**ENTREPRENEURSHIP EDUCATION FOR ENGINEERS: TECHNOLOGY EVALUATION AND COMMERCIALIZATION THROUGH PROJECT-BASED LEARNING**

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**Abstract**

Engineers can benefit from gaining skills and knowledge associated with the commercialization of technology and start-up formation as part of the business planning process. This includes understanding how to evaluate emerging technologies towards formulation of new products and services as well as wider practical and transferable skills, such as understanding financial management, risk management, intellectual property and other commercial considerations associated with developing new technologies. This research study provides insights gained from the delivery of technology entrepreneurship education for students as part of graduate level engineering programs. This involves students working in project-based teams to evaluate emerging technologies and subsequently prepare a business plan for new venture creation. The experiential learning model is augmented with teaching material and theoretical content on both technology management and business management. The study builds on a supporting literature review to provide an exploration of the main elements of this model for technology entrepreneurship education for engineers, including insights on the pedagogical aspects as well as the unique combination of business and technological focused content. The study concludes with a summary of lessons learned from this application of entrepreneurship education for engineers, which can help practitioners to deliver related programs and inform future research studies.

**Keywords**

Engineering education, technology entrepreneurship, project-based learning, start-up formation.

# Introduction

It is widely recognized that entrepreneurship education can benefit engineers (Philbin, 2020) through enabling access to a wider set of transferable skills thereby providing greater options to adapt to future work and career changes (RAE, 2017a). Indeed, it has been found that there is a growing need for multidisciplinary engineers with access to a wider set of skills (Philbin et al., 2019), where equipping engineers with improved skills and knowledge in entrepreneurship can be viewed in this context (Barba-Sánchez and Atienza-Sahuquillo, 2018). These wider skills have been described as being part of the engineering habits of the mind, which includes systems thinking, adapting, problem-finding, creative problem-solving, visualizing and improving – ultimately focused on enabling the core engineering objective of “*making things that work and making things work better*” (RAE, 2017b). Furthermore, inclusion of entrepreneurship education into engineering programs can support the development of soft skills across areas such as project management, teamwork, communication as well as personal development (Soareset al., 2013). These enterprise related competencies are viewed as being valuable skills to possess when graduates are pursuing employment opportunities (Galloway et al., 2006). In order to improve the entrepreneurial mindset of engineers and over the last couple of decades, there has been an increasing preponderance of academic institutions that have integrated entrepreneurship and business management courses and materials into engineering programs (Nichols and Armstrong, 2003).

The case for incorporating entrepreneurship into engineering education can also be linked to the current and potential future challenges and opportunities that engineering faces. Such challenges include mitigating the impact of climate change and adopting renewable forms of energy; enabling sustainable development across society and achievement of the United Nations sustainable development goals (SDGs); providing access to healthcare, which is becoming increasingly costly; and not least continuing to respond to the COVID-19 pandemic. In this context, for a treatment of how innovation can drive forward sustainable development, see the work of Silvestre and Ţîrcă (2019). These challenges are however accompanied by many opportunities, such as those associated with the Industry 4.0 technological paradigm (Dalenogare et al., 2018) and related technologies including the internet-of-things, artificial intelligence and digital twins. This landscape of challenges and opportunities provides fertile ground for engineers to be enterprising; this includes entrepreneurship through start-up formation; intrapreneurship through building a new program, product or business area within an existing organization; as well as more generally leveraging R&D (research and development) as part of the innovation process. In this regard, Ries (2011) viewed entrepreneurship from a broader perspective through defining a start-up as “*a human institution designed to create a new product or service under conditions of extreme uncertainty*”. Consequently, it is important that engineers are provided with a solid grounding in multidisciplinary skills and especially those relating to technology entrepreneurship (Bailetti, 2012) and related areas such as business planning (Philbin and Mallo, 2016) and technology transfer (Hamilton and Philbin, 2020).

The structure of this article is as follows. After the introduction is the literature review on entrepreneurship education for engineers. This is followed by the case study investigation, which discusses key aspects of the technology evaluation and commercialization module that underpins technology entrepreneurship education and is currently delivered as part of MSc level engineering programs at London South Bank University in the United Kingdom (UK). The case study includes details on the background of the case, module structure and delivery, module assessment, team-based approach and lessons learned. This is followed by the conclusions and future work.

**Literature Review**

Entrepreneurship education for engineers has been investigated according to a range of different perspectives, for instance, exploring the role of entrepreneurship education in motivating students (from business and engineering programs) to start their own business as a viable alternative to entering the employment market (Herman and Stefanescu, 2017), entrepreneurship assessment in higher education in the context of research on engineering education (Huang‐Saad et al., 2018) as well as the challenges associated with assessing entrepreneurial skills and mindsets for engineering entrepreneurship education (Miranda et al., 2020). Researchers have identified that entrepreneurship education in engineering programs can be supported by adoption of action-based learning methods towards the beginning of programs and that explicit business knowledge should be included gradually in programs and only when discipline-specific engineering knowledge has been adequately accumulated (Mäkimurto-Koivumaa and Belt, 2015). In regard to the content of entrepreneurial education, there is a need to include traditional business focused disciplines, such as management, marketing, information systems and finance (Grecu and Denes, 2017). This focus enables students to gain skills associated with opportunity recognition, commercializing a concept, managing resources and initiating a new business venture.

In other studies, a new framework for entrepreneurship education that combines business model development and computational thinking has been evaluated, where undergraduate students were tasked to identify a social problem, develop a solution and implement the appropriate products and services through using relevant software and hardware technologies (Kang and Lee, 2020). This innovative approach to technology entrepreneurship education highlights the merits of deploying project-based learning for generating business value and new venture creation. This project-based approach to facilitate entrepreneurship education focused on the creation of a technology-based enterprise, which is a recognized pedagogic methodology. In this regard, Arias et al. (2018) investigated the project-based learning model where students were involved in the identification, development and final presentation of a business model. They found that the gap between studies and business practice was reduced and the whole process benefited from all the subjects across the master’s degree being involved in the entrepreneurial learning experience.

In the case of technology entrepreneurship education, Choi and Byun (2013) have argued that such programs should integrate coursework on fundamental theory and processes with real team-based projects on technology commercialization. In other studies, Duval-Couetil et al. (2021) highlighted that science and technology entrepreneurship education can be aligned to four main priority areas, which are technology readiness and timing (i); intellectual property pathway decisions (ii); engagement with the entrepreneurial ecosystem (iii); and personal career choices (iv). Moreover, Fayolle et al. (2021) investigated the merits of entrepreneurship being taught to students in engineering, science and technology majors according to the use of dedicated teaching models. Technology entrepreneurship education also has the potential to encourage students that have participated on such programs to subsequently engage in start-up business formation thereby leading to economic development and wider benefits (Militaru et al., 2015).

The literature review identifies that there is consensus on the merits of integrating technology entrepreneurship into engineering educational programs, including the wider set of business and multidisciplinary skills that can be gained and their usefulness in regard to employment prospects as well as the potential to promote new venture creation and the commercialization of technologies. The extant literature also emphasizes the role of project-based learning as an experiential pathway to support technology-based entrepreneurship education for engineers. Although there are different viewpoints on the specific arrangements that can be implemented to support the goal of providing technology entrepreneurship education for engineers, it is nevertheless useful to identify specific practices that have been adopted to enable engineers to become more enterprising. Therefore, it is advantageous to provide the findings from the case study investigation on technology entrepreneurship education, including lessons learned from the case.

# Case Study Investigation

The research adopted a case study approach that was designed in order to explore and depict a setting with a view to advancing the level of understanding (Cousin, 2005). The within-case analysis approach was used, since insights from the case are provided according to a structured framework, including the context and outcomes of the case as well as the processes that are revealed from the case (Eisenhardt, 1989).

**Background on the Case**

The Technology Evaluation and Commercialisation (TEC) module is delivered in the School of Engineering at London South Bank University in the UK for postgraduate MSc students in engineering and is the primary mechanism to provide technology entrepreneurship education for this cohort of students. The module involves use of an adapted version of the TEC Algorithm that was originally developed by North Carolina State University in USA (Markham et al., 2000; Boocock et al., 2009). The TEC module enables students to be guided towards identifying an emerging technology idea that is evaluated for its commercial potential. Detailed research and analysis is conducted according to a prescribed process-based model in order to evaluate the business potential of a range of technologies. This project-based learning approach allows students to prepare the commercialization strategy and write the business plan for a potential high-tech start-up company based on an emerging technology.

The educational model adopted in the module represents a simulation exercise for start-up business planning – although at the end of the course students are not required to actually launch a real company. The students work as part of project-based teams and consequently they encounter many of the real world issues associated with team working and are required to meet deadlines through submission of the assignments. In addition to the process-based (algorithmic) approach, students are also provided with lectures and theoretical content across a range of business and technology management areas.

**Module Structure and Delivery**

The module is delivered over an academic semester (13 weeks) and this involves weekly sessions of 3 hours, which comprise roughly half the time focused on a lecture that addresses an underpinning area associated with technology-driven innovation and entrepreneurship along with the remaining time allocated to tutorial and group work. This split of time allows students to work in teams on the technology evaluation and commercialization planning work in the tutorial session with the lecturer being able to provide guidance and answer any queries that the students may have on the overall process. Additionally, the more structured lecture part of the session provides the opportunity for wider background and supporting theory to be made available to the students. The students work as part of teams of 4-5 students and this approach means there is adequate resource available in the team to conduct the detailed research and analysis to evaluate the business potential of technologies and prepare the commercialization strategy and detailed business plan for a high-tech start-up company.

A key part of the module is that students are directed to evaluate a number of emerging technologies for commercial potential. In order to avoid a situation with students having to spend an extended period of time deciding on which technologies to evaluate, a useful approach is to provide the student teams with a selection of technologies. Therefore, since the top 10 breakthrough technologies are published each year by the publication MIT Technology Review (2020), it was decided that these technologies would be suitable for this purpose. Since the list is updated each year, the technologies are refreshed and can also be viewed as exciting areas that generate curiosity thereby making the module both relevant and interesting to students. In order to illustrate the types of technologies that have been recently evaluated in the module, Table 1 provides details of the top 10 breakthrough technologies for the last three years (2018-20). As can be observed, the technologies represent a broad range of areas across different aspects of engineering, including computing and digital technologies (such as artificial intelligence), materials and mechanical engineering, energy related technologies as well as biomedical technologies and healthcare applications. Therefore, each year students are presented with a range of potential technologies where they are likely to have an interest in at least a few of the areas.

**Exhibit 1. Top 10 breakthrough technologies for 2018-20 (source: MIT Technology Review, 2020).**

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| **Year** | **Top 10 Breakthrough Technologies** |
| 2018 | 1. 3-D Metal printing to create engineering parts that are not accessible via conventional methods. 2. Artificial embryos utilising the potential of stem cells. 3. Sensing city based on smart cities technology. 4. AI for everybody involving cloud-based artificial intelligence (AI). 5. Dueling neural networks based on generative adversarial network (GAN) technology. 6. Babel-fish earbuds (inspired by the *Hitchhiker’s Guide to the Galaxy*). 7. Zero-carbon natural gas as the basis for clean energy technology. 8. Perfect online privacy through cryptographic technology. 9. Genetic fortune-telling based on DNA testing and related technologies. 10. Materials’ quantum leap through leveraging quantum computing technology. |
| 2019 | 1. Robot dexterity where robots are teaching themselves to handle the physical world. 2. New wave nuclear power based on advanced fission and fusion technologies. 3. Predicting preemies involving to test if a pregnant woman is at risk of giving birth prematurely. 4. Gut probe in a pill where a swallowable device captures detailed images of the human gut. 5. Customer cancer vaccines through identifying mutations unique to each tumor. 6. The cow-free burger based on lab-grown and plant-based alternatives. 7. Carbon dioxide catcher to capture excess greenhouse gas (GHG) emissions. 8. An ECG (electrocardiogram) on your wrist for real-time tracking of cardiac activity. 9. Sanitation without sewers technology for energy-efficient toilets. 10. Smooth-talking AI assistants to improve machine understanding of natural language. |
| 2020 | 1. Unhackable internet enabled through next generation on quantum computing technologies. 2. Hyper-personalized medicine where genetic medicine is tailored to a single patient. 3. Digital money utilising distributed ledger technology that is backed by a national reserve. 4. Anti-aging drugs to treat different diseases, such as cancer, heart disease and dementia. 5. AI-discovered molecules to improve drug development pipelines. 6. Satellite mega-constellations to enable global provision of high-speed internet. 7. Quantum supremacy enabling through deployment of quantum computing technology. 8. Tiny AI technologies via small-scale systems that do not need to communicate with the cloud. 9. Differential privacy to counter the threat from de-anonymization of large datasets. 10. Climate change attribution to clearly identify the impact of climate change on weather patterns. |

The technology evaluation process involves the initial evaluation of the 10 breakthrough technologies that are reviewed, whereupon 4 technologies are selected for more detailed evaluation. After this additional level of evaluation, a single technology is recommended for further commercialization planning and development of the business plan for the technology-driven start-up company. This technology evaluation process can be viewed in terms of the funnel as depicted in Exhibit 2, where the detailed evaluation criteria are summarized including technology uniqueness and maturity, competition, economic and market-driven factors.

The evaluation of technologies is a key feature of the module, which can also be considered in the context of four main stages that are depicted in Exhibit 3. Stage 1 involves ideation and description, where the technologies are initially evaluated according to the approach summarized in Exhibit 2, which results in identification of the minimum viable product (MVP). Stage 2 is based on extensive use of the SWOT (strengths; weaknesses; opportunities; threats) and PESTLE (political; economic; social; technological; legal; environmental) analysis techniques as part of the opportunity assessment for the proposed start-up company. Stage 3 involves preparing the detailed business plan that brings together the planning and analysis on the technology idea, problem and solution, MVP, operations, market analysis and marketing plan, company organizational structure, risk management and financial analysis (including the outline income and expenditure for the start-up and capital investment requirements). Once the business plan has been prepared and submitted for assessment, the module delivered in the School of Engineering is completed. Although it is worth noting that the whole process could if required be followed through to Stage 4, which would involve implementation of the business plan and actual launch of the start-up company (this stage is outside the scope of the educational delivery of the module).

As mentioned previously, a key feature of the module is that student teams are guided to evaluate technologies and thereafter build a start-up business plan. The module includes delivery of a range of lectures designed to give the students a broader education in areas such as technology management, business management, innovation and entrepreneurship. In this regard, the process-based approach for business planning is augmented with the use of a range of further business analysis tools and models. This includes Porter’s five forces (Porter, 1989), which allows the competitive forces that shape an industrial sector to be analysed; Ansoff’s matrix (Ansoff, 1957), which is a marketing planning tool that allows growth strategies to be identified – charting existing and new markets vs. existing and new products; Porter’s value chain analysis (Porter, 1985), which allows value adding functional areas of the business to be identified; VRIO analysis (Barney & Wright, 1998), which is a business analysis framework to identify resources that assesses the value, rarity, imitability, and organisation of resources that provide competitive advantage; and the process model for university‐industry research collaboration (Philbin, 2008), which is a management framework that can be used to develop and manage research collaborations between universities and industry. Exhibit 4 provides details of the main content-based lectures according to the module schedule.

**Exhibit 2. Selection of leading technology for commercialization and business planning.**



**Exhibit 3. Main stages of the technology evaluation and commercialization process.**



**Exhibit 4. Summary of lectures delivered across the semester according to module schedule.**

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| **Week** | **Module schedule and lecture contents** |
| # 1 | Introduction to the technology evaluation and commercialization module. |
| # 2 | Fundamentals of R&D, innovation & entrepreneurship, and technology management. |
| # 3 | Digital awareness, information management and database skills. |
| # 4 | Exploring process-based innovation models. |
| # 5 | Introduction to intellectual property rights (IPR). |
| # 6 | Business, innovation and commercialization strategy frameworks. |
| # 7 | Developing a marketing strategy. |
| # 8 | Insights from business planning for major research programs and supporting infrastructure. |
| # 9 | Fundamentals of risk management. |
| # 10 | Financial analysis and return on investment (and submission of technology evaluation assignment). |
| # 11 | Summary and recap of lecture material. |
| # 12 | Finalization of business plan assignment. |
| # 13 | Submission of business plan assignment. |

The lecture sessions provide detailed material, supporting theory, worked examples and case applications according to the content areas. For example, lecture # 10 on financial analysis and return on investment includes the following core material:

1. Financial statements: Income and expenditure, balance sheet and cash flow statement.
2. Return on investment (ROI): Introduction and ROI calculation.
3. ROI factors: Timeframe, consistency and precision.
4. Cost analysis for ROI: Start-up costs, expenses of tailoring innovative technology and longer-term strategic outlays.
5. Quantifying revenues for ROI: Organization, stakeholder and technology adoption dimensions.
6. Investment appraisal: Calculation of net present value (NPV) and internal rate of return (IRR) through use of the discounted cash flow technique, venture capital company investment example and exercise.
7. Financial modelling: Introduction, uses of financial models and types of models.
8. Financial risks and financial ratios: Definition and types of financial risk, financial ratios (categories and ratios provided).

**Module Assessment**

The summative assessment for the module is through the submission of two assignments, which are each weighted 50%. Firstly, there is a formal report (assignment # 1) evaluating the breakthrough technologies suitable for commercialization in accordance with the algorithmic approach that is evidenced. Secondly, there is a business plan (assignment # 2), which includes the strategic analysis and planning for the commercialization of the technology identified in the previous assignment.

In regard to formative assessments, tasks and exercises are given to students each week, which relate to the relevant lecture contents provided from that week. For example, the formative assessment in the lecture on ‘Fundamentals of Risk Management’ involves students being asked to prepare a risk register for atechnology project to commercialize a new shielding device that will allow patients with heart pacemakers to undergo a scan from an MRI (magnetic resonance imaging) machine. Later in the lecture, students are also asked to conduct a numerical Pareto Analysis (statistical technique for decision-making) for sample data showing the relative frequency of causes for errors on websites. This formative assessment helps to embed learning in the module.

**Team-based Approach**

The module is delivered according to a team-based approach as there is significant analysis and planning to be carried out as part of the technology evaluation and commercialization process. Adopting a team-based approach with students working in teams of 4-5 has both pros and cons as highlighted in Exhibit 5. However, on balance it is felt that the pros outweigh the cons and that overall there is merit in students working as part of teams on the project-based module.

**Exhibit 5. Pros and cons of the team-based approach adopted in the module.**

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| **Pros** | **Cons** |
| * Students are faced with real-world conditions similar to those encountered by entrepreneurs setting up a real start-up company. | * Not all student team members contribute at the same level of input and with the same level of enthusiasm, which can lead to difficulties. |
| * Students enhance their communication skills on the module, including both verbal and written skills. | * Some team members may hide in the background and especially if students are lacking in self-confidence. |
| * The assignment workload can be shared across the team and according to the strengths of the individual team members. | * There is the potential for conflict or disagreements to arise between student team members. |
| * Students gain different perspectives from their peers as well as the broader education delivered via the lecture contents. | * There can sometimes be challenges for students in finding time to meet and discuss the required work (especially part-time students). |

**Lessons Learned**

A number of lessons learned and insights from the design and delivery of the technology evaluation and commercialization module have been identified, which are as follows:

1. There needs to be adequate time made available for students to assimilate the required level of detail from the TEC Algorithm and corresponding worksheets – if not, it may be overwhelming for some students. This is because there is a large amount of analysis and research to be carried out to enable the systematic evaluation of all 10 technologies combined with development of a robust start-up business plan.
2. The lecture material provides further background, theory and context for students on the module. The material also provides additional tools and models, which can be deployed to evaluate technologies and support the business planning process, e.g. TRL (technology readiness level) framework, risk management (Ishikawa diagram), VRIO analysis and NPV (net present value) financial analysis.
3. Although the module includes a significant level of business related content, since the module is taught within the School of Engineering it is important that the business theory, tools and techniques are described and used in an engineering context with relevant technology examples provided. This leads to the material being more relevant to engineering students and avoids it being overly generic in nature.
4. Team-based projects can have pros and cons but on balance there is still merit in adopting this approach, although there is a need for a careful approach when marking assignments to ensure that students receive personalized marks.
5. The experiential learning aspects of the module can be highly beneficial for the participating students – they are effectively participating in a start-up business planning simulation and consequently this form of education can help provide the students real-world skills and experiences that help them prepare for the workplace.
6. Adopting the top 10 breakthrough technologies from the MIT Technology Review each year as the set of technologies to be evaluated allows the technology areas to be refreshed and kept up-to-date. The diverse range of areas also stimulates curiosity and an enquiring interest, thereby helping to motivate student teams to focus on the detailed analysis required to complete the module assignments.
7. The combination of business management, innovation and technology management areas covered in the module enables students to gain a thorough grounding in different aspects of technology-based entrepreneurship education. This is relevant to a range of applications, including new venture creation, planning for a new program or business unit (i.e. intrapreneurship) as well as others forms of innovation, such as new product development (NPD).
8. In regard to teaching practice and pedagogy, the module requires the lecturer to engage in both didactic teaching of theory and models through the lecture sessions combined with a more coaching style of teaching as part of tutorial sessions focused on guiding the student teams to evaluate technologies evaluation and undertake business planning activities. Consequently, there is a need for appropriate flexibility in the teaching style that is provided in the module.

**Conclusions and Future Work**

Entrepreneurship education for engineers enables students to develop a wider set of skills and knowledge that has a positive contribution to the overall educational experience and long-term development of career and professional opportunities. Indeed, employers and industry continue to seek for engineers with professional and enterprise skills to complement the technical engineering knowledge – especially in the context of addressing the global challenges and major technology developments. Furthermore, technology-based entrepreneurship education can also help stimulate technology commercialization towards new venture creation and the resulting economic impact that is generated from such activities.

This research study has explored technology-based entrepreneurship education for engineers through a supporting literature review and case study investigation of the technology evaluation and commercialization module, which underpins entrepreneurship education for MSc students in the School of Engineering at London South Bank University. This has provided detailed insights on the design and structuring of such courses, including pedagogic, assessment and content related considerations. The module enables students to be equipped with background knowledge on technology, innovation and business management as well as an understanding of the tools and techniques to support enterprise behaviours – and support those who are interested in becoming more entrepreneurial to launch a technology-based start-up company. The case study investigation reported in this article provides a number of lessons learned that can be considered when practitioners are designing new entrepreneurship programs for engineers and can also inform future research studies in this area.

It has been observed that blending theory-driven lecture material with the TEC Algorithm process-based material allows broader knowledge to be made available across different aspects of technology commercialization, e.g. related to IP (intellectual property) as well as a historical perspective on innovation theory and models. Moreover, the project-based approach results in experiential learning alongside the more traditional provision of complementary taught material, thereby resulting in a comprehensive treatment of the area of technology entrepreneurship for engineers.

Future work is recommended to investigate the relationship between entrepreneurship education for engineers and an enhanced entrepreneurial mindset and corresponding behaviours. This research should identify how education in entrepreneuship can support engineering students to become more innovative and enterprising. Such studies may involve quantitative research through use of a survey instrument employed at multiple academic institutions engaged in technology entrepreneurship for engineers and where possible appropriate longitudinal studies should be carried out to investigate the phenomenon over an extended period.

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