and was launched in August 2019. The course is comprised of 10 units with each one representing approximately 1 hour of learning and each unit is comprised of 4-5 modules. Each unit has an introductory video of approximately 5 minutes given by the unit author followed by the modules that contain the educational content delivered via the e-learning platform. The development schedule involved 1 month of design, planning and preparation for the course, followed by 6 months for the development of the teaching material, and finally 2 months for quality control, marketing planning and final project activities. Upon launch of the course, it was made available alongside the engineering society’s suite of other educational CPD programs designed for professional engineers.

**Design and structure of the online course**

The new online course was designed around three core themes that are interlinked and collectively provide students with a comprehensive view of the supporting areas related to innovation and entrepreneurship in an engineering context. This includes understanding the tools and techniques that can be used in relation to developing new products and services as part of the innovation process as well as the entrepreneurial development and management of new businesses. The structure of the course was broadly aligned with the overall approach adopted in the ‘EntreComp Framework for Entrepreneurial Competencies’ (Bacigalupo et al., 2016). This recognized framework supports the development of entrepreneurial skills and is based on three main competence areas (namely, ideas & opportunities; resources; and into action) and 15 individual competences. In regard to the design of the online course, the main competence areas were translated into course themes as follows: Ideas and opportunities – Translated into the ‘from ideas to solutions’ theme; Resources – Translated into the ‘business planning and resources’ theme; Into action – Translated into the ‘delivery to market’ theme.

Each theme has three units giving nine units and along with an introductory unit that means the overall course has ten units. The specific units were identified by the program leader based on enterprise related industrial experience augmented by benchmarking of similar programs. The educational content was provided by the academic educational delivery team members who acted as unit authors. Exhibit 1 provides the overall structure of the online course and Exhibit 2 provides further details on the course units.

**Exhibit 1**. Overall structure of the online course, including themes and units.



**Exhibit 2**. Further details of course units.

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| **No.** | **Unit** | **Description** |
| 1 | Introduction | This unit provides an overall understanding of the course and the units. Students gain an appreciation of the benefits of being entrepreneurial as well as the wider context of innovation and entrepreneurship. Students are also able to describe their own learning objectives for the course. |
| 2 | Ideation and creativity | This unit provides a description of the analytical approaches to identify entrepreneurial opportunities as well as the different techniques to test innovative ideas with end users. The unit allows students to describe and explain different problem-solving strategies and understand how innovations diffuse in society, culture and the market. |
| 3 | Leveraging research and development | This unit provides details on the main features of research, technology development and the commercialisation of technology. Students are able to demonstrate knowledge of technology management tools (such as technology roadmapping) and be able to outline the concept of open innovation. The unit also allows students to demonstrate an understanding of intellectual property (IP) and the protection of IP. |
| 4 | Product design | This unit provides an overall understanding of the product design process used by engineers to identify and solve problems. Students are able to demonstrate know how to capture design requirements through using a systems engineering approach as well as understand other key design areas, such digital design and sustainable development. |
| 5 | Entrepreneurial finance | This unit provides a description of the various stages of a successful venture’s life cycle along with the relevant type of financing and investors. Students are able to demonstrate an understanding of the financial capital available to the entrepreneur as well as the construction of venture valuation models. Students also gain an understanding of exit strategies as well as going public through an IPO (initial public offering). |
| 6 | Capturing market needs | This unit provides a description of how to define target customers and articulate their needs as business strategies. Students will understand the importance of segmenting different target markets within the marketing strategy. There is also coverage of competitor research to help differentiate the business in the marketplace. |
| 7 | Managing innovation projects | This unit provides a description of the project management process and how it applies to innovation projects. Students will gain an understanding of how to manage technologically complex projects through taking a holistic approach. There is also coverage of the main concepts of agile project management (including key tools and techniques) as well as project risk management. |
| 8 | Leading the team | This unit provides a description of how entrepreneurs can bring together a team and how to motivate team members. Students will understand how to pitch effectively to investors as well as the value created by teaming up with distributed communities through digital technologies. Students will also be able to engage in collaborative working. |
| 9 | Strategic business development | This unit provides a description of the strategy development process for a business, including the tools and techniques that can be used to support the business planning process. Students will be able to describe strategies to help expand a business and how a customer relationship management (CRM) system can be used to support business development. |
| 10 | Driving continuous improvement into your business | This unit provides a description of the difference between product improvement and process improvement. There is coverage of selected tools and techniques for continuous improvement and how to develop a culture to support continuous improvement. Students will be able to describe examples of continuous improvement from industry. |

**Illustrative details from one of the course units**

In order to illustrate the type of material assembled for the course, it is useful consider in more detail the illustrative content for Unit 7: Managing innovation projects. This unit helps students to understand how to manage innovation projects in the context of business planning and resource management. The unit provides a good understanding of the tools and techniques that can be used to manage innovation projects as part of the entrepreneurial journey. The unit is comprised of four modules, which are as follows: Setting the context for managing innovation projects (1); adopting a holistic view of managing innovation projects (2); managing project risks (3); and introduction to agile project management (4).

After introductory remarks, module 1 provides material associated with the process-driven approach for project management. The module describes how innovation projects may potentially be more challenging than a standard project and asks the question – why is this? This is answered by a discussion on the level of uncertainty for innovation projects. This could be uncertainty over the technical requirements to be delivered, or uncertainty over the engineering design that is required. However, adopting a structured approach while drawing on project management principles can still guide such projects to result in a successful outcome. In order to highlight how a project management approach can be beneficial the following example is considered: a project to develop a new lightweight nozzle that can easily be fitted to high pressure lines while being manufactured on site. This example is provided in order to help understand the project lifecycle (see Exhibit 3).

**Exhibit 3**. Project lifecycle for innovative nozzle project.



The start of the project and stage 1 is the identification of this specific challenge, following by idea generation and formulation of an innovative solution to address the project need. This could be the use of additive manufacturing of a polymeric based nozzle assembly that is designed by a multidisciplinary team and this design part would be stage 2 of the project. This allows the new nozzle to be manufacturing using a 3-d printer, followed by assembly of the components and this is stage 3. The nozzle system would need to be installed and thoroughly tested, which would be stage 4. Finally, once the new nozzle system has been commissioned and is operational in the high pressure facility the project can be closed as part of stage 5 of the project. Although this illustrative example is high level, and there would no doubt be a need for extensive engineering to be undertaken, it does nevertheless highlight how taking a structured project management approach can be used to develop and manage technology innovation projects.

Module 1 also includes an exercise (formative assessment) based on two examples of innovative projects, which is depicted in Exhibit 4. The first project is Innovation Project A. This is a project to develop and test a new shielding device that will allow patients with heart pacemakers to undergo a scan from an MRI (magnetic resonance imaging) machine. The second project is Innovation Project B. This is a project to develop and test a new sensor for smart traffic lights that will adapt to the level of traffic that is present on the road. Both of these projects involve the development of an innovative engineering solution to address a specific need. In this exercise the students are directed to answer the questions through carefully considering the case for each project and the answers can be posted on the course e-learning platform.

In module 2, students are asked to read a research paper that advocates the benefits of using a wider (or holistic) view of projects and especially for the case of complex innovation projects (Philbin & Kennedy, 2014). As an exercise (formative assessment), students are directed to prepare a 250 word summary of the benefits of using a holistic view of projects and especially for the case of innovation projects.

Module 3 is focused on project risk management. There is initial material on the subject, including description of a project risk, which is an uncertain event or scenario that if it occurs will impact the performance and eventual completion of the project. Risk management is a key part of managing all projects and this includes a need to identify project risks and assess them in terms of the probability of the risk occurring as well as the impact of the risk on the project. This is followed by a short exercise (formative assessment) to highlight that there can be different types of project risks. The exercise is based on the case of a project to develop a new metal matrix composite via a novel powder metallurgy process. The material is to be used for an automotive application and the development work is being undertaken by a startup company that is funded by an automotive supply chain company. In the exercise, students are asked to match the four different risk types with the example risks that are provided (see Exhibit 5).

**Exhibit 4**. Exercise based on analysis of two examples of innovative projects.



**Exhibit 5**. Exercise based on matching types of risks with risks (matches are shown).



Module 3 also has an exercise (formative assessment) based on the assembly of a risk register, which is carried out for either Project A or Project B (see Exhibit 6).

The final module in this unit covers agile project management. The students are initially asked to read *The Agile* *Manifesto* (Fowler and Highsmith, 2001), which sets out 12 guiding principles that support adoption and use of agile project management. Although they apply to IT (information technology) projects, they can also be applied to other types of projects including innovation projects. Agile involves the use of several tools and techniques to ensure delivery of projects in a flexible manner, while still meeting the business objectives for a project. One such technique is the so called MoSCoW approach. This agile planning method is used to prioritize work areas on a project through a process of analyzing the project requirements according to whether they are one of the following categories:

* ‘*Must haves*’ are project requirements that are critical to delivery of the project and must remain as part of the project specification.
* ‘*Should haves*’ are important project requirements but are not essential for the delivery of the project – ideally they should remain part of the project specification but they are not as crucial as must haves.
* ‘*Could haves*’ are desirable project requirements, but are not strictly necessary and so the project can be delivered without them. Although where they can be delivered and result in improved project performance they should be retained.
* ‘*Won’t haves*’ are project requirements that have not been agreed by all project stakeholders at this point and therefore do not need to be delivered as part of the current project.

**Exhibit 6**. Exercise based on assembly of risk register for a chosen innovation project.



Agile practitioners use the MoSCoW technique to prioritize work on projects and an exercise is provided on the example project covered earlier in this unit. This project involves development of a new metal matrix composite via a novel powder metallurgy process. In the exercise there is a need to match the four technical project requirements with the MoSCoW categories that are provided. This process allows consideration of the relative priority for each of the engineering requirements as part of the agile project management process.

**Exhibit 7**. Exercise based on matching project requirements with MoSCoW categories (matches are shown).



**Unit summative assessment**

The summative assessment for units is through a series of multiple choice questions. Each module has an end of module assessment, for example, the following question is for the end of the module 1 assessment in unit 7.

*Question*. Which definition of project management do you think is the most accurate?

1. Project management is a structured process that is designed to ensure all workers on the project are kept busy.
2. Project management is the process through which projects are prioritized according to a defined set of organisational criteria.
3. Project management involves many aspects that need to be managed in order for the project to be delivered on time, within budget and scope, and according to the desired quality level.
4. Project management is the process of managing corporate relations with the project’s funder.

*Note*: The underlined answer is the correct one.

Each unit also has five end of unit questions and the following question is an example from one of the five end of unit questions for unit 7.

*Question*. What is the correct sequence for the project lifecycle?

1. Planning and design; project initiation; installation and testing; manufacture and assembly; project closure.
2. Project initiation; planning and design; manufacture and assembly; installation and testing; project closure.
3. Planning and design; project initiation; manufacture and assembly; installation and testing; project closure.
4. Project initiation; planning and design; installation and testing; manufacture and assembly; project closure.

*Note*: The underlined answer is the correct one.

Finally, each unit also contributes four questions towards an end of course assessment based on forty questions, i.e. four questions from each unit.

# Lessons learnt from the case

Following on from the design and delivery of the new online course a number of lessons learnt and insights were captured, which are as follows:

1. Development of a significant amount of teaching material for a new online course benefits from the workload being shared across several team members. There is also merit in having a dedicated project manager to ensure teaching material is developed on schedule along with coordination of administrative tasks.
2. Partnering with a professional organization that has an existing capability and crucially the supporting e-learning platform allows the academic partner to concentrate on the development of the teaching and assessment material. Also, the professional society can concentrate on the design of the course in the platform as well as the marketing of the course.
3. The design of the course structure (including themes and units) should be tailored for the specific educational application, although it is useful to align the overall course structure with a recognized framework (e.g. entrepreneurship competence).
4. The development of a new online course can be a significant undertaking. It is very important that adequate time and resources are made available to support the delivery of the content as well as the various other tasks that need to be done. It is also important that adequate time is made available to support the quality control of both the source material and also once it has been converted on to the e-learning platform.
5. Delivery of an online course benefits from there being regular formative assessment in the form of exercises throughout delivery of the course in order to reinforce learning of specific points. This can be balanced with summative assessment at the end of modules and units as well as the end of the overall course, with this latter type of assessment ensuring that the module, unit and overall learning outcomes have been met.
6. In regard to the design of an online course focused on entrepreneurial skills, it is useful to include educational content related to a broad interpretation of this area. This includes topics related to ideation and creativity, innovation and technology management, product design, marketing, business development and finance, through to managing innovation projects and leading teams as well as continuous improvement. This broad set of topics allows engineers to gain the skills and knowledge to develop new products and services as well as develop new business areas within organizations (i.e. intrapreneurial) and develop new business ventures (i.e. entrepreneurial).
7. The development of a course oriented towards business but designed for technical specialists (i.e. engineers) needs to blend business management theory and frameworks with technological areas and an overall engineering context. If this blending is not achieved, then such a course is not likely to be relevant to the technical specialists and may therefore be considered as being more generic in nature.
8. The design of an online course should include the necessary educational content based on recognized theory but this needs to be accompanied by a significant level of interaction with the online student cohort. Such interaction can be through a range of different channels, such as exercises and quizzes accompanies by different forms of content delivery, e.g. written text, audio commentary as well as video content. It is suggested that such a multiplicity of interaction points and content delivery formats should be optimized where possible in order to maintain the interest and engagement by the student cohort.

# Conclusions and future work

When considering the education of engineers a number of questions arise. How can engineers be successful in knowledge-driven organizations and tackle the challenges and opportunities arising today? How can they build on their technical foundation and numerical skills by becoming more innovative and entrepreneurial? These questions can be addressed through the provision of teaching and education focused on the development of enterprise skills. Such an approach is beneficial for STEM graduates in order to enable an improved understanding of how to develop a technological idea into a new product line or engineering program as well as the development of a new business as part of new venture creation.

This research study has reported on the case where an online program has been developed by a university team in partnership with a professional engineering society. The study provides details on how the program was designed and developed, including the structure and educational content of the program. Furthermore, illustrative details have been provided on the content from the managing innovation projects unit as well as discussion of the formative and summative assessment strategy adopted in the program. This has allowed a number of lessons learnt to be generated that are useful for engineering faculty and others who are seeking to develop enterprise related programs for engineers.

In regard to future work, it is suggested that longitudinal studies are conducted on the impact of enterprise education for engineers that will provide evidence on this form of education for enhancing the professional skills and employability of graduate engineers. Future research is also suggested on the suitability of different models of enterprise education, including experiential-based learning and online provision.

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